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Timber Volume and Aboveground Carbon Sequestration of Rubber-Tree (*Hevea Brasiliensis*, Muell. Arg.) Plantations in Edo-South Rainforest Ecosystem, Nigeria

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ABSTRACT

Capturing carbon-dioxide (CO_2) from the atmosphere and storing it in forest/agroforest ecosystems via phototropic carbon sequestration is a strategy that has been prioritized for reducing atmospheric CO_2 concentration to mitigate the global warming problem. The objective of this study was to evaluate carbon sequestration potential of rubber-tree plantations. Plantations of different age levels: 4, 6, 14, 18 and 25 years were selected for sampling. From each plantation, one-hectare area was sub-divided into 25 quadrants (20 x 20 m²) as temporary sampling plots, while 4 quadrants were randomly selected as permanent sampling plots where we measured girth-DBH of all individual trees; and total heights; diameters at base, middle and top of two mean trees. From a reference natural forest, a one-hectare area was subdivided into ten (50 x 20 m²) quadrants, while 4 quadrants were randomly selected as permanent sample plots for measurements of heights and girth/DBH of individual trees. Results showed that bole volume ranged from 9.4 to 385.9 m³/ha in the plantations between age 4 and 25 years. Species-specific mean biomass expansion factor (BEF) value of 2.8 was obtained in our estimation, indicating that BEF of rubber trees decreases with increasing girth/DBH. Aboveground carbon sequestration of the 25-year-old rubber plantation was 175.7 Mg C ha-1. As at the time of this study, the 70 ha rubber trees that were examined had removed a total of 3.67 Giga-grams CO_2 from the atmosphere. This was considered very significant in view of the fact that it is an ongoing ecosystem service of the plantations in helping to mitigate global warming induced largely by atmospheric CO_2 pollution.

INTRODUCTION

The hazardous high concentration of carbon dioxide (CO_2) in the atmosphere is understood to be the major cause of the present-day global warming and climate change problem. The problem is worsened by continuous deforestation and emission of CO_2 into the atmosphere (Lal, 2004). Anthropogenic (human) activities particularly the burning of fossil fuels and deforestation has severely increased the concentration of CO_2 in the atmosphere causing the planet to warm abnormally. This is majorly due to the greenhouse effects of heat-trapping gases including CO_2 which warm the atmosphere of the Earth (IPCC, 2014). There is need to mitigate the global warming and climate change effects by decreasing the rising concentration of CO_2 in the atmosphere. To achieve this, one of the viable strategies is capturing CO_2 from the atmosphere and storing it in biological carbon sinks provided by trees and forests ecosystems (Houghton *et al.* 1998; Brahma *et al.*, 2016). Forests and agro-forest ecosystems are known to be carbon sink (long-term storage reservoir of atmospheric CO_2 by means of photosynthetic carbon sequestration). Rubber-tree plantations are forest tree crop established mainly for the production of natural rubber (industrial isoprene), but the plantations can be harnessed for both economic and environmental benefits.

Carbon sequestration and timber production are ecosystem services from rubber-tree plantations which have not been maximized for human benefit in Nigeria. For instance, much is not known about the carbon sink potential of rubber-tree plantations; and rubber tree (*Hevea brasiliensis*) is one of the least studied non-commercial wood species in terms of wood utilization in Nigeria, hence the use of rubber-wood as alternative timber is not developed in the country. The specific objectives of the study are: i) to carry out inventory-based estimation of timber stem (bole) volume and above-ground biomass of rubber-tree plantations using a non-destructive sampling method; and ii) to quantify above-ground carbon sequestration of the plantations in the study area. In order to quantify above-ground biomass carbon stock per hectare, the inventoried bole volume data (as primary data) was combined with species–specific biomass expansion factor and mean wood density of rubber trees in Nigeria.

Timber stem volume refers to the amount of wood that the main trunk of a tree constitutes, excluding the branches and roots. It is a crucial measurement in forestry for evaluating timber resources and carbon stocks. Accurate stem volume estimation is vital for understanding forest ecosystem dynamics. The measurement of aboveground biomass (bole, branches, and foliage) of trees is crucial to the management of forest resources, and for assessing the productivity and sustainability of the forests (Gower *et al.*, 1997). Estimates of above-ground biomass (AGB) are required for evaluating carbon stocks and fluxes in terrestrial ecosystems it enables us to quantify the amount

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of CO_2 that has been sequestered from the atmosphere by the forest, and also provides an indication of the potential amount of CO_2 that would be emitted when the forest is cleared or burned (Gower *et al.*, 1997). Also; AGB increment is a major component of net primary production (NPP); and estimation of AGB is required for evaluating the amount of primary energy obtainable from forests as an alternative to fossil fuels (Návar, 2009a; Richardson *et al.*, 2002). Internationally, there is a growing political and economic interest in carbon accounting (the Kyoto Protocol and Paris Accord), which requires ways and means of estimating carbon sources and sinks. This is motivated by the growing world consciousness aimed at mitigating climate change.

LITRATURE REVIEW

Aboveground biomass (AGB) is usually the largest fraction constituting more than 80% of the total plant biomass in forest ecosystem and matured rubber-tree plantations (Braham *et al.*, 2016). The traditional destructive sampling method for quantifying biomass is costly, counterproductive and unacceptable to resource owners. And in modern-day context, there is need for finding and advancing alternative (non-destructive) methods for biomass quantification. Research projects emphasizing non-destructive sampling methodologies for evaluating biomass and carbon stocks are worthwhile. The traditional methodology for estimating ABG of a tree is the development and use of allometric equations (Brown, 1997). This method requires destructive sampling of trees by conducting fresh and dry weights measurements on the biomass components of harvested trees; followed by recording independent tree variables to construct allometric equations (Brown *et al.*, 1989; Brown, 1997; Chavé *et al.*, 2001; Návar, 2009a). Alternatively, a non-destructive sampling method can be used to determine AGB as the product of inventory bole volume, wood density and a dimensionless biomass expansion factor (BEF) which helps to obtain total AGB (bole, branch and foliage) of the tree (Bohre *et al.* 2013; Goslee *et al.* 2015; Oke *et al.*, 2020).

FAO (1997) defined biomass expansion factor (BEF) as the ratio of total aboveground oven-dry biomass density of trees (with a minimum DBH of 10 cm) to the oven-dry biomass density of the inventoried bole volume. Simply put: BEF = Total AGB/Biomass of bole volume. Such ratios have been calculated from many inventory sources throughout the tropics. Sharp *et al.* (1975) estimated the regional forest biomass for Northern Carolina in the USA using a constant BEF of 2.0. Likewise, a default (constant) BEF value of 2.3 was used by Oke *et al.*, 2020 as prescribed by Nigerian REDD+ RPP (2013) for lowland Rainforest National Parks. However, studies carried out by Brown and Lugo (1992), Fang and Wang (2001), and Teobaldelli *et al.* (2009) have indicated that BEF (dimensionless) is not a constant value, but varies with forest age, site class and stand density. For instance, Brown and Lugo (1992) showed that BEFs are significantly related to the corresponding biomass of the inventoried bole volume as follows:
BEF = Exp {3.213 - 0.506*Ln(BV)} (for BV < 190 t/ha; where: BV = Biomass of inventoried volume (t/ha), calculated as the product of bole volume/ha (m^3/ha) and wood density (t/m^3). Thus, in order reduce the bias of using constant BEF in estimating aboveground biomass of forest plantations, species-specific BEF equations with stand variables as predictors must be used (Brown and Lugo, 1992; Hossain *et al.*, 2021). The use of generic (constant) biomass expansion factor (BEF) could cause significant bias in estimating biomass of forest plantation. This study seeks to contribute to knowledge in this aspect by using Hevea species-specific BEF based on rubber-tree stand variables instead of using constant BEF. Therefore, this study will contribute to the knowledge of biomass estimation using a non-destructive sampling method. The study will also contribute to knowledge of rubber-tree plantations as forest tree crops and their role in carbon sequestration for climate change mitigation.

MATERIALS AND METHODS
The Study Area
The study area (figure 1) is situated in the humid tropical rainforest region of Nigeria in Ikpoba-Okha Local
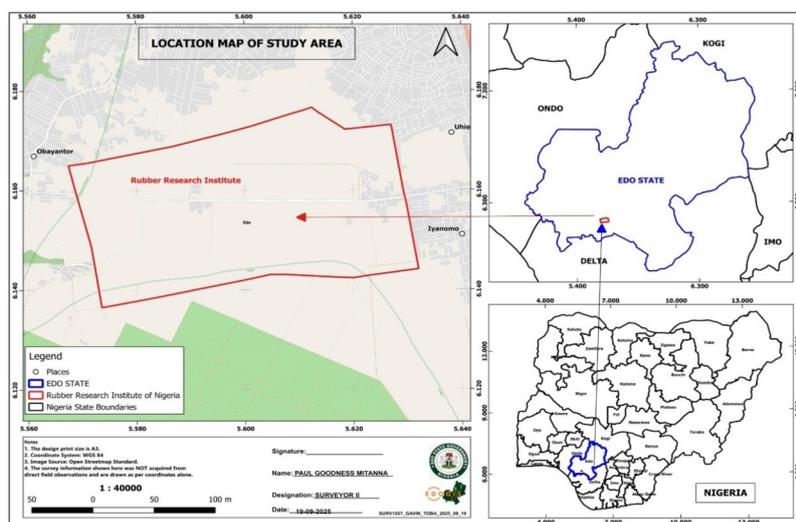

Figure 1: Location Map of the study Area

Government Area of Edo State, Nigeria. The main access road to the study location is through Obaretin Village situated at km 19, Benin-Sapele Road. The study area, occupying a land area of 2070 hectares, lies within the co-ordinates of Longitudes 5^0 34'E and 5^0 38'E; and Latitudes 6^0 08'N and 60 11'N (Orimoloye, 2011). The study area is plain land without undulations. The rainfall pattern is bimodal with peaks in July and September and a short rainfall break in August. Mean annual rainfall, relative humidity and temperature are 2000 mm, 65±5%, and 23^0 C – 26^0 C respectively, while the soils are mainly ultisols with 4.0 – 5.5 pH range (Waizah *et al.*, 2010).

Data Collection

Data were collected from five plantations of different age levels: 4, 6, 14, 18 and 25 years. Some of the plantations are shown in figure 2. Also, table 1 shows the age and size of the five (5) rubber-tree stands as selected for this study. One-hectare block was selected from each stand and subdivided into 25 quadrants (20m x 20m) as temporary sampling plots. Four (4) quadrants were randomly selected as permanent sampling plots for detailed enumeration resulting to a total of 20 sample plots for the study.

Within each sample plot, diameter at breast height (DBH) of individual trees was measured at 1.3m from ground

(a) Plantation aged 6 years   (b) Plantation aged 14 years   (c) Plantation aged 25 years

Figure 2: Plantations aged 6, 14 and 25 years

level (Feldpausch *et al.*, 2011). In order to determine mean plot DBH, two trees having their DBH nearest to the mean plot DBH were selected (as mean trees) for further measurements of tree total height; and diameters at the top, middle and base. Measurements of total height, diameters at the base, middle and top of mean trees were carried out with the aid of a Spiegel Relascope; while measurement of DBH was made using girth measuring tape (Uzoma and Akindele, 2011). From the reference natural forest, one-hectare area was sub-divided into ten (50 x 20 m_2) quadrants according to Wilson (2010) and Hamdan *et al.*, (2013). Four quadrants were randomly selected as permanent sample plots for measurements of girth/Dbh and total heights of individual trees.

Data Analysis
Estimation of Timber Volume over Bark of Bole (VOB)

The bole volumes of two mean trees per plot were calculated using (equation 1), which is the Newton's equation for estimating bole volumes of trees (Husch *et al.*, 2003).

$$V = (\pi h/24)(D_b^2 + 4D_m^2 + D_t^2) \tag{1}$$

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

Mean volume of trees per sample plot was estimated using (equation 2):

$$V_t = [V_1 + V_2](1/2) \tag{2}$$

Where: Vt = mean volume of trees in a plot; V_1 = volume of mean tree 1; V_2 = volume of mean tree 2; Trees 1 and

2 are the two mean trees in each sample plot.

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 3):

$$V_T = (1/2)[V_1 + V_2]*n \tag{3}$$

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

Volume over Bark of Bole per ha (VOB/ha): to calculate the stem (bole) volume of trees per hectare, the mean plot volume per hectare was multiplied by 25, which is the number of (20m x 20m) sample plots in one hectare (equation 4):

$$VOB/ha = (V_{T1} + V_{T2} + V_{T3} + V_{T4})(1/4)*25 \tag{4}$$

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

Evaluation of Biomass Productivity and Carbon Sequestration of Rubber Trees
Estimation of Total Above-ground Biomass (AGB) of Reference Natural Forest

AGB of individual trees in the reference natural forest was estimated using allometric equation of Djomo *et al.* (2016) for moist forest ecosystems (equation 9)

$$M = Exp\{-2.847 + 2.145*Ln(D) + 0.627*Ln(H)\} \tag{9}$$

Total AGB per hectare of natural forest was calculated as follows:

$$AGB_{Total} = (AGB_{T1} + AGB_{T2} + AGB_{T3} + AGB_{T4})(1/4)*10 \tag{10}$$

Where: AGB_{T1}, AGB_{T2}, AGB_{T3}, AGB_{T4} are the total AGB of all individual trees across the DBH-classes in the four sampling plots.

Estimation of Total Above-ground Biomass (AGB) of Rubber-tree Plantations

Biomass density (biomass per unit volume) of rubber trees was calculated based on existing bole volume estimate per hectare. That is, using (equation 4), estimated bole volume of trees per hectare was used as the primary data for estimating AGB per ha. Biomass of bole volume (BV) i.e. biomass of inventoried volume (t/ha) was calculated as the product of VOB/ha (m^3/ha) and wood density (t/m^3) [equation 5 and 6]

$$BV = (VOB/ha)*WD \quad (5)$$
$$\rightarrow BV = (V_{T1}+V_{T2}+V_{T3}+V_{T4})(1/4)*25*WD \quad (6)$$

Where WD = wood density.

Total AGB was determined by multiplying biomass of bole volume (BV) with biomass expansion factor (BEF) [equation 7 and 8] (Bohre *et al.* 2013; Goslee *et al.* 2015; Oke *et al.*, 2020):

$$Total\ AGB=BV*BEF \quad (7)$$
$$\rightarrow AGB_{Total}=(VOB/ha)*WD*BEF \quad (8)$$

Where: BEF = biomass expansion factor (species-specific) for rubber trees = $24.872*D^{-0.765}$ (Hossain *et al.*, 2021);

WD = wood density of rubber trees in Nigeria = 0.52 g/cm^3 (Chukwuemeka, 2016) which is the same as the global mean wood density of rubber tress (*Hevea brasiliensis* (0.53 g/cm^3) (FAO, 2000; Yang *et al.*, 2017).

Carbon Sequestration in Above-ground Biomass: Carbon content of AGB (Carbon stocked in aboveground biomass) was calculated as AGB*0.5 (Houghton *et al.*, 1997; IPCC, 2008); while the CO_2 captured was computed as CO_2 = AGB*0.5*3.67 (IPCC, 2006); where 3.67 = 44/12 = molecular mass of CO_2/atomic number of C.

RESULTS AND DISCUSSION

Table 2: Above-ground Carbon Stock of Reference Natural Forest

S/N	DBH Class (cm)	No. of trees	Mean DBH (cm)	Mean Height (m)	Mean AGB (kg ha^{-1})	Total AGB (kg ha^{-1})	Total AGB (t ha^{-1})	Carbon Stock-AG (Mg ha^{-1})
i	10-14	65	12.0	12.4	58.5	3,802.5	3.8	1.9
ii	15-19	43	16.6	15.6	134.2	5,770.6	5.8	2.9
iii	20-29	45	25.7	19.1	389.0	17,505.0	17.5	8.8
iv	30-39	32	35.5	28.1	995.9	31870.2	31.9	15.9
v	40-49	20	45.6	27.2	1661.9	33,238.4	33.2	16.6
vi	50-59	23	55.4	30.4	2712.9	62396.7	62.4	31.2
vii	60-69	15	66.0	33.8	4218.1	63,271.4	63.3	31.6
xiii	70-79	10	76.0	36.0	5939.0	59,389.6	59.4	29.7
ix	≥ 80	7	89.3	40.3	9016.0	63112.0	63.1	31.6
Total	-	260	-	-	-	340,355.4	340.4	170.2

Note: Carbon Stock-AG (= Carbon stock above-ground); kg ha^{-1} (= kg/ha); t ha^{-1} (= tons/ha)

Bole Volume (Timber Production)

Table 3 shows the results of stand development and bole volume yield (timber production). Bole volume increased from 9.4 to 385.9 m3/ha in the plantations between age 4 and 25 years. The steady increase in bole volume with stand age indicates that the rubber trees are in active growth stage, and are able to trap and sequester more CO_2 with increasing age. The timber stem (bole) volume per hectare yield of the 25-year old rubber-tree plantation in this study was 385.9 m3/ha whereas bole volume per hectare yield ranging from 140 to 200 m3/ha was reported by the global rubber wood study carried out under the auspices of the International Trade Centre, with higher ranges observed in Malaysia, Thailand, India and Sri Lanka (FAO, 2000). However, the bole volume per hectare yield of the 14-year old *Hevea brasiliensis* plantation in this study was 126.6 m3/ha which is lower in comparison with the 259.1 m3/ha for a 14-year old Tectona grandis plantation in Nigeria (Adekunle, 2011). This is probably due to higher density of trees in the T. grandis plantations compared with H. brasiliensis plantations (≤400 trees/ha) in our study. Since bole volume yield also depends on stand density, wood volume yield from H. brasiliensis will be higher at stand density >400 trees per hectare. The Latex-Timber clones (RRIM 2023 – 2026 series) have been developed in Malaysia with significantly higher wood volume (0.8–1.9 m3) per rubber tree, compared to 0.7–1.3 m3 from earlier clones (Balsiger *et al.*, 2000). Therefore, there are prospects of genetic improvement of the Nigerian Hevea population for improvement in timber volume.

Timber production is an aspect of rubber-tree cultivation that has gained significance (Mydin *et al.*, 2005). It is expedient to expand the management objective of rubber-tree plantations in Nigeria to cover both natural rubber latex and timber production, and to carry out studies to determine the effective planting spacing that will yield optimum latex with timber. Developing rubber-tree plantations as alternative source of timber for suitable uses is in line with present-day quest for sustainable and renewable alternative sources for energy and materials. Rubber-tree plantations are sustainable alternative source of timber and industrial wood. In the south Asian countries, rubber-tree plantations have become

an important source of timber (biomass of commercial value) contributing more than 10% of log production in Malaysia since 1993 ((Serkhar, 1992). In the past, old rubber trees that had exhausted their latex supply were burnt or left to rot. However, it was discovered that this wood, when dried and treated, was suitable for production of furniture and other commodities. Thus, timber production is an aspect of rubber tree cultivation that has gained significance (Mydin *et al.*, 2005; Gonçalves *et al.*, 2005 Goncalves *et al.*, 2011). The rubber tree is a very fast growing species; new plantations can be re-established on a 25-year rotation period on the same land management unit. If rubber-tree plantations are well managed on a 25-

year rotation, they could constitute alternative source of commercial timber (Pengprecha, 1976). A total of 240,000 hectares rubber plantations could be a good source of pulpwood if replanting is done at the rate of 8,000 ha/ yr. in a 30-year rotation. This guarantees a continuous yield of rubber wood at the rate of about 816,000 tons per year or about 102 tones/ha (Jayasingham, 1974). The annual rate of deforestation is so alarming that a country like Thailand has completely banned logging from natural forests. Therefore, rubber wood has become the main non-forest timber resource decreasing the logging pressure on natural forests in some rubber growing countries. This is a good example for Nigeria.

Table 3: Summary of Bole Volume Yield, Above-ground Biomass and Carbon Sequestration of Rubber-tree Stands

Plantation Age (yrs.)	Density (Trees/ha)	Mean DBH (cm)	Mean Height (m)	Bole Volume (m^3ha^{-1})	BV ($t\ ha^{-1}$)	BEF	Total AGB (t ha^{-1})	Carbon Stock-AG (Mg ha^{-1})	CO_2-e (Mg ha^{-1})
4	350	8.0	6.0	9.4	4.9	4.2	20.8	10.4	38.1
6	400	10.4	8.0	28.1	14.7	4.1	60.7	30.4	111.4
14	369	20.8	14.1	126.6	65.8	2.4	160.9	80.4	294.7
18	338	28.5	19.6	201.1	104.5	1.8	200.4	100.2	367.7
25	331	32.1	23.2	385.9	200.7	1.7	351.4	175.7	644.2
Mean	-	-	-	-	-	(2.8)	-	-	-

Note: BV (= biomass of bole Volume); t ha¹ (=tons/ha = Mg/ha); BEF (= biomass expansion factor);
Carbon Stock-$_{AG}$ (= Carbon stock above-ground);
CO_2-e (= CO_2 equivalent of carbon stock = amount of CO_2 captured/sequestered)

Above-Ground Biomass and Carbon Sequestration of Rubber Plantations in the Study Area
Table 3 shows the results of total above-ground biomass and carbon stock estimates per hectare of the rubber-tree plantations. Species-specific mean BEF value of 2.8 was obtained in our estimation, indicating that BEF of rubber trees decreases with increasing DBH (table 3). Meanwhile, a constant mean BEF value of 2.3 was used by Oke *et al.* (2020) as prescribed by Nigerian REDD+ RPP (2013) for lowland Rainforest National Parks. However, studies carried out by Brown and Lugo (1992) and Teobaldelli *et al.* (2009) have indicated that BEF (dimensionless) is not a constant value, but varies with forest site/stand variables such as age, DBH and biomass of inventoried volume (Brown & Lugo, 1992; Hossain *et al.*, 2021).
For the plantations aged 4 to 25 years that were studied, above-ground Carbon sequestration increased from 10.4 to 175.7 Mg C ha-1. This was the C stock in above-ground biomass alone excluding below-ground portion. The aboveground carbon stock (obtained in rubber-tree stand aged 25 years) was 175.7 Mg C ha–1 (table 3) which was equal with the aboveground carbon stock (170.2 Mg C ha–1) of the reference natural forest in our study area (table 2). Similarly, Cheng *et al.* (2007) reported that total biomass carbon stock of a 30-year old rubber-tree plantation on the island of Hainan was 272 Mg C ha–1, which was higher than the total biomass carbon stock of a natural rainforest (234 Mg C ha–1) in the same location.

Comparing these carbon sequestration rates, it can be discerned that rubber-tree plantations in our study area are very productive. The plantations are as productive as forest plantations of other exotic species (Gmelina arborea and Tectona grandis) which are notable for their fast growth rate and ability to produce high amount of timber (biomass of commercial value) within a relatively short period of time (Evans & Turnbull, 2004; Onyekwelu *et al.*, 2006). For instance, total AGB of the 25-year old rubber plantation in this study was 351.4 tons/ha, while Onyekwelu *et al.* (2006) reported total AGB (382.3 tons/ ha) for a 25-year old Gmelina plantations in Omo Forest Researve in Nigeria. Meanwhile, Gmelina is an exotic timber species with notable higher biomass productivity in intensively spaced plantations with higher number of trees per hectare compared to H. brasiliensis plantations in this study. *Hevea brasiliensis* (rubber trees) are more effective in capturing CO_2; for instance, physiological studies show that the photosynthetic rate of a mature rubber-tree leaf is about 10–15 μmol CO_2 per m2 per second as compared to about 5-13 μmol CO_2 per m2 per second in many other tree species including Tectona grandis (an exotic teak species) grown in plantations (Sethuraj & Jacob, 1997; Nataraja & Jacob, 1999).
Cultivating rubber trees on non-forested, marginal or degraded lands will act as carbon sink by sequestering carbon in biomass and indirectly in soils. Rubber trees effectiveness in this respect is probably at least equal with

that of virgin forests and may even exceed it (Sethuraj *et al.*, 1996). This is due to the higher photosynthetic rate of rubber trees; as such, their biomass production per unit land area within a given time (productivity) is very high resulting in higher carbon sequestration capability (Sethuraj *et al.*, 1996; Cheng *et al.*, 2007). Therefore planting fast growing species like rubber is a potential means of climate change mitigation.

Table 4: Summary of CO_2 Captured by the rubber-tree plantations that were studied

Plantation Age	CO_2 Captured (Mg C ha^{-1})	Stand Size (ha)	Total CO_2 Sequestered (Mg)
4	38.1	8	304.8
6	111.4	8	891.2
14	294.7	6	1,768.2
18	367.7	8	2,941.6
25	644.2	40	25,768.0
Mean	(291.2)	-	-
Total	1456.1	70	31,673.8

The results (table 4) shows that for the total of 70 ha plantations aged 4 to 25 years that were studied, total amount of CO_2 (31,673.8 Mg) was captured which means that as at the time of this study, 31.67 Gg CO_2 had been removed from the atmosphere by 70 ha rubber-tree plantations in the study area. This was considered quite significant in view of the fact that it is an on-going ecosystem service of the plantations with increasing capacity as trees continue to grow. Our study area occupies a land area of 2070 hectares; and the average CO_2 sequestered by rubber-trees in the area amounted to 291.2 Mg ha-1. This indicates that the entire area can absorb more than 602,825 Mega-gram i.e. 602.8 Giga-gram CO_2 from the atmosphere if land cover is maintained with rubber-tree stands of different ages up to a rotation period of ≥25 years.

The use of biological carbon sinks (forest ecosystems) to reduce atmospheric CO_2 level was part of the core aim of the Kyoto Protocol Clean Development Mechanism (CDM) which allowed a country or organization that emits CO_2 and other GHG's above agreed limits to purchase carbon offsets from an entity that uses biological means (forests and forest plantations) to absorb CO_2 and reduce its concentration in the atmosphere (UNFCCC, 2006). With this growing international interest in climate change mitigation via forest carbon conservation (Paris Accord-2015; COP-21), highly diversified rubber-tree agroforest plantations in Nigeria could attract carbon credits.

CONCLUSION

Bole volume (timber production), above-ground biomass and carbon sequestration capability of Rubber-tree plantations were evaluated in this study. The results showed that rubber-tree plantations in the study area are very productive with high potential for biomass carbon sequestration (an ecosystem service of the plantations). Rubber-tree plantations are thus recommended for aforestation on marginal lands, and for restoration of degraded lands in the tropics including Nigeria. Rubber-tree plantations in Nigeria as forest tree crop can become an important resource for national carbon sink

for climate change mitigation. The rubber tree (*Hevea brasiliensis*) is a versatile species because in addition to its socio-economic value, it can provide environmental and climate regulatory services for human benefit. Timber production (woody biomass of commercial value) is an aspect of rubber-tree cultivation that has gained significance. Rubber-tree plantations should be developed and managed to maximize primary production of timber, fuelwood and biomass energy (e.g. charcoal) for human benefit. Developing rubber-tree plantations as alternative source of timber for suitable uses will reduce the logging pressure on the remaining natural forests. Therefore, it is expedient to expand the management objective of rubber-tree plantations in Nigeria to cover both rubber latex and timber production by developing latex-timber clones via genetic improvement of the Nigerian Hevea population as well as carrying out studies to determine the effective planting spacing that will yield optimum latex with timber.

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