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Full Length Research Paper

Sequestered carbon stocks in eight selected woody species of the Guinea Savanna ecosystem in Makurdi, Benue State, Nigeria

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Carbon sequestration potentials of eight selected trees (*Prosopis africana, Parkia biglobosa, Daniella oliveri, Morinda lucida, Vitex doniana, Terminalia avecinioides, Sarcocephallus latifolius and Parinari curatellifolius)* were investigated using a pan-tropical non-destructive allometric model (Y=Exp{-2.4090+0.9522In(D^2xHxS)}) in Makurdi, Benue State Nigeria. Data on plant height (H), diameter at breast height (DBH) and wood density (S) were applied in the model to determine the above ground mass (Y) while % carbon in plant and soil were determined by Walkley-Black and loss on ignition methods respectively. Mean AGB and BGB (Kg/tree) were highest in *Prosopis africana*, (3171.62 ± 2211.46 and 634.23±197.80) and lowest in *Sarcocephallus latifolius* (256.694±57.14 and 51.33±7.86). AGB increased significantly ($p<0.05$, r = 0.8 and Y=80 * x + -1600) with DBH and plant height ($p<0.01$, r = 0.7 and Y=320 * x); plant height also correlates positively with DBH ($p<0.01$, r = 0.7 and Y=4 * x + 20), in all the species. TSC and SCO_2E (Tones/Tree) were highest in *P. africana* (1.24±0.39; 4.54±1.42) and least in *S. latifolius* (0.10±0.02; 0.37±0.06) respectively. % carbon in plant and soil varied significantly ($p<0.01$) with species and depth. The species potentials in carbon sequestration are implicated in this study, hence their relevance in climate change mitigation and ecosystem stability.

Key words: Carbon sequestration, climate change, guinea savanna, above ground biomass, below ground biomass, *Prosopis africana, Parkia biglobosa, Daniella oliveri, Morinda lucida, Vitex doniana, Terminalia avecinioides, Sarcocephallus latifolius, Parinari curatellifolius*

INTRODUCTION

The global concentration of atmospheric carbon dioxide (CO_2) has significantly increased by 18% since 1750 (from ~280 to 391ppmv) with yearly increase estimated at 1.5ppb between 1990 and 2000; 2ppb between 2001 and 2009 and 2.3ppb between 2009 and 2010 (Chavan and Rasal, 2011; 2012; Macias and Arbestain, 2010). Increased CO_2 concentration and other Greenhouse gases (GHG) such as methane, Nitrous oxide, Sulphur-hexafluoride, chlorofluorocarbon is known to increase atmospheric temperature by trapping heat radiations in the atmosphere, thereby causing global warming and climate change (Chavan and Rasal, 2010; IPCC, 2007; Ravindranath *et al*., 1997). This obviously poses great danger to the entire universe hence, the earth summit in Rio de-Janeiro (1992), Kyoto protocol in Japan (1997), Copenhagen conference in Denmark (2009), Kankum conference in Mexico (2010) and the Darban conference in South Africa (2011), all called for the reduction of GHG and CO_2 from the atmosphere in other to save our environment (Chavan and Rasal, 2012; McHale *et al*., 2007). the Kyoto protocol advocated the Clean Development Mechanisms (CDM) which provides for emissions reduction projects that generate carbon credits that can be traded (IPCC, 2007) and report same to the United Nations Frame Work Convention on Climate Change (UNFCCC) and the Kyoto Protocol (Green *et al*.,

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2007; Almgir and Al-Amin, 2007). Carbon storage (sequestration) in terrestrial systems can be easily inserted into the national GHG inventories of each nation and be paid for, with Nigeria, a signatory to the Kyoto Protocol. Terrestrial or biogeochemical carbon sequestration as suggested by Parr *et al*. (2010) and Song *et al*. (2011) is cost effective and largely dependent on woody plants which stay longer and are not easily degradable (Parr *et al.*, 2009).

Consequently, sequestered carbon in live stocks have been estimated in the agro-ecosystems of the Himalayas in India (Prakash and Lodhiyal, 2009), tropical moist lowland forests in Costa Rica (Fonseca *et al*., 2012) and in newly established *Annona reticulata, A. squamosa* and *Mangifera indica* at the University of Aurangabad, India (Chavan and Rasal, 2010, 2011, 2012); in the Lobeke National Park, Cameroon (Zapfack *et al*., 2013). In Nigeria, similar studies on carbon stocks have also been carried out by various researchers (Odiwe *et al*., 2012; Makinde *et al*., 2015; Jibrin and Abdulkadri, 2015; Olayode *et al*., 2015). Data from this research will therefore be documented for carbon credit trading and provide information on the contribution of the Nigeria vegetation to mitigating climate change. The non-destructive allometric model involving one or more tree components in computing tree biomass (Brown *et al*., 1989; Chave *et al*., 2005; Ravindranath and Ostwald, 2008; Manish *et al*., 2004) will be employed. The method is based on the link between individual tree and the whole-stand biomass and the assumption that wood mass is about 50% carbon (Birdsey, 1992; Parresol, 1999; Jana *et al*., 2009; Paladinic *et al*., 2009).

AIM AND OBJECTIVES OF THE STUDY

The aim of this research is to evaluate carbon storage and accumulation in the selected woody species of the guinea savanna ecosystem (Makurdi, Nigeria) while specific objectives include; estimating the total biomass (above ground and below ground), total carbon stock, carbon dioxide sequestered and % of carbon in the plant and soil of the selected species.

MATERIALS AND METHODS

Study area

The research was carried out at the Agan open forest area of Makurdi, Benue State. The area falls within the Guinea Savanna agro ecological zone of Nigeria (latitudes 70 38' and 70 50' North of the Equator and longitude 80 24' and 80 38' East of the Greenwich Meridian). The relief is generally low lying, ranging from below 90m to 150 m above sea level with three soil types (alluvial, clayey loam and sandy), with a total land mass of 3,993.3 Km2 and divided by the River Benue into North and South Banks (Kogbe, 1989; Abah, 2013; Tyowua *et al*., 2013) (Figure, 1). The region is a tropical area with alternating wet and dry seasons and an annual average precipitation of 1240-1440 mm. Temperature generally is high during the day especially in March and April, with daily maximum and minimum temperatures between 37 ^{0}C and 16^{0}C (NIMET, 2015, 2016).

Data collection

Plant species selection

Eight common woody species namely *Daniellia oliveri*, (Rolfe) Hutch and Dalz., *Vitex doniana* (Joris de wolf), *Morinda lucida* Benth., *Parinarri curatellifolia* Planch. ex Benth., *Parkia biglobosa* (Jacq.) R. Br. ex G. Don., *Sarcocephallus latifolius* (J.E. Sm.) E.A. Bruce., *Terminalia avecinioides* (Guill. and Perr.) and *Prosopis africana* (Guill, Perr. and Rich.) Taub were selected at the Agan forest area (with reduced human interference). At the site, a 50m×50m area was mapped out for study and stands of each species with diameter at breast height (DBH) >30cm within the mapped area were selected for study. The study site was selectively mapped out such that all the species of interest were included).

Biophysical measurements

Plant height and diameter at breast height (DBH), crown diameter and basal area were the measurements taken for each specie. Data generated were used in estimating the total biomass (above and below ground) for each species. Tree height was measured using a Haga altimeter while diameter was measured using a measuring tape.

Laboratory analysis

Total carbon in plant was determined by the Walkley-Black wet oxidation method (ALPHA, 1980) while the loss on ignition method (Heiri *et al*., 2001) was used to determine soil organic carbon.

Data analysis.

All data were analysed statistically using Predictive Analytical Soft Ware package (SPSS) version 21.0 software for windows.

Above ground biomass (AGB) and below ground biomass (BGB).

The mathematical model Y=Exp{-2.4090+0.9522 In (D^2 x H x S)} was used (Brown *et al*.,1989); Where, Y is the above ground mass (kg), H is the height of the tree (meters), D is diameter at breast height (cm) and S is the wood density (gm/cm^3). Species wood densities were

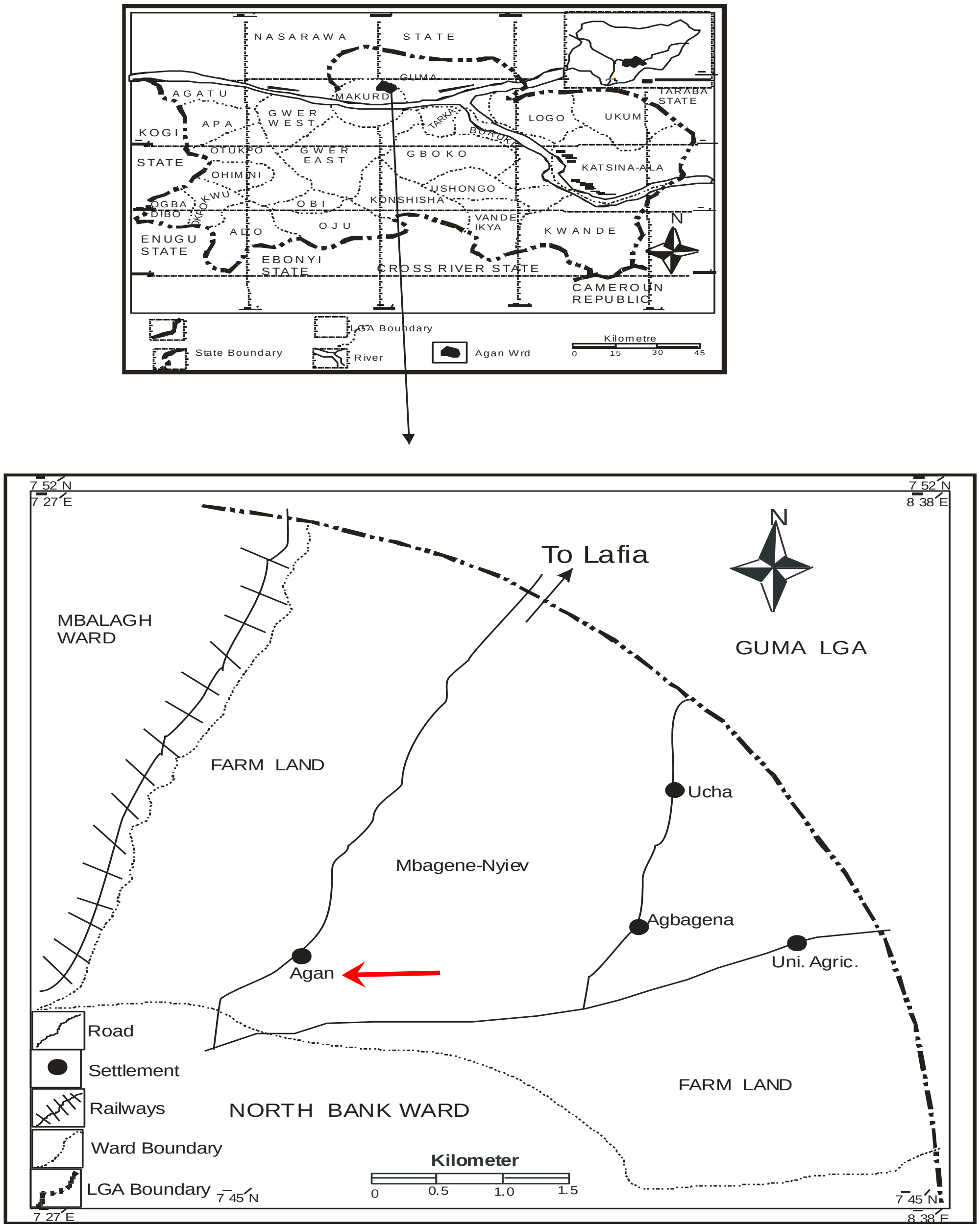

Figure 1. Map of study site. A. Map of Benue State B. Map of study site (indicated by red arrow in Makurdi, Benue State.
Source: Ministry of Land and Suvey Makurdi.

extracted from the world agro-forestry database (http://www.worldagroforestrycentre.org/Sites/TreeDBS/aft.asp). Where wood densities are not known, the standard average value of 0.6 gm/cm^3 was used (Patwardhan *et al*., 2003). Based on the assumption that 35% of plant matter is water, 65% AGB was taken as dry biomass (DB) while 50% of dry biomass was used to determine the above ground carbon in plant biomass (Losi *et al*., 2003; Jana *et al*., 2009).

Below ground biomass was calculated as 20 % AGB (Ponce-Hernandez, 2004). BGB = 20 % x AGB (DB). Total biomass was determined as sum of above ground and below ground biomass respectively (AGB + BGB). Total sequestered carbon was determined as 50% of total above ground biomass (dry biomass). Sequestered carbon dioxide equivalent (SCO_2E) was determined by multiplying carbon in plant biomass by a carbon correction factor (3.67).

The relationships between plant parameters (plant height, diameter at breast height and crown diameter) and above

Table 1. Mean above ground biomass, below ground biomass, total sequestered carbon and sequestered carbon dioxide equivalent (Tonnes/Tree) in eight woody species in Makurdi, Benue State, Nigeria.

Species	AGB (Kg)	DB (Kg) (65% of AGB)	BGB (Kg) (20% of AGB)	BGDB (Kg) (65% of BGB)	TAGC (Kg) (50% DB)	TBGC (Kg) (50% BG DB)	TSC/Tree (Tonnes/Tree)	SCO_2E (Tonnes/Tree)
PA	3171.62±989.00	2061.55±642.85	634.23±197.80	412.30±128.57	1030.77±321.42	206.15±64.28	1.24±0.39	4.54±1.42
PB	1174.11±236.77	763.17±153.90	234.82±47.35	152.63±30.78	381.59±76.95	76.32±15.39	0.46±0.09	1.68±0.34
ML	297.88±52.96	193.62±34.43	69.90±59.57	38.72±6.89	96.81±17.21	19.36±3.44	0.12±0.02	0.43±0.08
DO	1934.40±578.33	1257.36±375.91	386.87±115.67	251.47±75.18	628.68±187.96	125.74±37.59	0.75±0.23	2.77±0.83
VD	1100.49±311.68	715.32±202.59	220.09±62.34	143.06±40.52	357.66±101.30	71.53±20.26	0.43±0.12	1.58±0.45
TA	320.14±31.35	208.09±20.38	64.02±6.27	41.62±4.08	104.05±10.19	20.81±2.04	0.12±0.01	0.46±0.04
SL	256.69±39.31	166.85±25.55	51.33±7.86	33.37±5.11	83.42±12.78	16.68±2.56	0.10±0.02	0.37±0.06
PC	617.60±136.94	401.44±89.01	123.52±27.39	80.29±17.80	200.72±44.51	40.14±8.90	0.24±0.05	0.88±0.20

AGB (Above ground biomass, Y= exp[-2.4090+0.9522*Ln(D2*H*S]); DB (Dry Biomass); BGB (Below ground biomass); BGDB (Below ground dry biomass (weight); TAGC (Total above ground carbon); TBGC (Total below ground carbon); TSC/Tree (Total sequestered carbon/Tree) = TAGC+ TBGC SCO_2E (Sequestered carbon dioxide equivalent) = TSC×3.67 (Correction factor)
± = Standard errors

ground biomass were investigated using correlation and regression analyses.

Soil total carbon

% organic matter = loss in weight/ weight of soil used x 100. % organic carbon =% organic matter ⁄1.729 (Correction factor; van Bemmelen factor). Total organic carbon = % organic carbon x bulk density x soil depth. Bulk density was determined as dry weight of soil ⁄ soil volume. Soil volume was estimated as x r^2 x h. where, π = 3.142; r = 3 cm (radius of soil auger) and h = 15 cm (height of soil auger). Soil dry weight = oven dry weight- fresh weight.

RESULTS

Biomass estimation

Mean above ground and below ground biomass (AGB and BGB) and total sequestered carbon (TSC) in plant biomass are presented in Table 1. Mean AGB and BGB were highest in *Prosopis africana*, (3171.62 ± 2211.46 and 634.23±197.80 Kg/tree) and lowest in *Sarcocephalus latifolius* (256.694±57.14 and 51.33±7.86 Kg/tree). One-way analysis of variance (ANOVA) showed highly significant differences ($p<0.01$) among species total sequestered carbon in plant biomass. *Prosopis africana* had the highest total sequestered carbon and CO_2 equivalents (1.24±0.86; 4.54±3.17 tones/tree) while *Sarcocephalus latifolius* had the lowest estimates (0.1±0.03; 0.37±0.13; Table 1). Linear regression analyses indicated strong positive relationships between AGB and DBH (r = 0.882; R^2 = 0.778; $p<0.05$) and plant height (r = 0.774; R^2= 0.599, $p<0.01$) and plant height with DBH (r = 0.728; R^2 = 0.530; $p<0.01$; Table 2) in all the species; indicating that AGB increased with increasing DBH and plant height across all species. % carbon was highest in *V, doniana* (25.76) and least in *T*. *avecinioides* (16.37), while that of soil varied with species depth (figure 2).

Discussion

Biomass determination and carbon sequestration.

Estimates of mean above ground and below ground biomass (Tones /tree) and total sequestered carbon (Tones/tree) in this study (Table 1) are generally below the average rates of above ground carbon accumulation (6.4-10.0 t ha^{-1} yr^{-1}) in the tropics (Nilsson and Schopfhauser, 1995), though with varying area extent. The results are lower than those recorded in other species in Nigeria and other African ecosystems such as: 81 Mg ton/ha of carbon and 359 Mg t/ha

Table 2. Correlation, regression coefficients and equations showing relationships between measured parameters in eight woody species in Makurdi, Benue State, Nigeria.

Comparison	Pearson Correlation r	R^2	Strength of Correlation	Significance	Equation (y)
Height vs DBH	0.728	0.530	Strong Positive	0.000**	Y=4 * x + 20
Height vs AGB	0.774	0.599	Strong Positive	0.000**	Y=320 * x
DBH vs AGB	0.882	0.778	Strong Positive	0.000**	Y=80 * x + -1600

** Statistically significant (p<0.01) *statistically significant (p<0.05).

of CO_2 in Olorun forest, Osun State (Makinde *et al*., 2015), 28.18 ton/ha in Ile-Ife (Odiwe *et al*., 2012), 152 Mg C ha^{-1} in a cocoa agro-forestry in south Cameroon (Duguma *et al*., 2001); 66-88 Mg C ha^{-1} and 248-264 Mg C ha^{-1} in the Oil palm and rubber plantations in Cameroon respectively (Egbe *et al*., 2012). When compared with similar studies on per tree basis, the results are also lower than the carbon stock estimates in *Ficus religiosa* (4.27, t/tree); *Ficus bengalensis* (3.89, t/tree); *Mangifera indica* (3.13, t/tree); *Delonix regia* (2.12, t/tree); *Butea monosperma* (2.10, t/tree), *Peltaforum pterocarpum* (2.01, t/tree), *Azadirachta indica* (1.91, t/tree), *Pongamia pinnata* (1.57, t/tree), and *Hyophorbe amercaulismort* (1.53, t/tree) respectively, as reported by Chavan and Rasal (2010, 2011 and 2012).

The positive relationships ($p<0.01$) between above ground biomass (AGB), diameter at breast height (DBH) and plant height indicates that above ground biomass increases with increasing plant height and diameter respectively (Table, 2), hence the variation in biomass estimates. The positive relationship also indicates the suitability of the model as it integrates individual plant attributes. Zapfack *et al*. (2013) demonstrated that carbon stock varies with type of wood, DBH and basal area. Redondo-Brenes (2007) and Dutca *et al*. (2009) reported that fast growing species stores carbon faster in the early stages of their life cycle, while the high specific gravity of slower growing species stores carbon gradually. Variability in biomass estimates among the species in this study reflects differences in plant parameters (plant height, diameter at breast height and densities) employed in the allometric model as well as the age and growth rate of the species. As the diameter of species increase, the biomass and carbon storage capacity increase and also sequestered more carbon dioxide from the atmosphere. Sequestered carbon was highest in *Prosopis africana* (1.24 tonnes/tree; Table 1) compared to other species in this study, while the average total sequestered CO_2 in the species explains the important ecological services provided in the area by the species, hence their relevance in global warming and climate change mitigation.

Although the result varied with other studies, tropical systems especially forests record high accumulation of biomass and sequestered carbon. Aerts and Chapin (1999), Cornelissen *et al*. (2007) explained that, woody plants have some features that strongly affect their physico-chemical composition which confer in them, high recalcitrant carbon, reduced soil carbon loss (through respiration and leaching) and carbon immobilization (in plant residues). Such traits include phytoliths and lignin, both with long resident time in soil, polyphenols and tannins which offer protection against pathogens and herbivory in live plants (Hattenschwiler and Vtousek, 2000) and growth rate (Chapin, 2003; Lavorel *et al*., 2007).

% carbon in plant and in soil

Mean percentage carbon content in plant is comparable to that of soil carbon at each depth, but lower than the soil total carbon (Figure 2). Davidson and Janssens (2006) explained that savanna soils generally have low carbon content due to high temperatures that mineralizes carbon; hence more carbon is lost from the top soil. Clay type (whether it is 1:1 or 2:1) as well as its content has shown to increase soil organic carbon concentration and retention (Bationo *et al.,* 2007). Olson *et al*. (2013) stated that soil carbon sequestration is influenced by soil and plant interactions. Lavorel *et al.* (2007) also stated that environmental stress such as extrem

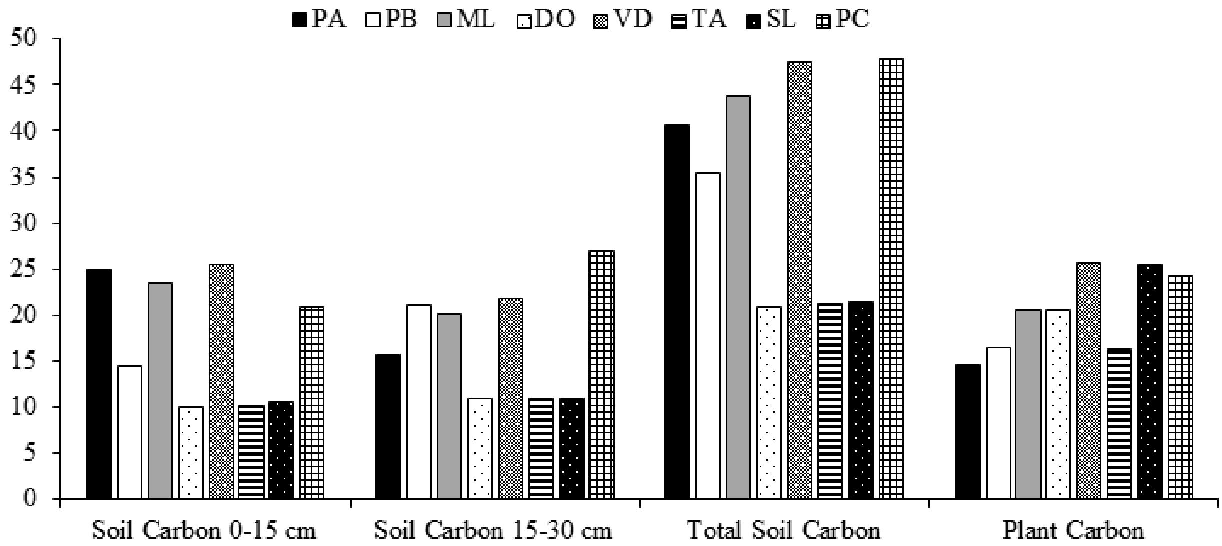

Figure 2. % Carbon in plant and soil at different depths for all the species.

thus influencing soil carbon imputes by different plants. temperature and low nutrient availability influence carbon cycling. This means that, differences in soil characteristics reflects plant performance, productivity and biomass production, Lal (1995; 2003), Arriaga and Lowry (2005) reported that accelerated soil erosion results in carbon emissions, with a possible release of 20% of the carbon released as CO_2 into the atmosphere, 10% transported as dissolved carbon in water bodies, and 70% remains on the lower landscape position. According to Baker *et al.* (2007), differences in soil carbon distribution is attributable to differences in land use practice. Olson *et al.* (2013) stated that soil inversion also translocates surface soil carbon to lower depths. This result suggests that more carbon was allocated to the above ground shoot system to support growth and productivity (King *et al.,* 1997).

CONCLUSION

The study revealed that the species stored a considerable quantity of CO_2 in their biomass and showed their relevance in climate change mitigation. The findings have implications for understanding and predicting the accumulation and distribution of organic matter in the study area. Variation among the species carbon stocks is attributable to differences in age, height, diameter and wood densities. The species which harvest more CO_2 from the atmosphere should be planted more since our natural forests at present are faced with deforestation and degradation resulting in loss of sequestered carbon stocks as well as the high increase in the level of atmospheric CO_2 attributable to human actions. This will improve the ecosystems ability to provide the much needed ecological services especially climate change mitigation.

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