Biomass and carbon stock estimation of five selected tree species in a secondary forest at Obafemi Awolowo University Campus, Ile-Ife, Nigeria

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ABSTRACT

Biomass and carbon stock of five tree species were investigated in a secondary forest in Ile-Ife, Nigeria in order to assess the contribution of individual tree species to above and below ground biomass, and carbon stock in the forest. Fifty individual trees each of *Celtis zenkeri*, *Funtumia elastica*, *Holarrhena floribunda*, *Sterculia tragacantha* and *Newbouldia laevis* were sampled. The diameter at the base (at the ground level), middle (approximately half of the tree height), top (diameter of the tip of the tree) of the trees as well as at breast height; height of individuals of each species $\geq$ 10 cm DBH were measured. Above ground biomass was calculated as a product of stem volume and wood basic density while carbon stock was determined as the product of dry weight and an assumed carbon content of 50% of the tree biomass while below ground biomass was estimated using root:shoot ratio relationship. Results showed significant ($p < 0.05$) differences in biomass and carbon stock between the tree species. The order of biomass accumulation and carbon stock was *Celtis zenkeri* > *Holarrhena floribunda* > *Funtumia elastica* > *Newbouldia laevis* > *Sterculia tragacantha*. The lower DBH size class (21-30 cm) had the highest biomass contribution in the species. The study showed that the forest was generally characterized by small individuals and also provided information that will enhance prediction of biomass and carbon stock determination in tree species.

Keywords: Biomass, carbon, sequestration, stock, secondary forest, tree species.

INTRODUCTION

The importance of carbon as one of the life supporting components can't be over-emphasized. Plants have been reported to use carbon for growth and development as well as storing it in various parts of its organs for future use (Kiran and Kinnary 2011).

Plant biomass is developed using carbon streams and sinks by a process of photosynthesis (Atkin *et al.* 2012), and the biomass in plant tissues is stored as above and below biomass (IPCC 2003, Gorte 2009). The carbon cycle has attracted attention and is still attracting a worldwide consideration in view of CO_2, a dominant ozone depleting substance, which has been shown to contribute to overall environmental climate change (Brown 1993) due to the fact that it remains longer in the atmosphere. The concentration of CO_2 in the atmosphere has been estimated to contribute around 60% of the worldwide climate change (Grace 2004). This is generally connected to consumption of petroleum derivatives and destruction of forestland across the world (Hamburg *et al.* 1997).

Vashum and Jayakumar (2012) have pointed out that in the terrestrial biological systems; the forest ecosystem stands out amongst the most overwhelming carbon sink. The tropical forests obviously dominate the part of forestlands in the worldwide carbon cycle both on carbon transition and the volume of carbon put away (Kaul *et al*. 2010). This has been observed to be a one of the most encouraging methods of reducing the accumulation of greenhouse gasses in the air.

The tropical forest ecosystems store more carbon than forests outside the tropics (Kaewkrom *et al.* 2011) and have been used as distinct/marked sites for the investigation of climate change regarding complete net carbon emission and worldwide storage limit (Terakunpisut *et al*. 2007). The living biomass of trees, understorey vegetation and deadwood, which incorporates the standing and the fallen deadwood, woody debris and soil fertility issues make up the fundamental carbon pool of the tropical forest ecosystems (FAO 2005, IPCC 2006).

Acquiring information on tree biomass is pivotal to our understanding of the carbon sequestration process and carbon cycle between these pools (Durkaya *et al*. 2013). This data is critical in decision making for forest ecosystem management aimed at addressing climate change. Similarly, evaluation of carbon stock and changes in stock in tree biomass has been indicated to be significant part of the United Nations Framework Convention on Climate Change (UNFCCC), Kyoto Protocol, Reducing Emission from Deforestation and Forest Degradation (REDD) and thereafter, Reducing Emission from Deforestation and Forest Degradation in addition to conservation and sustainable of management of forest (REDD+) programmes with the end goal of the change of national carbon recordkeeping, and for marking out the potential regions for carbon credits (Gibbs 2007, Green *et al*. 2007, Hall 2012, Ekoungoulou *et al.* 2014).

However, studies on ground biomass estimation and carbon stock are sparse in Nigeria. Few of the reported studies on biomass allotment and carbon stock focused just on forest ecosystem, with little consideration paid to contribution of individual tree species to the total biomass and carbon stock in the forest ecosystems. Therefore, this study looked at the contribution of individual tree species to the above and below ground biomass and assessed the tree species carbon stock in a secondary forest in Ile-Ife, Nigeria.

MATERIALS AND METHODS

Study Area

The work was carried out at the Obafemi Awolowo University Estate, Ile-Ife, Nigeria (Figure 1). The Latitude and Longitude of Ile-Ife are on N 07^0 31' and (E 04^0 30') respectively, and the altitude ranges from 215 m to 457 m above sea level (Hall 1969). The details of the climate, soil and the vegetation of Ile-Ife have been described by Olatunde *et al.* (2012). Most of the original lowland rainforests have been greatly destroyed leaving remainder of secondary forest scattered around. Tree crop plantations like *Theobroma cacao*, *Cola nitida*, *Tectona grandis* and *Elaeis guineensis* are presently found in the area.

Data Collection

Five tree species namely *Celtis zenkeri*, *Hollarhena floribunda*, *Funtumia elastica*, *Sterculia tragacantha* and *Newbouldia laevis* were used in this study. A reconnaissance survey was carried out on the locations of the tree species inside the study area within the main campus of Obafemi Awolowo University. The area comprises of forest patches, re-growth secondary forest and some open area within the campus covering about 420 hectares (ha) (Figure 1). GPS coordinates of these locations were taken. Fifty healthy trees (complete and intact, not damaged, no parts snapped off or broken) with diameter at breast height DBH $\geq$ 10 cm were selected for each species. The trees were measured for DBH and a non-destructive approach was used to determine their diameter at the top, middle and base (at the ground level) as well as the total height (merchantable height to 10 cm top diameter) using a Spiegel Relaskop. A summary of the species, number of individual sampled for each species, DBH and height measurement range in this study is presented in Table 1.

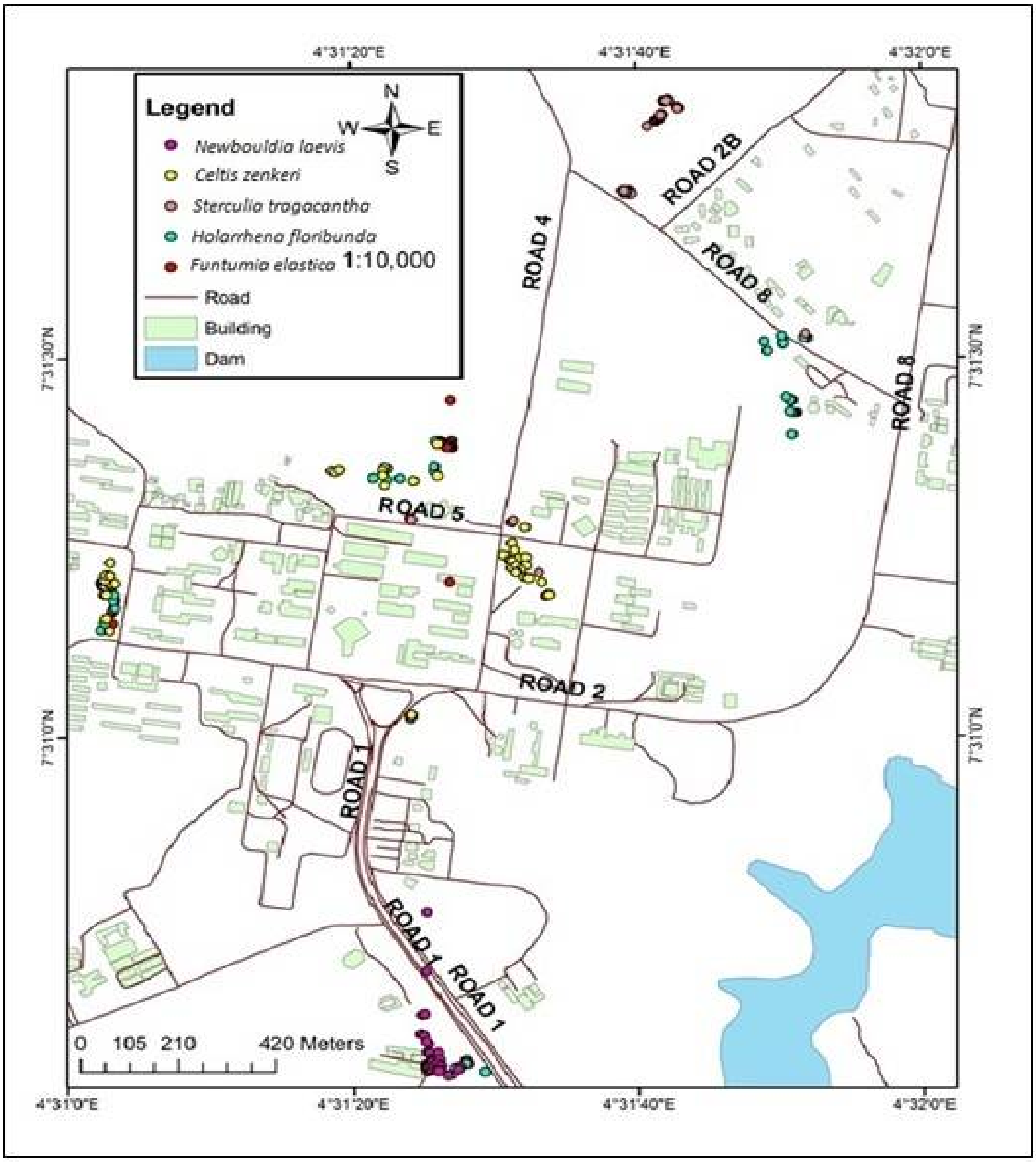

Figure 1. Map of Obafemi Awolowo University showing the locations of the different sampling points.

Table 1. Description of sampled trees, DBH range and tree height range for each of the species recorded at the study site

Species	Number of trees	DBH range (cm)	Tree height range (m)
Celtis zenkeri	50	15.8-51.0	14.5-37.5
Holarrhena floribunda	50	14.1-40.2	17.4-37.9
Funtumia elastica	50	11.0-42.0	8.0-26.1
Sterculia tragacantha	50	11.6-35.2	4.5-34.0
Newbouldia laevis	50	10.9-26.9	16.7-27.1

Estimation of stem volume

Individual tree stem volume for each species was calculated using Newton's formula (Hush *et al.* 2003).

$$V = \frac{h}{24}\pi(Db^2 + 4Dm^2 + Dt^2) \quad \ldots\ldots. (1)$$

Where V = merchantable volume (m^3),
h = Merchantable height (m),
π = pi (22/7)
Db = diameter at the base (m),
Dm = diameter at the middle position along the stem,
Dt = diameter at the top (m).

Wood basic density measurement

Wood basic density was determined using the core sampling method. A 5.0 mm increment borer was used. Cores were collected at two locations opposite to each other at 1.3 m above the ground level and retrieved without removing the bark. The fresh volume of cores was calculated based on the measured length of the collected cores and the diameter of the increment borer. The weight of fresh cores was measured immediately after retrieval and the oven-drying at 70 °C to a constant weight. Wood basic density of individual of each species was then calculated as oven-dried weight per fresh volume (Guendehou and Lehtonen 2014).

Determination of biomass of the tree species

Aboveground biomass for individual trees of each species was determined as a function of stem volume and wood basic density of the tree species (Brown 1997, Ravindranath and Ostwald 2008).

Above Ground Biomass (kg) = Tree stem volume (m^3) x wood basic density (kg m^{-3}… …………………..…. (2).

Below ground biomass was calculated as 26% of the aboveground biomass (Cairns *et al.* 1997, Snowdon *et al.* 2000, Eamus *et al.* 2002).

Below ground biomass (BGB) = Above Ground Biomass (kg) x 0.26 ………….(3)

Determination of carbon stock of tree species

The above ground carbon stock of individual trees of each species was determined as the product of the dry weight and an assumed carbon content of 50% (IPCC 2006).

Data Analysis

One-way analysis of variance was used to test for significant differences between above and belowground biomass, tree stem volume, wood density as well as carbon stock across the selected tree species. Significant means were separated using a Least Significant Difference post hoc test. The SPSS 17.0 software package was used and the level of significance used was 0.05%. The mean, coefficient of variation and bar chart were used in presenting some of the results.

RESULTS

Tree stem volume

There was a significant ($p > 0.05$) difference between stem volumes of the investigated tree species (Table 2). Among the species, *Celtis zenkeri* had the highest (1.10±0.09 m^3) stem volume while

Sterculia tragacantha had the lowest (0.22±0.02m³) stem volume. Generally, the pattern in terms of size is *Celtis zenkeri* > *Holarrhena floribunda*> *Funtumia elastica* > *Newbouldia laevis*>*Sterculia tragacantha.*

Table 2. Mean tree stem volume (m³) recorded for the studied species

Species	Maximum	Minimum	Mean ± Standard Error
Celtis zenkeri	3.43	0.27	1.10±0.09[a]
Holarrhena floribunda	1.76	0.18	0.67±0.06[b]
Funtumia elastica	1.08	0,07	0.43±0.04[c]
Newbouldia laevis	0.66	0.05	0.31±0.03[d]
Sterculia tragacantha	0.85	0.05	0.22±0.02[e]
LSD (0.05)			0.15

Means with the same letter along the same column are not significantly different at p>0.05.

Wood basic density

Results showed that for all the species, wood basic density was lowest in the lower DBH classes. *Celtis zenkeri* whose wood basic density was 711.02±30.16 kg m⁻³ was the highest among the species studied while that of *Sterculia tragacantha* of 448.02±22.44 kg m⁻³ was the lowest (Table 3). The order of the magnitude in this case was *Celtis zenkeri* > *Newbouldia laevis* > *Funtumia elastic* > *Holarrhena floribunda* > *Sterculia tragacantha tragacantha*.

Table 3. Mean wood basic density (kg m⁻³) of studied species

Species	Maximum	Minimum	Mean ± Standard Error
Celtis zenkeri	1448.98	342.11	711.02±30.16[a]
Holarrhena floribunda	716.22	260.16	463.71±14.44[b]
Funtumia elastica	876.71	281.25	511.73±16.08[c]
Newbouldia laevis	865.17	421.49	604.64±16.25[d]
Sterculia tragacantha	1135.14	196.85	448.02±22.44[e]
LSD (0.05)			57.70

Means with the same letter along the same column are not significantly different at p > 0.05.

Aboveground biomass accumulation

Aboveground biomass ranged from 782.21±70.63 kg in *Celtis zenkeri* to 94.31±8.013 kg in *Sterculia tragacantha* (Table 4). In all the species studied, the largest number of trees occurred in the 21-30 cm DBH size class (Figure 2). Generally, the trend in terms of aboveground biomass in all the species was *Celtis zenkeri* > *Holarrhena floribunda* > *Funtumia elastica* > *Newbouldia laevis* > *Sterculia tragacantha*.

Table 4. Mean aboveground biomass (kg) accumulation in the studied tree species

Species	Maximum	Minimum	Mean ± Standard Error
Celtis zenkeri	2768.34	111.18	782.21±70.63[a]
Holarrhena floribunda	1108.07	63.37	321.97±33.12[b]
Funtumia elastica	559.96	37.59	217.96±18.72[c]
Newbouldia laevis	524.55	33.04	184.90±19.02[d]
Sterculia tragacantha	298.76	20.16	94.31±8.01[e]
LSD (0.05)			103.2

Means with the same letter along the same column are not significantly different at p>0.05.

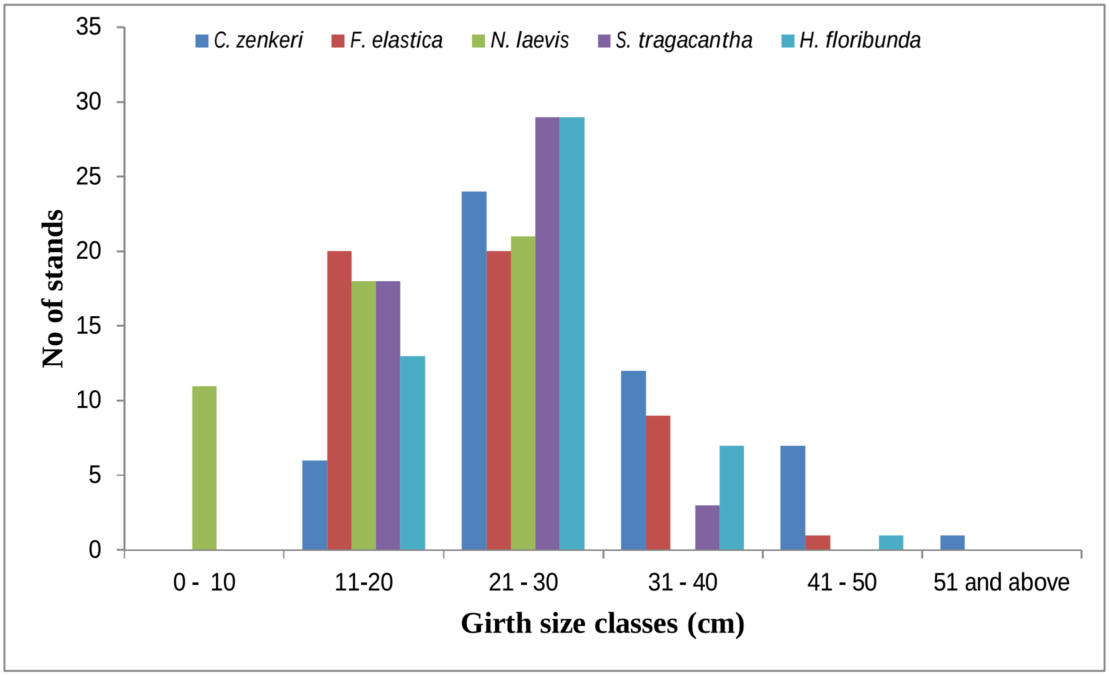

Figure 2. Distribution of number of trees in each species across the different girth-size classes

Belowground biomass allocation among the different species

Results (Table 5) show that *Celtis zenkeri* had the highest belowground biomass (203.37±18.36 kg) while *Sterculia tragacantha* had the lowest value of 24.52 kg. The order of belowground biomass increase was similar to aboveground biomass.

Table 5. Mean belowground biomass (kg) allocation across the studied species

Species	Maximum	Minimum	Means ±Standard Error
Celtis zenkeri	719.77	28.91	203.37±18.36[a]
Holarrhena floribunda	288.01	16.48	83.71±8.61[b]
Funtumia elastica	145.59	9.77	56.67±4.87[c]
Newbouldia laevis	136.38	8.59	48.07±4.95[d]
Sterculia tragacantha	77.68	5.24	24.52±2.08[e]
LSD (0.05)			26.831

Means with the same letter along the same column are not significantly different at $p > 0.05$.

Total biomass recorded in the studied species.

The mean total biomass of the different tree species is shown in Table 6. The Table shows that *Celtis zenkeri* had the highest mean total biomass while *Sterculia tragacantha* had the lowest.

Table 6. Mean aboveground, belowground and total biomass (kg) recorded across the studied species

Trees species	Mean Above ground biomass	Mean belowground biomass	Mean total biomass
Celtis zenkeri	782.21±70.63	203.37±18.36	985.58±88.99
Holarrhena floribunda	321.97±33.12	83.71±8.61	405.68±41.73
Funtumia elastica	217.96±18.72	56.67±4.87	274.63±23.59
Newbouldia laevis	184.90±19.02	48.07±4.95	232.97±23.97
Sterculia tragacantha	94.31±8.013	24.52±2.08	118.83±10.09

Aboveground carbon stock in the studied species

The aboveground biomass carbon stock in *Celtis zenkeri* was found to be significantly higher than the other species (Table 7). The trend of *Celtis zenkeri* having highest carbon stock compared to other species was similar to the trend observed in biomass, where the highest biomass was also recorded in the *Celtis zenkeri* species.

Table 7. Mean aboveground carbon stock (kg/m^3) for studied species

Species	Maximum	Minimum	Means ±Standard Error
Celtis zenkeri	1384.17	55.590	391.10±35.32[a]
Holarrhena floribunda	554.037	31.685	160.98±16.56[b]
Funtumia elastica	279.977	18.794	108.98±9.36[c]
Newbouldia laevis	262.274	16.521	92.45±9.51[d]
Sterculia tragacantha	149.380	10.078	47.15±4.01[e]
LSD (0.05)			51.598

Means with the same letter along the same column are not significantly different at $p > 0.05$

DISCUSSION

Tree Stem Volume

The significant differences observed in tree stem volume of the species can be the result of variations in their growth rates and different girth sizes. Tree size (diameter and height) are function of the volume increment of a tree, and this might have contributed to the trend observed in the species studied. Egbe and Tabot (2011) have reported that volume increment is a function of biomass growth. Thus, by having individuals with a larger proportion of stem diameter and height, *Celtis zenkeri* recorded the highest stem volume compared with *Sterculia tragacantha* which had the lowest stem volume.

Wood Basic density

The density measurements can vary among tree species, and also within the individuals of the same species. The large interspecies variation in the wood basic densities of the species recorded in this work agrees with results of Rueda and Williamson (1992) and Wiemann *et al.* (2002), where differences in densities between species were reported to be higher in the tropics compared to the values in the temperate region. This observation was attributed to the high diversity of species found in the tropical region. The highest wood basic density recorded in *Celtis zenkeri* of 711.02 kg m^{-3} could be from its matured individuals while *Sterculia tragacantha* with the lowest wood density (448.02 kg m^{-3}) had young trees (based on DBH size class distribution). In this study, *Celtis zenkeri* had 20 of the 50 individual trees in the size class > 30 cm, whereas *Sterculia tragacantha* had only 3 of the 50 trees in the size class > 30 cm. This observation agrees with the finding of Rueda and Williamson (1992), Bauch and Dünisch (2000), Bao *et al.* (2001), Jonnes and O'hara (2012) who have all pointed out that juvenile trees have lower wood densities compared to matured trees.

Local data on wood basic densities of Nigeria's tree species are generally not available. Therefore, wood basic density results obtained from this study were compared with the IPCC (2006) documented values sourced from the report of Reyes *et al.* (1992) and Zanne *et al.* (2009), which are the most prominent international data base available for tree species wood densities in tropical Africa. In summary, it is clear that the mean wood basic density of 711.02 kg m^{-3} obtained in this study for *Celtis zenkeri* was greater compared with the reported mean values of 590 kg/m³ by Reyes *et al.* (1992) and 600 kg m^{-3} by Zanne *et al.* (2009) for *Celtis zenkeri*. The average wood basic density obtained in this study for *Holarrhena floribunda* (464 kg/m³) is similar to the value of 469 kg m^{-3} reported by Zanne *et al.* (2009) for the same species and Gossanous *et al.* (2016) in Benin who reported an average of 540 kg m^{-3} (430-610 kg m^{-3}). The wood basic density value of 512 kg m^{-3} for *Funtumia elastica* reported in this study was higher than the values of other species namely *Funtumia africana (*400 kg m^{-3}) and for *F. latifolia (*450 kg m^{-3}) *reported in* the global database (Ryes *et al.,* 1992). Also, the mean wood basic density value of 448 kg m^{-3} recorded in this work for *Sterculia tragacantha* was not too different from the range of reported global values by Ryes *et al.* (1992) for the other species of *Sterculia* namely *Sterculia oblonga* (611 kg m^{-3}), *S. rhinopetala* (640-699 kg m^{-3}), *S. africana* (276 kg m^{-3}), *S. appendiculata* (607 kg m^{-3}), *S. quinquoloba* (671 kg m^{-3}) and *S. setigera* (320 kg m^{-3}). This interspecies variation in wood density could be due to the fact that they are different species although they belong to the same genus.

The values of wood basic density recorded in this study are similar to the values of wood basic density reported for trees in Africa varying from 580 to 670 kg m^{-3}, with an average value of 600 kg m^{-3} (Brown 1997, Flyn Jr and Holder 2001, Sylla and Picard 2009, ICRAF 2009). Henry *et al.* (2010) in Ghana also reported average wood basic density of 590 kg m^{-3}, while the average value of 620 kg m^{-3} was reported by IPCC (2003). It should however be noted that wood basic density for individual tree is more reliable than using average values.

Aboveground Biomass Accumulation

The significant difference observed in aboveground biomass in all the species studied reflects interplay between wood basic density and stem volume which are different in all the species. Various authors (Nelson *et al.* 1999, Ketterings *et al.* 2001, Chave *et al.* 2004, Kenzo *et al.* 2009) have noted that lower wood basic density usually shows lower biomass estimate while a higher wood basic density shows a higher biomass estimate. Our observation of *Celtis zenkeri* having the highest aboveground biomass compared to the other four species may be due to its higher wood density value (711 kg m^{-3}), while *Sterculia tragacantha* with the lowest wood density (488 kg m^{-3}) recorded the lowest above-ground biomass is therefore in agreement with the reported trend. Biomass allocation in plants was also reported to be functions of tree volume and wood density (Egbe and Tabot 2011). Elias and Potvin (2003); Redondo and Montagnini (2006) have also pointed out that biomass accumulation may be as a result of differences in wood density and patterns of growth between rapid and slow growing species.

The stem volume is obviously closely related to stem biomass and also to tree biomass. Even though *Holarrhena floribunda* had a lower wood density (464 kg m^{-3}) than *Funtumia elastica* (512 kg m-

^{3}) and *Newbouldia laevis* (605 kg m^{-3}), the aboveground biomass of *Holarrhena floribunda* was still higher than that of *Funtumia elastica* and *Newbouldia laevis*. This could be as a result of higher stem volume recorded in *Holarrhena floribunda*. Values of aboveground dry biomass in tropical forests differ among studies; Chave *et al*. (2014) reported values varying from 291.8 to 559.7 M ha^{-1} in pantropical forest; Djomo *et al.* (2010) and Fayolle et al. (2013) reported values that ranged from 461.3-713.3 and 465.3-730.4 in Cameroun; Goussanou *et al.* (2016) reported a range of 264.6-465 in Benin.

Belowground Biomass Content

With respect to the root: shoot ratio method of belowground biomass estimation used in this study, *Celtis zenkeri* with the highest aboveground biomass also had the highest below ground biomass while *Sterculia tragacantha* with the lowest aboveground biomass recorded the lowest belowground biomass. The reason for this observation might be as a result of the link between belowground biomass accumulation and the dynamics of aboveground biomass and that resulted in the observed trend in all the species studied. Data on belowground biomass of tree species are generally not available in Nigeria. Therefore, results obtained from this study were compared with values from other parts of Africa and the world. The value of 185.01- 221.75 kg obtained in *Celtis zenkeri* was found to be slightly higher than the values of 45.9-106.4 reported for *Celtis mildbraedii* (Ekoungoulo, *et al*. 2018) but lies within the values reported in *Celtis tessamannii* of 86.82- 559 kg (Ekoungoulou *et al.* 2018). The value of 56.67±4.87 kg obtained in *Funtumia elastica* was found to be close with the value of 34-6-55.82 kg reported for *Funtumia Africana* (no data for *Funtumia elastica*). Generally, the values obtained in the tree species except for *Celtis zenkeri* in this study fall within the range reported in other studies namely Henry *et al*. (2010) in Ghana (68.5-131.5); Mugasha *et al*. (2013) in Tanzania (142-218); Ekougoulou *et al*. (2018) also in Congo reported (46.2-154); Chave *et al*. (2014) and Mokany *et al*. (2006) reported (68.5-131.5) for pantropical forest.

Carbon Content

Variations in carbon stock in plants have been pointed out to be the result of many factors: forest type, plant age, size class of trees, tree density, wood density, tree volume forest disturbances including illegal logging and forest fire (Perez-Cordero and Kanninen 2003; Tschakert *et al.* 2006, Terakunpisut *et al*. 2007, Egbe and Tabot 2011). In all the species investigated in this study, the significant variation in carbon stock might be due to combined effects of volume increment and wood density. These two properties are obviously directly proportional to tree biomass and the same holds for carbon content. Increment in volume is a function of the biomass buildup; density of the wood also impacted on the amount of carbon recorded in plant biomass.

The highest carbon stock in *Celtis zenkeri* could be due to the high values of tree volume and wood basic density while *Sterculia tragacantha* with the lowest carbon stock recorded the lowest values of tree volume and wood density. This result is in agreement with report of Rahayu et al. (2005) and Vieira et al. (2005), who reported more carbon stock in rubber plantation trees with increased rates of increment volume and wood densities. Similar results in agroforestry systems have been reported (Duguma *et al.* 2001, Masera *et al.* 2003, Shin *et al.* 2007). Results of carbon stock in aboveground biomass that ranged from 30 to 255 Mg C ha^{-1} have been reported in tropical forests in Africa (Brown 1997, Houghton and Hackler 2006, IPCC, 2007).

CONCLUSION

It is clear from this study that biomass and carbon stock differ among the tree species studied, *Celtis zenkeri* had the highest biomass (above and below) as well as carbon stock among the species studied. The tree species investigated in this study are generally characterized by small and young individuals, they should be protected and properly managed in order to enhance biomass build up through absorption of atmospheric CO_2. Similar study on contribution of other tree species to biomass and carbon stock should be carried out. The data on biomass and carbon stock estimation of the tree species in the secondary forest will complement available information that will be useful in predicting future global C stock scenarios.

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