International Journal of Sciences

Research Article Volume 10 – March 2021 (03)

Effect of Spacing Regimes on Growth and Carbon Storage of *Tectona grandis*, *Gmelina arborea* and *Terminalia ivorensis* in a Nine Year old Forest Plantation in the Transition Rainforest of Sierra Leone

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Abstract: The study was conducted to investigate the effect of spacing on growth and carbon storage of *Tectona grandis, Terminalia ivorensis* and *Gmelina arborea* in a nine year old Plantation Forest experimental plots at Njala University, Sierra Leone. The aim was to assess the effect of four different spacings (1.8m x 1.8m, 2.0m x 2.0m, 3.0m x 3.0m and 4.0m x4.0m) on tree growth and carbon storage in tree biomass of the three species. The species were planted in square plots consisting of four different spacings with a split plot design in three replications. Measurements of DBH, height, volume, biomass and carbon percentage of biomass were taken and the data was subjected to analysis of variance (ANOVA). The results showed that spacing had significant effect on DBH, height, biomass, carbon percentage and volume. The 4.0m x 4.0m spacing had the highest DBH, biomass, carbon percentage of biomass and volume whilst the highest height was recorded at 2.0m x 2.0m. *Gmelina* arborea dominated among the three species selected followed by *Tectona*. *Terminalia* was poor in most parameters except for height and volume. Strong positive relationships were observed between tree DBH and biomass (r^2 = 0.79) DBH and carbon percentage of biomass (r^2 = 0.89) and DBH and volume (r^2 = 0.95). The results indicate that 4m x 4m spacing and *Gmelina arborea* can be recommended for afforestation and reforestation programmes aimed at wood and timber production for fast growth and higher carbon sequestration.

Keywords: Spacing, Growth, Diameter at Basal Height, Carbon Percentage, Biomass

1.0 Introduction

Large scale plantations of some indigenous and exotic tree species are being established in Sierra Leone in order to meet the increasing demands for wood and timber. Spacing trials were established to determine the optimum spacing at which the various species should be planted for optimum growth. Spacing is the cutting of undesirable trees within a young stand to reduce competition among the residual trees for water, nutrients and sunlight. It is the distance between individual trees in a forest stand. One of the vital decisions a forester has to make is the financially best spacing of species to be planted (Omiyale, 1980). Appropriate planting spacing has beneficial effect on stand development, tree form, and the economics of a plantation. The need to study the growth variations exhibited by three plantation species namely: *Tectona grandis, Gmelina arborea, Terminalia ivorensis* planted at different spacings, had been the idea for establishing a spacing trial at Njala University forest plantation in June 2009. Planting escapement has a considerable effect on stand development, tree form and growth rate and can influence the value and marketability of timber produced. (Lowe, 1971). It is necessary to determine which planting spacing promote early canopy closure to control weed growth, reduce coarse branching and optimize wood production. E-spacing can be decided by management objective; for fire wood less spacing is necessary because less consideration is needed in terms of girth increment unlike timber production which need large girth for more planks. Also the bole of trees is determined by appropriate spacing and pruning. Spacing has significant effects on parameters of trees in terms of increase in tree size as measured by units of height, diameter at breast height, basal area, volume, crown width and their potential to store carbon in various pools with time

Published at: http://www.ijsciences.com/pub/issue/2021-03/
DOI: 10.18483/ijSci.2270; Online ISSN: 2305-3925; Print ISSN: 2410-4477

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(Kayandeh, 2014). *Tectona grandis, Gmelina arborea, Termilania ivorensis* exhibit variations in growth characteristics when planted at different spacing in plantations. The main aim of this research is to assess how the different tree spacings in the spacing trial influence their growth and carbon storage. Spacing has an effect on growth as it is an important parameter in forestry considering its relevance in determining the volume of wood derivable and the time interval required for trees to reach merchantable size. Initial spacing affects the stand growth rate and mean tree size (Harrington *et al*., 2009; Amateis & Burkhart, 2012) and determines the timing and intensity of competition among trees for resources (Harrington *et al*., 2009). Therefore, quantitative evaluations of effects of initial spacing on stand growth rates are needed for a better understanding of the effects of spacing in achieving specific management objectives. Additionally, determination of proper spacing is important for producing not only more wood, but also to increase its quality. A closer spacing induces branch mortality, which consequently leads to production of higher quality stem volume (Kerr, 2003; Rais *et al*., 2014). Large scale plantations of some indigenous and exotic tree species are being established at the Njala University plantation site for research work by students, lecturers, and other researchers. However, there have been limited studies on the effects of spacing on various stand parameters on *Gmelina arborea*, *Tectona grandis* and *Terminalia ivorensis* in Sierra Leone. Spacing trials were established to determine the appropriate spacing at which the various species should be planted for optimum growth.

The appropriate evidence on espacement and its effects on tree growth gives vital information in choosing the right spacing for planting tree species. Espacement is a useful technique for addressing age-class imbalances in timber supply from forest plantations. The spacing trial established at the Njala University forest plantation is therefore essential for the provision of adequate information on growth variations exhibited *by Tectona grandis, Gmelina arborea, and Termilania ivorensis* planted at different spacings.

This work will provide recommendations for implementing the appropriate spacings for the three species in question because these species are widely used for plantation establishment in Sierra Leone and other developing countries. These three species are highly demanding in agro forestry systems, so a spacing study of this nature will be useful to farmers in providing valid recommendations on the most suitable for agroforestry, which will improve crop yield with minimal adverse effect on the overall crop performance.

The main aim of this work is to determine the effect of spacing on *Tectona grandis, Gmelina arborea, and Termilania ivorensis* on growth, tree form and carbon sequestration or storage.

Specific objectives

To examine the effect of spacing on tree growth and wood volume

To determine the effect of spacing on the tree biomass and carbon storage

2.0 Materials and Methods

2.1 Description of study area

This work was conducted at the spacing trial established in the Njala University plantation in July 2009. Njala University is located in Moyamba district, Southern Sierra Leone. Njala is located at an elevation of 54m above sea level on 8^{o}06' N latitude and 12^{o}06' W longitude. The spacing trial is situated at the back of Matturi hostels, close to the fishpond established by the Fisheries project with funds from the West and Central African Council for Agricultural Research and Development (WECARD). It is also adjacent to the Sierra Leone Agricultural Research Institute (SLARI) cassava demonstration plot. The topography of the soil is a rolling type and the soil is of the Njala soil series. Njala experiences a distinct dry and wet season. The monomodal rainy season last from April to November, while the dry season extends from December to March. The mean monthly air temperature ranges from 21^{o}C - 23^{o}C maximum for the greater part of the day and night. Average annual precipitation of the district ranges from 3,330mm to 4000mm with mean maximum temperature of 29^{o} C to 30^{o} C (Jusu, 1990).

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2.2 Establishment of the spacing trial

The spacing trial was established with potted seedlings for each species, raised in the nursery by the production unit of the Forestry Department. The entire experimental area was 1.44 hectares (14,400m2) and was divided into three blocks. Each block was further divided into three experimental plots. The size of each plot is 0.16 hectare and measure approximately 40 meter by 40 meter. The species were planted in square plots consisting of four different espacements. The spacings are 1.8m×1.8m, 2.0m×2.0m, 3.0m×3.0m and 4.0m×4.0m

Table 1: Number of tree stands per hectare for each tree spacing

Spacing	No. of trees planted/ ha	No. trees present
1.8m x 1.8m	3086	2260
2.0m x 2.0m	2500	1050
3.0m x 3.0m	1111	840
4.0m x 4.0m	625	501

3.2 Experimental Design

The split-plot design with three replications was employed in this work. Two experimental factors or treatments where used, which are tree species, i.e. *Tectona grandis, Gmelina arborea, Termilania ivorensis* and spacing i.e. 1.8m × 1.8m, 2.0m × 2.0m, 3.0m × 3.0m, 4.0m × 4.0m. The main factor is the tree species and spacing represents the sub-factor. The species were planted out in square plots consisting of the four different planting espacement per plot.

2.3 Data collection

Data were collected for all trees of each species in the three blocks because 100% stock assessment (inventory) was be considered more effective to evaluate the effect of spacing on tree growth in the spacing trial. The tree position (number), height, diameter at breast (DBH) and crown width were measured. Tree height was measured to the nearest whole number using suunto clinometer and diameter calliper was used for DBH and width measurement. Per hectare values of basal area and standard volume were calculated.

Calculation of tree biomass

Measurements of DBH was converted to tree biomass using the allometric equation by Brown and Schroeder (1999) for all three species under study. The Intergovernmental Panel on Climate Change (IPCC) uses this equation as a tool to estimate above ground biomass of tropical tree species. The model was designed for tropical trees with diameter ranging from 4cm to 114cm.

The equation is $Y=21.297-6.953(DBH) + 0.74(DBH)^2$

Where Y = biomass per tree (kg) and
DBH = Diameter at Breast Height

Calculation of tree carbon (kg)

Tree biomass was converted to biomass carbon using 45% carbon as suggested by IPCC

Calculation of tree volume

Tree volume was calculated using Hober's volume with a form factor of one

$V = ghf$

Where $g = \pi d^2/40{,}000$

H = height and f is correction factor which is 1

2.4 Data Analysis

Data was analyzed using the standard analysis of variance procedure for split plot design, with tree species and spacing as factors. Statistical significant was set at $P < 0.05$. Mean comparison was done using the least significant difference (LSD.) at $P < 0.05$.

3.0 Results and Discussion

3.1 Effect of Spacing on Tree Growth

3.1.1 Effect of Spacing on tree Diameter at Breast Height of *Tectona grandis, Terminalia ivorensis* and *Gmelina arborea*

The results showed significant ($P < 0.05$) difference in diameter at breast height (DBH) due to spacing on *Tectona grandis, Terminalia ivorensis and Gmelina arborea*. The 4.0m x 4.0m spacing had the highest DBH (14.46cm) whilst the 1.8m x1.8m spacing had the least mean DBH (11.32cm).

However, there was no significant difference in mean DBH between the 3.0m x 3.0 m spacing and the 2.0m x 2.0m and 1.8m x 1.8m spacings (Fig. 2). This is in agreement with Zahabu *et al* (2015) who reported that diameter at breast height increased with spacing. The results of analysis of variance at P = 0.01 also showed that there was significant difference in mean DBH among the tree species. *G. arborea* had the highest mean DBH of 14.35cm followed by *T. grandis* which had 12.23cm whilst *T. ivorensis* had the least mean DBH of 11.4cm (Fig. 1). Significant ($P < 0.05$) difference was observed between the 4.0m x 4.0m and the 2.0m x 2.0 but there was no significant difference in mean DBH between the 3.0m x 3.0m and the 2.0m x 2.0m spacing No interaction ($P > 0.05$) effect between spacing and tree species in mean DBH.

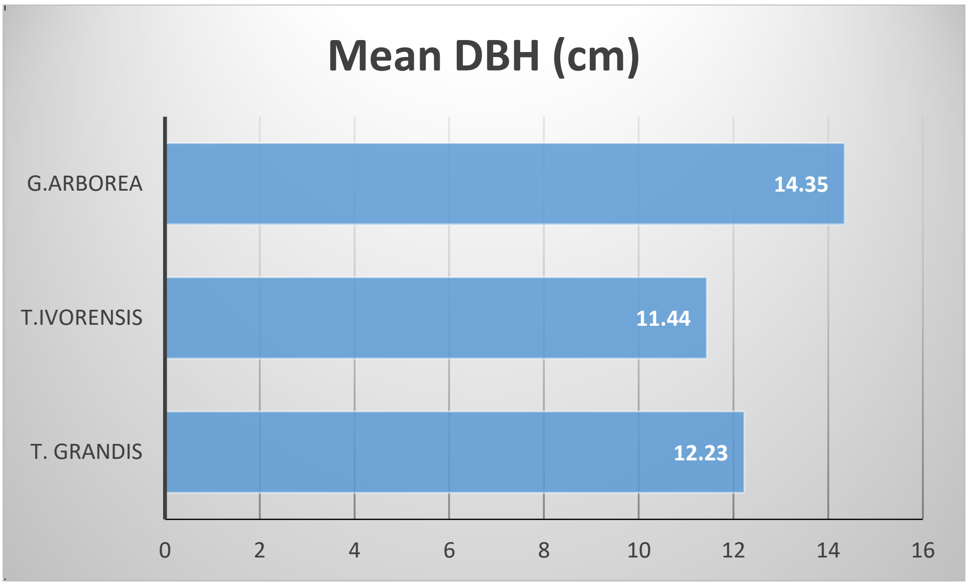

Figure 1: Mean DBH of the three tree species

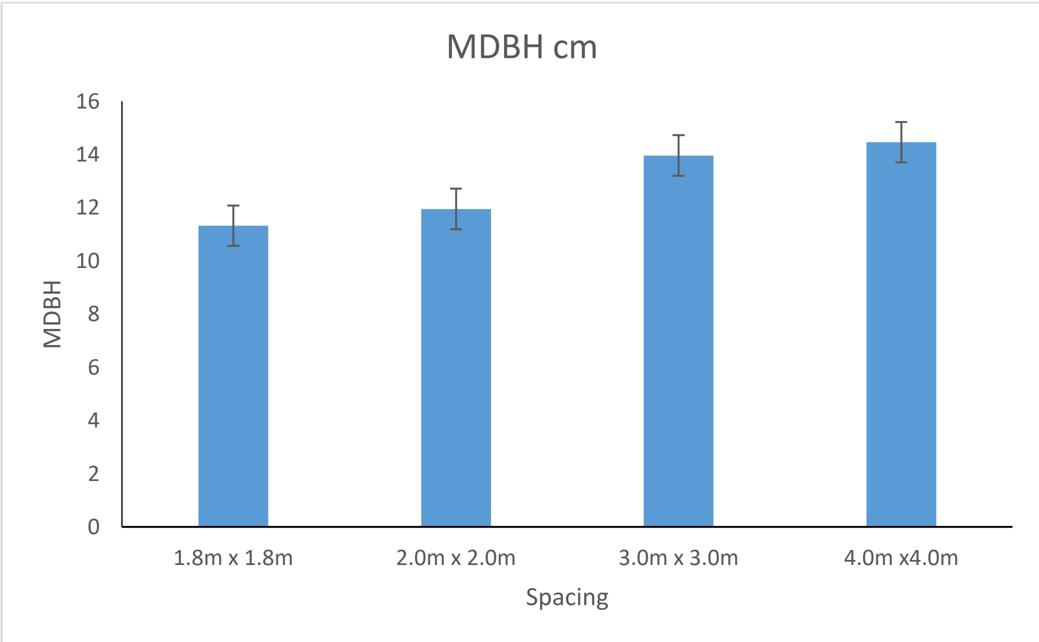

Figure 2: Effect of spacing on DBH

3.1.2 Effect of Spacing on tree Total Height of *Tectona grandis, Terminalia ivorensis* and *Gmelina arborea.*

The results showed significant ($P < 0.05$) difference among the tree species due to the spacing treatment. *G. arborea* had the highest height (13.35m) followed by *T. ivorensis* with 10.69m and *T. grandis* had the least height which is 10.13m. (Fig.3).This could be due to differences in their inherent genetic make- up. Previous studies have shown that at wider spacing the average height decreases. (Harms *et al*, 2000). Close spacing has a negative effect on tree height due to fight for sunlight in order to carry out photosynthesis as the terminal buds try to grow tall. The highest mean height (11.64m) was recorded at 2.0m x 2.0m, followed by 3.0m x 3.0m which had 11.61m, 4.0m x 4.0m had 11.53m and the lowest (10.77m) was obtained in the 1.8m x 1.8m spacing (Fig.4). Higher height values at early ages in closer spacing compared to wider spacing may be due to better micro ecological conditions in closer spacing.

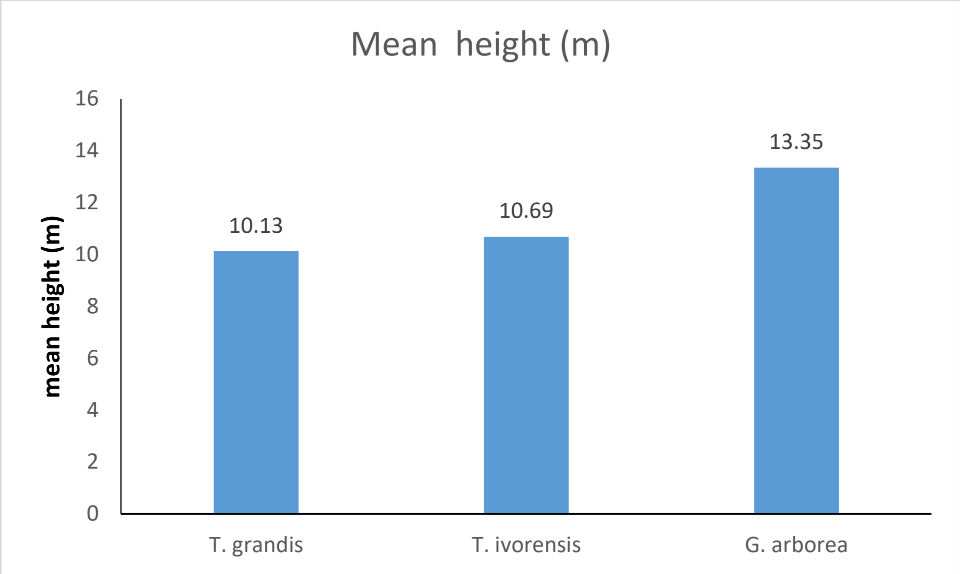

Figure 3: Mean height of the three tree species

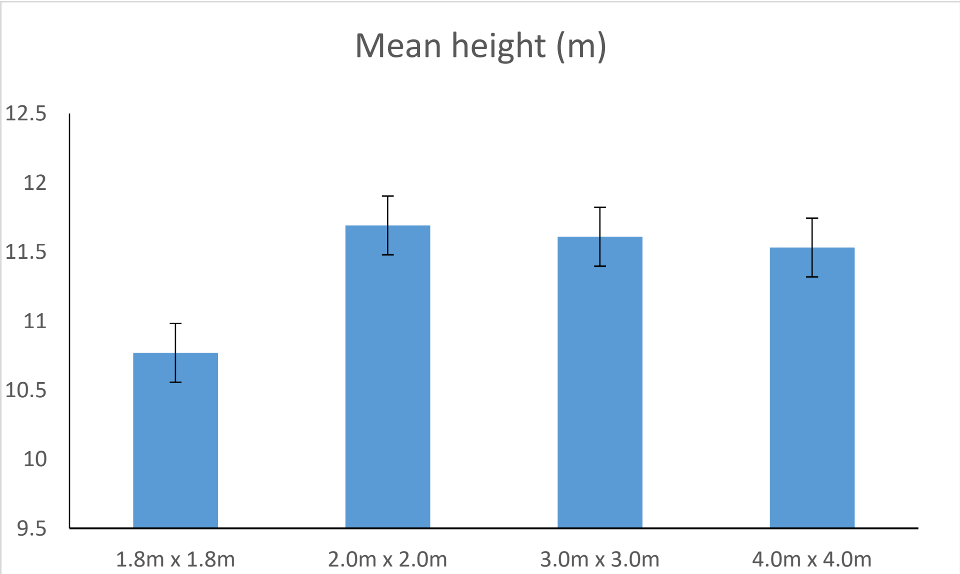

Figure 4: Effect of spacing on mean height

3.2 Effect of Spacing on Tree Biomass and Carbon percent of biomass of *Tectona grandis, Terminalia ivorensis* and *Gmelina arborea.*

The results revealed that spacing had a significant ($P < 0.05$) effect on the mean biomass of the tree species. Significant difference ($P < 0.5$) was also observed among the tree species in carbon percentage of biomass. *Gmelina* had the highest (31.2%), followed by *Tectona* (19.9%) and *Terminalia* had the least with 19.5%. (Fig.5). *Gmelina* and *Tectona* grow large due to their broad leaf structure while *Terminalia* has small leaves. Similar results were obtained by Yeboah (2011) who found out that carbon concentration, wood density and carbon content differed significantly among species. Verma *et al* (2017) also reported the multifaceted volume of Gmelina in agroforestry including carbon sequestration potential and its desirability in home gardens and agroforestry systems.

Significant difference ($P < 0.05$) was observed between 4.0m x 4.0m and the 3.0m x 3.0m spacing while the 2.0m x 2.0m had no significant difference with the 1.8m x 1.8m. From the results of the study the 4.0m x 4.0m spacing had the highest mean biomass of 80.8kg followed by the 3.0m x 3.0m (58.7kg) whilst the 1.8m x 1.8m spacing had the least biomass of 39.3kg. (Fig.6).This could be due higher canopy size resulting to increase light interception by the leaves and light energy conversion to biomass (Beadle, 1997). A highly significant interaction ($P < 0.001$) was observed between tree species and spacing. This means that the tree species responded differently to the different spacing treatment. There was also significant difference (P < 0.5) among the three tree species in terms of biomass. *Gmelina* had the highest mean biomass of 70.8kg followed by *Tectona* with a mean biomass of 49.8kg and *Terminalia* had the least mean biomass of 39.6kg (Fig. 5). The probable reason is that *Gmelina* and *Tectona* have broad leaves and are exotics while indigenous Terminalia has small leaves and the broader the leaves of trees, the higher the rate at which they capture sunlight and this resulted in increased growth. The result also indicated that spacing had a significant (P < 0.05) effect on carbon percentage of biomass. There was a significant difference (P < 0.05) between the 4.0m x 4.0m and the 3.0m x 3.0m but no significant difference (P < 0.05) was observed between the 2.0m x 2.0m and the 1.8m x 1.8m. The result shows that the 4.0m x 4.0m spacing had the highest mean percentage of carbon which is 34.1% followed by the 3m x 3.0m spacing whilst the 1.8m x 1.8m spacing had the least with 18.2%. (Fig.6) .This could be due to the intensity of competition among trees for resource in closer spacing which is a major factor reducing the growth and carbon fixation These.results are in agreement with Erkan and Aydin. (2016) who also reported that at wider spacing wood properties and density increase which increase biomass of a tree. Similar trend was also observed in carbon percentage of biomass of the tree species in the current study.

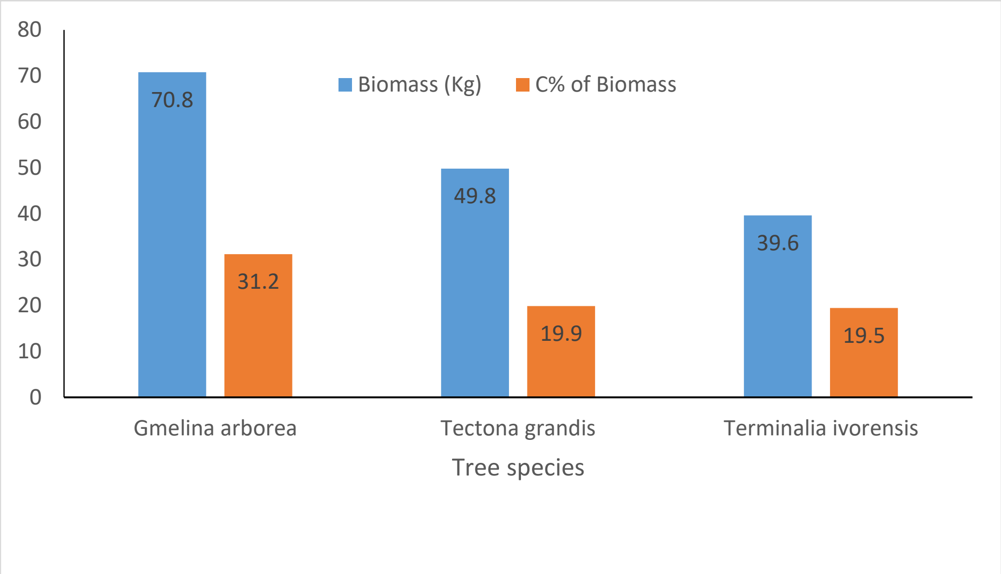

Figure 5: Effect of tree species on biomass and Carbon % of biomass

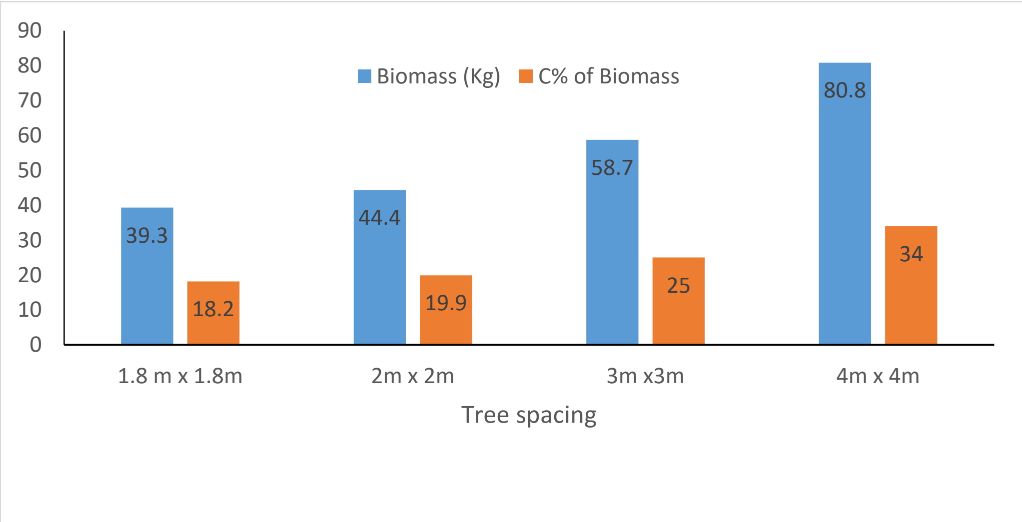

Figure 6: Effect of spacing on biomass and C% of biomass

3.3 Effect of Spacing on Tree Volume of *Tectona grandis, Terminalia ivorensis* and *Gmelina arborea.*

The results showed that spacing had a significant (P < 0.05) effect on volume. Similar trend was also observed in volume of the different spacings. The highest mean volume was recorded in 4.0m x 4.0m spacing with a mean volume of 0.208m³ followed by 3.0m x 3.0m spacing with a mean volume and the least is 1.8m x 1.8m with a mean volume of 0.123m³ (Table 2). Spacing had a negative effect on tree volume, narrow spacing produces high volume. This is true because stand density in the closer spacings is higher compared to wider spacings. (Kayandeh, 2014). The results also showed significant difference (P < 0.5) among the tree species. *Gmelina* had the highest volume (0.225m³) followed by *Terminalia ivorensis* (0.124m³) and *Tectona* had the least volume (0.123m³).

Table 2: Effect of Spacing on Tree volume (m³) of the three species

	Spacing (m)				
Tree Species	1.8 x 1.8	2.0 x 2.0	3.0 x 3.0	4.0 x4.0	Mean
T. grandis	0.091	0.107	0.111	0.183	0.123
T. ivorensis	0.139	0.118	0.111	0.127	0.124
G. arborea	0.139	0.172	0.276	0.313	0.225
Mean	0.123	0.132	0.166	0.208	
L.S.D (0.05)species = 0.025					
LSD (0.05) spacing = 0.028					
LSD (0.05) spacing x tree sp = 0.102					
CV (%) = 38.2					

Correlation among various parameters using Pearson's Correlation Coefficient Analysis.

From the correlation analysis using Pearson correlation coefficient, there is a weak correlation between mean DBH and height (r = 0.64044) whilst there is a strong correlation between mean DBH and tree biomass (r = 0.79), carbon percentage of biomass (r = 0.89) and volume (r = 0.95). This is probably because, increase in DBH increases; biomass, carbon percentage and volume. The mean biomass c had weak correlation at (r = 0.47) with the height and strong correlation at (r = 0.79) with men DBH, at (r = 0.88) with mean carbon percentage of biomass and at (r = 0.81). This is probably because high biomass resulted in high percentage carbon. Mean volume had strong correlation with the mean of all the other parameters because increase in DBH, height, biomass and carbon percentage increase volume.

Table 3: Pearson's Correlation Coefficient Analysis of some parameters

	Mean DBH(cm)	Mean height(m)	Mean biomass(kg)	Mean C% of biomass	Mean volume(cm³)
M DBH(cm)	1.00000	0.64044 P < 0.0001	0.79037 P < 0.0001	0.89942 P < 0.0001	0.95760 P < 0.0001
M H(m)	0.64044 P < 0.0001	1.00000	0.46825 P < 0.0040	0.57046 P<0.0003	0.76734 P< 0.0001
M biomass	0.79037 P < 0.0001	0.46825 P < 0.0040	1.00000	0.88335 P < 0.0001	0.80592 P < 0.0001
M c%	0.89942 P < 0 .0001	0.57046 P < 0.0003	0.88335 P< 0.0001	1.00000	0.92978 P < 0.0001
M volume	0.95760 P< 0.0001	0.76734 P < 0.0001	0.80592 P< 0.0001	0.92978 P<0.0001	1.00000

4.0 Conclusion and recommendations

The results of this study revealed significant differences among tree species in wood density, carbon concentration and carbon content at a given age .after nine years of planting of the three species (*Gmelina arborea*, *Tectona grandis* and *Terminalia ivorensis*) in the four different spacings (1.8m x 1.8m, 2.0m x 2.0m, 3.0m x 3.0m and 4.0m x 4.0m) and that the 4.0m x 4.0m spacing gave the best performance in terms of DBH measurement, biomass, carbon percentage of biomass and volume. The best height was recorded at 2.0m x 2.0m the 3.0m x 3.0m is the second best for all parameters calculated. The 1.8m x 1.8m performs poor for all the parameters calculated. In terms of species Gmelina gave the best result for all the parameters calculated followed by *Tectona* and the indigenous Terminalia performs poorly. From the result the following recommendations were made:

Planting spacing regimes play an important role in tree growth since they influence the quantity and quality of wood produced. The 4.0m x 4.0m spacing is suitable for increase in DBH, tree biomass, carbon percentage and volume and *Gmelina arborea* is highly recommended for industrial plantations and wood production due to its high growth in tree parameters. Closer spacing maximize industrial wood production especially for short rotations.

Conflict of Interests

The authors have not declared any conflict of interests

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