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Assessments of Carbon Credit Potentials Of *Mangifera indica* and *Tectona Grandis* Agroforestry Plantations as Viable Options in Climate Change Mitigation

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ABSTRACT

Comparative assessments of sequestered carbon in above ground biomass, herbaceous standing plants and litter in *Mangifera indica* and *Tectona grandis* plantations at Akperan Orshi Polytechnic Yandev, Gboko Local Government, Benue State, Nigeria, was carried out in January 2021. The plantations were partitioned into three plots. The above ground biomass (AGB) of *M. indica* and *T. grandis* was determined by the allometric model: Volume (m^3) × Density (0.6, kg). Total sequestered carbon (TSC) of herbaceous standing plants and litter was determined as 50% oven dry weight. The diversity of herbs within the plantation was determined using Shannon diversity index, with plot 1 and 2 being the most diverse in *M. indica* and *T. grandis* plantations, respectively. AGB (37.84 kg), TSC (18.92 kg) and Sequestered carbon dioxide equivalent (SCO_2E, 9.44 kg) were highest in plot 1 of *M. indica* plantation; while AGB (9.8 kg) TSC (4.9 kg) and SCO_2E (17.99 kg) were highest in plot 2 of *T. grandis* plantation respectively. In *M. indica* plantation, plot 2 gave the highest herbaceous standing biomass (0.105 kg), TSC (0.053 kg) and SCO_2E (0.193 kg); while the herbaceous standing biomass (0.072 kg), TSC (0.036 kg) and SCO_2E (0.133 kg) were also highest in plot 2 of *T. grandis* plantation. Furthermore, in *M. indica* plantation, plot 1 gave the highest litter biomass (0.073 kg), TSC (0.037 kg) and SCO_2E (0.135 kg; while in *T. grandis* plantation, plot 3 gave the highest litter biomass (0.124 kg), TSC (0.062 kg) and SCO_2E (0.227 kg), respectively. Also, in *M. indica* plantation, there was a strong significant linear regression between AGB and DBH ($p<0.000$, R^2 = 0.89), and weak significant linear relationships between AGB and plant height ($p<0.000$, R^2 = 0.35), and DBH and plant height ($p <0.000$, R^2 = 0.19). Similarly, in *T. grandis* plantation, there were weak significant linear regressions between AGB and DBH ($p<0.000$, R^2 = 0.36), AGB and plant height ($p<0.000$, R^2 = 0.19), and DBH and plant height ($p<0.000$, R^2 = 0.13). The species potentials in carbon sequestration are elucidated, hence their relevance in climate change mitigation and ecosystem stability.

Keywords: Carbon sequestration, Agroforestry, Herbaceous Standing and Litter Biomass, *Mangifera indica, Tectona grandis*.

INTRODUCTION

The influence of carbon on earth and the atmosphere can be beneficial or detrimental (Nimbalkar *et. al*., 2017). Since the industrial revolution, there has been a drastic increase of greenhouse gases (GHG) in the atmosphere particularly carbon dioxide (CO_2) and other GHGs such as: methane, nitrous oxide, sulphur-hexafluoride, chlorofluorocarbon that are known to increase atmospheric temperature by trapping heat radiation in the atmosphere thereby causing global warning and climate change (Okoh *et al.*, 2019; Dugaya *et. al*., 2020). Although, carbon is essential to sustain biological activity, biodiversity and ecosystem productivity, excessive release of carbon into the atmosphere, primarily by human activity, has led to adverse consequences. Thus, the concerted global efforts to reduce carbon emission, foremost among them is the biogeochemical sequestration of carbon (Ahmedin *et.al*., 2013, Nimbalkar *et. al*., 2017; Paul *et. al*., 2019; Okoh *et. al*., 2019). Anthropogenic activities such as fossil fuel consumption, indiscriminate non-biodegradable waste disposal, deforestation and land degradation resulting in loss of biodiversity and climate change have brought about serious public and political concerns on GHGs emissions and their consequences on the ecosystem (Gebrewahid *et. al*., 2018; Ganeshamurthy *et. al*., 2019; Atsbha *et al*., 2019).

Agroforestry has been recognized as a viable tool in the Clean Development Mechanism (CDM) suggested by the Kyoto protocol with high potentials to store large amounts of atmospheric carbon hence, play a key role in climate change mitigation (Chenge and Osho, 2018, Okoh *et al*., 2021). Agroforestry is extensively practiced throughout the tropics and developing countries, with an estimated 1.2 billion people around the world dependent upon Agro-forestry farming systems (Zomer, 2016; Otokiti *et al*., 2019). Since agroforestry is mostly practiced by subsistence farmers in developing countries, there is an attractive opportunity for these farmers and the nation to benefit economically since the carbon credit generated can be paid for. The present study was undertaken to comparatively estimate the total sequestered stocks in *Mangifera indica*, and *Tectona grandis* plantation in Akperan Orshi Polytechnic Yandev, Gboko Local Government, Benue State, Nigeria. Data generated will be useful for national planning and reported to the national carbon data base.

MATERIALS AND METHOD

Study area

Akperan Orshi Polytechnic Yandev (AOPY) is located in Gboko Local Government Area of Benue State, Nigeria and lies within longitudes 9º 10' 00''E and 9º 30' 00''E and latitudes 7º 23' 00''N and 7º 21' 00''N (Ujoh and Alhassan, 2014). The climate is characterized by two distinct seasons (rainy season which starts from May to October, and a dry season which lasts from November to April). The annual rainfall is 508-1041 mm, average minimum and maximum temperature of 21 ^{O}C and 35 ^{O}C, respectively, with an annual mean relative humidity of 60.36%. The vegetation is Guinea Savanna with scattered trees and a thick grass cover forming the lower stratum of the vegetation (Tyowua *et al*., 2013).

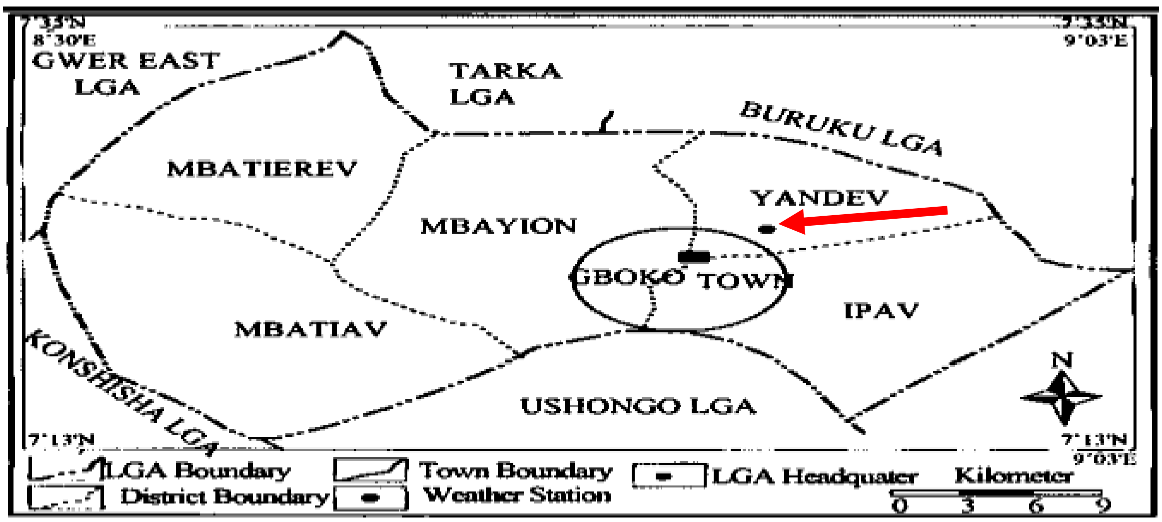

Figure 1: Map of Gboko showing the study area Akperan Orshi Polytechnic Yandev, Gboko Local Government, Benue State, Nigeria. Plantations indicated by red arrow.

Data Collection/ Sampling design

The sampling area consisted of two plantations of different ages *M. indica* (35 years) and *T. grandis* (42 years), respectively. In each of the plantations, a 100 m x 100 m plot was mapped out using a GPS for accurate placement of the plots that were further divided into 3 sub-plots (1, 2 and 3). In each plot, diameter at breast height (DBH, 1.3 m), plant height (m) and Basal Area (BA, m^2) of each species were measured.

Herbaceous standing plants and litter biomass

Herbaceous standing Plants were sampled destructively, using a sickle to harvest in whole parts, all herbs within each quadrat (1 m^2) in all the sampling plots, while the litter (leaves and dead plant debris) under the quadrats were separately collected. 5 quadrats were thrown randomly and all herbs and litter (leaves and dead plant debris) within the 1 m^2 were harvested. The harvested herbs and litter were labelled and identified at herbarium unit of the JOSTUM, and subsequently oven dried at 80 ℃ for 24 hours to obtain dry weight. Herbaceous and litter biomass were determined as 50% of dry weight per quadrat (m^2) (Jana *et al*., 2008; Labata *et al.*, 2012).

Estimation of aboveground biomass, total sequestered carbon and sequestered carbon dioxide equivalent

The aboveground biomass (AGB), Below ground biomass (BGB), Total carbon stocks (TSC) and sequestered carbon dioxide equivalent (SCO_2E) were calculated using the following formulae:

i. Diameter at Breast Height (m) = Girth at Breast Height/π
ii. Basal area (m^2) = $\pi/4 \times DBH^2$
iii. Volume (m^3) = Basal area × Height
iv. Above Ground Biomass (kg) = volume × Density (0.6)
v. Below ground biomass (kg) = 20% of AGB (Hangarge *et. al*., 2012)
vi. Total Sequestered Carbon (kg) = AGB × 0.50 (Pearson *et. al.,* 2005).
vii. Sequestered CO_2 Equivalent (kg) = 3.67 × TSC (Stoffberg *et. al*., 2010)

Shannon Diversity Index:

The Shannon index (DeClerck, 2006) was used to determine the diversity of herbs within the study area.

Statistical analysis

Data were analysed using descriptive statistics by Statistical Packaging for Social Sciences (SPSS) version 25. Linear regression was used to determine the relationship between AGB and DBH, AGB and plant height, and DBH and plant height respectively. Significantly different means were subjected to Tukey-HSD post hoc.

RESULTS

Distribution of DBH and height classes of *M. indica* and *T. grandis* plantations

In *M. indica* plantation, DBH class range 0.41-0.6 (m) gave the highest frequency (50), followed by DBH class range 0.21-0.4 (38) and 0.61-0.8 (8), with the least DBH class range being 0-0.2 (5). For height, class range 8.1-10 (m) gave the highest frequency (41), followed by 6.1-8 m (33), while the class range 2-4 (m) was the lowest as shown in Table 1. In *T. grandis* plantation, the DBH class range 0-0.2 (m) gave the highest frequency (136), followed by DBH class range 0.21-0.4 (56). Similarly, height class 6.1-8 (m) gave the highest frequency (113) and class 2-4.0 (0) the least frequency (Table 1).

Diversity of Herbaceous Standing Plants

In *Mangifera indica* plantation, plot 1 was the most diverse (18 species), with a frequency of 102 plants and a Shannon diversity index of 2.65 (Table 2), while in *Tectona grandis* plantation, plot 2 was the most diverse (19 species), with a frequency of 65 and a Shannon diversity index of 2.54 respectively (Table 3).

Carbon Sequestration

Sequestered Carbon in *M. indica* and *T. grandis* Plantations

The result obtained from *M. indica* plantation showed that plot 1 gave the highest AGB (37.84 kg), TSC (18.92) and SCO_2E (69.44 kg) compared to plots 2 and 3 (Figure 2A). In *Tectona grandis*, plot 2 gave the highest AGB (9.80 kg), TSC (1.96 kg) and SCO_2E (17.99 kg) compared to plots 1 and 3 (Figure 2B).

Sequestered Carbon Stocks in Herbaceous and Litter Biomass

In *M. indica* plantation, plot 2 gave the highest herbaceous standing biomass (0.105 kg), TSC (0.053 kg) and SCO_2E (0.193 kg) compared to other plots (Figure 2C). In *T. grandis* plantation the herbaceous standing biomass (0.072 kg), TSC (0.036 kg) and SCO_2E (0.133 kg) respectively were also highest in plot 2 compared to plots 1 and 3 respectively (Figure 2E). In *M. indica* plantation, plot 1 gave the highest oven dried litter biomass (0.073 kg), TSC (0.037 kg) and SCO_2E (0.135 kg) compared to other plots (Figure 2D). In *T. grandis* plantation, plot 3 gave the highest oven dried litter biomass (0.124 kg), TSC (0.062 kg) and SCO_2E (0.227 kg) compared to plot 2 and 3 respectively (Figure 2F).

Regression Analysis of *Mangifera indica* and *Tectona grandis* Plantations

In *M. indica* plantation, there was a strong significant linear regression between AGB and DBH ($p < 0.000$, $R^2 = 0.89$; Figure 3A), and weak significant linear relationships between AGB and plant height ($p < 0.000$, $R^2 = 0.35$; Figure 3B), and between DBH and plant height ($p < 0.000$, $R^2 = 0.19$; Figure 3C). Similarly, in *T. grandis* plantation, there were weak significant linear regressions between AGB and DBH (p 0.000, $R^2 = 0.36$; Figure 3D), AGB and plant height ($p < 0.000$, $R^2 = 0.19$; Figure 3E), and DBH and plant height ($p < 0.000$, $R^2 = 0.19$; $p < 0.000$, $R^2 = 0.13$; Figure 3F).

Table 1: DBH and Height Classes of *M. indica* and *T. grandis* plantations

Plantation	DBH (m)	Frequency	Height (m)	Frequency
Mangifera indica	0-0.20	5	2-4	1
	0.21-0.40	38	4.1-6.0	7
	0.41-0.60	50	6.1-8.0	33
	0.61-0.80	8	8.1-10.0	41
			10.1-12	19
Tectona grandis	0-0.20	136	2-4.0	0
	0.21-0.40	56	4.1-6.0	41
	0.41-0.60	0	6.1-8.0	113
	0.61-0.80	0	8.1-10.0	34
			10.1-12	4

Table 2: Diversity and distribution of herbs in *Mangifera indica* plantation at Akperan Orshi Polytechnic Yandev, Gboko Local Government, Benue State, Nigeria

S/N	Plot 1			Plot 2			Plot 3		
	Species	Count	Shannon Index	Species	Count	Shannon Index	Species	Count	Shannon Index
1	*Ageratum conyzoides*	15	-0.282	*Ageratum conyzoides*	8	-0.240	*Aspilia bussei*	3	-0.143
2	*Commelina bengalensis*	6	-0.167	*Boerhavia erecta*	2	-0.098	*Celosia leptostachya*	3	-0.143
3	*Commelina erecta*	2	-0.077	*Calopogonium mucunoides*	3	-0.130	*Digitaria gayana*	6	-0.222
4	*Cyperus esculentus*	4	-0.127	*Eclipta alba*	3	-0.130	*Digitaria longiflora*	4	-0.173
5	*Digitaria longiflora*	5	-0.148	*Eleusine indica*	1	-0.058	*Eclipta alba*	6	-0.222
6	*Kyllinga squamulata*	6	-0.167	*Gomphrena celosioides*	1	-0.058	*Indigofera hirsuta*	1	-0.065
7	*Laggera auriia*	4	-0.127	*Mitracarpus villosus*	7	-0.223	*Mitracarpus villosus*	16	-0.347
8	*Ludwigia decurrens*	1	-0.045	*Oldenladia corymbosa*	2	-0.098	*Oldenladia corymbosa*	3	-0.143
9	*Ludwigia hyssopifolia*	2	-0.077	*Paspalum scrobiculatum*	2	-0.098	*Paspalum scrobiculatum*	2	-0.108
10	*Mariscus alternifolius*	4	-0.127	*Pennisetum pedicellatum*	21	-0.357	*Pycreus lanceolatus*	7	-0.242
11	*Mitracarpus villosus*	13	-0.263	*Phyllanthus amarus*	4	-0.158	*Setaria barbata*	4	-0.173
12	*Oldenlandia corymbosa*	7	-0.184	*Pycreus lanceolatus*	4	-0.158	*Tephrosia bracteolata*	3	-0.143
13	*Panicum maximum*	2	-0.077	*Rhynchelytrum repens*	2	-0.098	*Tridax procumbens*	3	-0.143
14	*Pennisetum pedicellatum*	14	-0.273	*Sida rhombifolia*	2	-0.098	*Vernonia cinerea*	2	-0.108
15	*Rottboellia cochinchinensis*	6	-0.167	*Tephrosia bracteolata*	3	-0.130	*Vernonia perrottetii*	1	-0.065
16	*Spermacoce ocymoides*	3	-0.104	*Vernonia ambigua*	4	-0.158			
17	*Spigelia anthelmia*	2	-0.077	*Vernonia perrottetii*	5	-0.182			
18	*Vernonia cinerea*	6	-0.167						
	SUM	102	2.65		74	2.47		64	2.44

Table 3: Diversity and distribution of herbs in *Tectona grandis* plantation at Akperan Orshi Polytechnic Yandev, Gboko Local Government, Benue State, Nigeria

	Plot 1			Plot 2			Plot 3		
S/N	**Species**	**Count**	**Shannon Index**	**Species**	**Count**	**Shannon Index**	**Species**	**Count**	**Shannon Index**
1	*Andropogon tectorum*	5	-0.213	*Andropogon tectorum*	6	-0.220	*Andropogon tectorum*	6	-0.235
2	*Anonna senegalensis*	1	-0.071	*Anonna senegalensis*	2	-0.107	*Biophytum petersianum*	7	-0.255
3	*Brysocarpus coccineus*	2	-0.118	*Anthocleista djalonensis*	2	-0.107	*Canthium venosum*	1	-0.070
4	*Cyperus esculentus*	2	-0.118	*Biophytum petersianum*	4	-0.172	*Chromolaena odorata*	4	-0.184
5	*Eclipta alba*	4	-0.186	*Brysocarpus coccineus*	3	-0.142	*Commelina erecta*	2	-0.116
6	*Mariscus alternifolius*	13	-0.337	*Chromolaena odorata*	2	-0.107	*Eclipta alba*	8	-0.273
7	*Pennisetum pedicellatum*	5	-0.213	*Desmodium tortuosum*	2	-0.107	*Hyparrhenia rufa*	2	-0.116
8	*Rhynchelytrum repens*	2	-0.118	*Hyparrhenia rufa*	1	-0.064	*Maranthes polyandra*	1	-0.070
9	*Sporobolus pyramidalis*	2	-0.118	*Paspalum scrobiculatum*	2	-0.107	*Sporobolus pyramidalis*	1	-0.070
10	*Tacca leonotopetaloides*	1	-0.071	*Perotis indica*	6	-0.220	*Tephrosia linearis*	3	-0.153
11	*Tectona grandis*	16	-0.357	*Polygonium lanigerum*	1	-0.064	*Vernonia ambigua*	4	-0.184
12	*Waltheria indica*	4	-0.186	*Sida linifolia*	1	-0.064	*Tectona grandis*	19	-0.366
13				*Spermacoce ocymoides*	1	-0.064			
14				*Sporobolus pyramidalis*	2	-0.107			
15				*Tacca leonotopetaloides*	2	-0.107			
16				*Tectona grandis*	19	-0.360			
17				*Tephrosia linearis*	4	-0.172			
18				*Vernonia ambigua*	3	-0.142			
19				*Vernonia cinerea*	2	-0.107			
	SUM	57	2.11		65	2.54		58	2.09

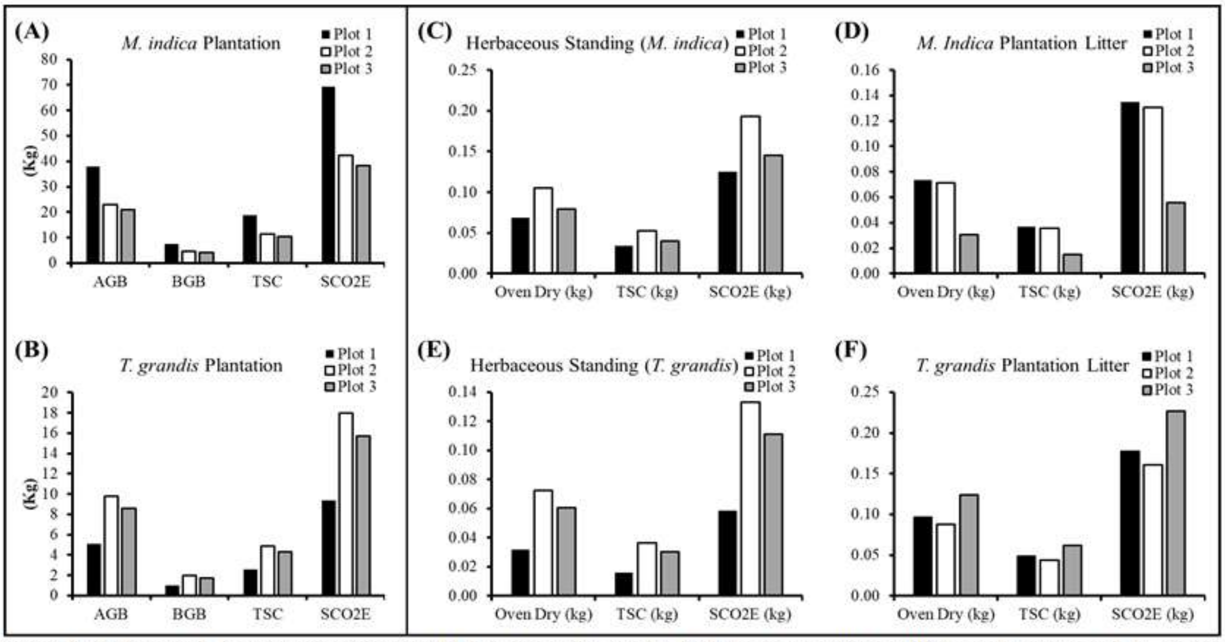

Figure 2: Biomass and carbon sequestration of *M. indica* and *T. grandis*, herbaceous standing and litter of *M. indica* and *T. grandis* plantations in Akperan Orshi Polytechnic Yandev, Gboko, Benue State, Nigeria. (A) Carbon sequestration of *Mangifera indica* plantation (B) Carbon sequestration of *Tectona grandis* plantation (C) Carbon sequestration of Herbaceous standing plants of *M. indica* plantation (D) Carbon sequestration of Litter of *M. indica* plantation (E) Carbon sequestration of Herbaceous standing plants of *T. grandis* plantation (F) Carbon sequestration of Litter of *T. grandis* plantation. AGB: Above ground biomass; BGB: Below ground biomass; TSC: Total Sequestered Carbon; SCO_2E: Sequestered carbon dioxide equivalent. All herbaceous standing and litter values are in kg/m

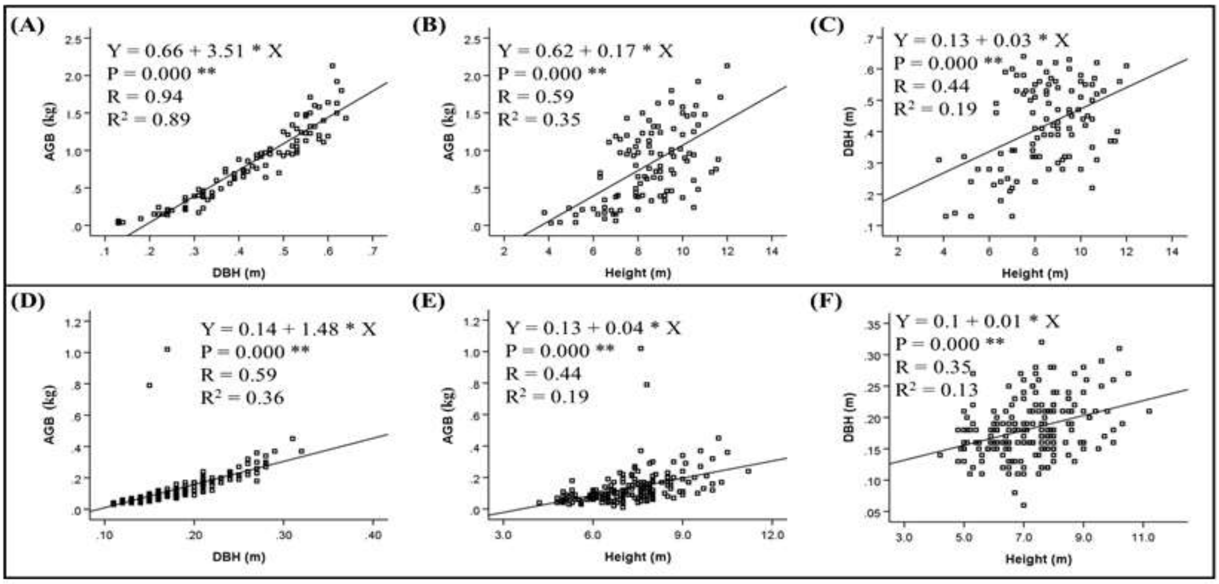

Figure 3: Regression between AGB and DBH, AGB and plant height, and DBH and plant height of *Mangifera indica* and *Tectona grandis* plantations in Akperan Orshi Polytechnic Yandev, Gboko, Benue State, Nigeria. (A) ABG and DBH (*Mangifera indica*); (B) ABG and plant height (*Mangifera indica*); (C) DBH and plant height (*Mangifera indica*); (D) ABG and DBH (*Tectona grandis*); (E) ABG and plant height (*Tectona grandis*); (F) DBH and plant height (*Tectona grandis*). $P < 0.000$ ** (level of significance $P < 0.001$; Tukey-HSD post hoc).

DISCUSSION

From the results, DBH and plant height ranges are generally low, hence the small amount of biomass and carbon stored in both plantations because both DBH and plant height are integral variables in determining biomass. The positive relationships between AGB, DBH and plant height also implied that AGB increases with both DBH and plant height. As the tree diameter and plant height increase with age, there is an increase in above-ground biomass respectively, hence the suitability of the allometric model as it integrates individual plant attributes. (Zapfack *et al.*, 2013; Okoh *et al*., 2019; Stoffberg *et. al*., 2010). The differences in TSC and SCO_2E between plantations in this study is probably due to differences in wood types, rate of carbon assimilation and individual growth factors, as suggested by other researchers (Ganeshamurthy *et. al.*, 2019; Magadlela *et. al.*, 2016). The AGB estimated in this study is comparable to the findings by Guiabao (2016) in four Mango plantations and those of Buvaneswaran *et al*. (2006) in *T. grandis*. Herbaceous standing biomass and litter biomass (on the floor) further protected the floor from soil erosion hazards and increased the overall productivity of the land (Novara *et. al*., 2019). From the result, both diversity and density of herbs varied in the plantations. This is probably due to differences in disturbance levels, canopy covers and the home field advantages offered by the individual species in the plantations.

CONCLUSION

Sequestered Carbon was higher in *M. indica* than in *T. grandis* plantation. The carbon sequestered in these species revealed their importance as carbon sinks and their relevance in climate change mitigation strategies. Although the carbon sequestered by the herbaceous standing plants and litter were correspondingly smaller compared to the *M. indica* and *T. grandis* trees, the rapid rates of growth and sequestration of these herbaceous plants represent additional carbon sinks within those plantations. The finding provides reference materials in understanding and predicting the accumulation and distribution of carbon stock in the study area.

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