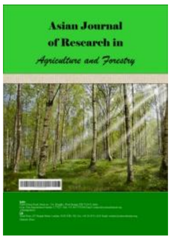

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Above-ground Carbon Stocks of *Tectona grandis* and *Gmelina arborea* Plantations in Njala University, Southern Sierra Leone

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The unprecedented increase in atmospheric CO_2 concentration has attracted global research attention on the potential role of tree plantations in climate change mitigation. There is an urgent need to estimate the above-ground biomass (AGB) and carbon stock in forest plantations. This is particularly essential for Sierra Leone, where above-ground biomass (AGB) and carbon stock data are presently lacking. This study estimated the above-ground biomass accumulation and carbon stock of *Tectona grandis* Linn.f. and *Gmelina arborea* Roxb. in the spacing and plantation trials at Njala University, Southern Sierra Leone. The assessment was based on a total inventory of trees having a diameter at breast height (DBH) ≥ 5 cm and tree height. Above-ground biomass (AGB) was estimated using the allometric equation by Chave *et al.* (2005), and above-ground carbon (AGC) stock was calculated by multiplying the biomass with a conversion factor of 0.5. The result showed that the mean above-ground carbon stock for *Gmelina arborea* was higher in the plantation trial (25.2 t ha^{-1}) than in the spacing trial (7.5 t ha^{-1}). For *Tectona grandis*, the mean above-ground carbon stock was similarly higher in the plantation trial (6.6 t ha^{-1}) than in the spacing trial (1.5 t ha^{-1}). The results further suggest that the variation in the means of above-ground carbon stock is not dependent on the tree species type and experimental site because there were no significant differences (P>0.05) between the tree species and experimental sites.

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Keywords: Above-ground biomass; above-ground carbon stocks; carbon sequestration potential; plantation forests; Sierra Leone.

1. INTRODUCTION

Deforestation and forest degradation, especially in the tropics, have contributed to 90% of the greenhouse gas emissions from Land Use, Land Use Change, and Forestry (LULUCF) [1]. As the problem of greenhouse gas emissions continues, part of the mitigation efforts relies on reforestation, particularly in tropical developing countries. Planted forests could potentially contribute to reducing the global concentration of greenhouse gases through carbon absorption in biomass [2]. According to the FAO [3], approximately 1.5 Gigatons of carbon are absorbed each year from the atmosphere by planted forests distributed over 264 million hectares. This has increased global attention on the importance of planted forests in climate change mitigation and the need for accurate methods for estimating the above-ground biomass and carbon stocks of these forests. This concern was similarly shared by several authors who expressed interest in quantifying the biomass of forest ecosystems and its potential carbon fixation [4,5,6]. Since most of the biomass in a forest is stored in trees [7], the focus of methods for estimating carbon relies on measuring the above-ground biomass of trees. Biomass is typically defined as the over-dried weight (kilograms or tonnes per hectare) of organic matter that can be found in an ecosystem at any given time [8], including both live and dead vegetal material. However, conventional methods for estimating above-ground carbon are very destructive because they require harvesting tree parts and weighing them, which often contravenes existing policies in some areas. Therefore, in our study, we circumvent this challenge by utilizing allometric equations to estimate the above-ground biomass of tree plantations. Our study aims to address the following objectives: (i) to estimate the carbon stock in the above-ground biomass of *Gmelina arborea* Roxb. and *Tectona grandis* Linn.f. plantations and (ii) to determine the influence of species type and experimental sites on above-ground carbon stock in the Njala university plantation forest. Our results are useful in providing insights into the carbon sequestration potential of *Gmelina arborea* and *Tectona grandis* which are widely used tree species for plantation establishment in the region and some parts of the country.

2. MATERIALS AND METHODS

2.1 Study Area

The research was conducted in the Njala University forest plantation. The forest plantation is situated within the Njala University campus, Moyamba District, Southern Sierra Leone (Fig. 1 and Fig. 2). The campus is about 204.4 kilometers away from the capital city of Freetown and 61.2 kilometers away from Bo city. Njala University lies between 8^0 07 ' North latitude and 12^0 05 ' West longitude. The climate of Njala University is humid tropical with distinct wet and dry seasons. The dry season lasts from November to April, and the rainy season extends from May to October. Generally, the mean monthly temperature and humidity are 29°C and 94%, respectively. The mean annual rainfall is 2500 mm and is well distributed for over eight months of the year. The topography of the Njala campus is flat to undulating, with an elevation of 54m above sea level. The soil in the study area belongs to the order Oxisols [9], which is the most widespread soil in the Njala area. The soils have been reported to have slight to severe erosion problems, poor nutrient supply, very poor water-holding capacity, and unfavourable gravel throughout the profile [10].

2.2 Description of Experimental Sites

The Njala University forest plantation consists of the spacing trial and plantation trial, which were planted in 2009 and 2010, respectively.

The spacing trial has a total size of approximately 1.5 ha. It is planted with *Tectona grandis,Gmelina arborea,* and *Terminalia ivorensis* in three distinct blocks consisting of four spacing regimes; 1.8m x 1.8m, 2m x 2m, 3m x 3m, and 4m x 4m. The entire spacing trial blocks were divided into three plots, with each constituting each of the species mentioned above. The size of the plot was 0.5 ha for each species. However, only the *Tectona grandis* and *Gmelina arborea* plots were considered in the data collection for this study.

On the other hand, the area of *Tectona grandis* in the plantation trial was 0.4 ha, and *Gmelina arborea* occupied 0.6 ha. Each species was planted in a rectangular plot design at a spacing of 3m x 3m.

Fig. 1. Map of study area
Source: Primary map from Google Earth, 2022

Fig. 2. Map of the Njala University plantation forest
Source: Primary map from Google Earth, 2022

Fig. 3. ***Tectona grandis* plots**

Fig. 4. ***Gmelina arborea* plots**

2.3 Data Collection

Data was collected for total tree height and DBH for all trees having DBH ≥ 5 cm in the spacing and plantation trials in 2015. A total of 1823 trees were measured for the estimation of the above-ground carbon stock. DBH was measured with a steel diameter tape, and a Haga altimeter was used for measuring tree heights. A graduated pole was also adopted for short trees when using the Haga altimeter proved difficult. Information on the geographic coordinates and the area of the experimental sites were obtained using a GPS for appropriate documentation.

2.4 Estimation of Above-ground Biomass (AGB)

Due to the lack of specific allometric equations for *Tectona grandis* and *Gmelina arborea* in Sierra Leone, the allometric equation developed by Chave *et al.* [4] was adopted to convert tree measurements to above-ground biomass. The equation was considered suitable because it was developed for trees in tropical regions and also due to the inclusion of tree height and wood density parameters into the equation. It is believed that including tree height and wood density in biomass equations helps to improve the equation and the biomass estimates [11]. The wood density for *Tectona grandis* and *Gmelina arborea* were obtained from the global wood density database compiled by Zanne *et al*. [12]. This was done to avoid the destructive method of felling the trees and weighing their parts.

$$AGB = exp(-2.977 + \ln(\rho \, DBH^2 \, H))$$
$$AGB = 0.0509 \times \rho \, DBH^2 \, H \qquad (1)$$

where:

AGB = aboveground biomass (kg).
ρ = specific wood density (kg/m^3)
DBH = diameter at breast height (cm)
H= total tree height (m)

The above-ground biomass of all the trees assessed was then converted from kilograms to tonnes per hectare (t ha^{-1}) by summing their values and dividing by the area [13].

2.4.1 Estimation of above-ground carbon stock (AGC)

Carbon is assumed to be 50% of the total biomass in the above-ground pools [14]. Therefore, to determine the carbon stock of *Tectona grandis* and *Gmelina arborea* plantations, the total above-ground biomass values were converted to carbon stock by multiplying dry weight with 0.5, as employed by Preece *et al.* [15].

$$AGC = AGB \times 0.5 \qquad (2)$$

where AGB is Above-ground biomass (t ha^{-1})

The total above-ground carbon (T_{AGC}) is the sum of all the AGC values obtained after multiplying AGB by the carbon conversion factor of 0.5 (see Equation 2).

2.4.2 Estimation of below-ground biomass (BGB)

26% of the above-ground biomass values were taken to estimate the below-ground biomass by multiplying the above-ground biomass values by 0.26 [16] using 50% for carbon stock conversion.

$$BGB = AGB \times 0.26 \quad (3)$$

Total below-ground biomass (T_{BGB}) was calculated by summing all the BGB values for the tree species across the experimental sites.

Total below-ground carbon (T_{BGC}) was calculated by multiplying the T_{BGB} values by the carbon stock conversion factor of 0.5.

2.4.3 Total carbon stock (TCS) and carbon dioxide equivalent sequestered

The total carbon stock stored was estimated following Semere and Gebreyesus [17]:

$$T_{CS} = T_{AGC} + T_{BGC} \quad (4)$$

where:

T_{CS}– total carbon stock [t ha^{-1}];
T_{AGC}– total above-ground carbon [t ha^{-1}];
T_{BGC}– total below-ground carbon [t ha^{-1}]

Carbon dioxide equivalent sequestered (TCO_2)= $T_{CS} \times 3.67$ (5)

where: T_{CS} is total carbon stock

2.5 Data Analysis

The data was analyzed using the standard analysis of variance procedure (ANOVA) to examine the above-ground biomass, below-ground biomass, total carbon stocks, and total carbon dioxide sequestration between the different tree species and experimental sites. The R program version 3.6.2 was deployed to carry out the statistical analysis of the data [18].

3. RESULTS AND DISCUSSION

3.1 Above-ground Biomass and Below-ground Biomass

The above-ground biomass ranged from 2.3 t ha^{-1} for *Tectona grandis* to 40.4 t ha^{-1} for *Gmelina arborea* (see Fig. 5). These values are comparable to those reported by Dabi *et al.* [19], who found ABG between the ranges of 0.10 t ha^{-1} to 50.15 t ha^{-1} for plantations of *Hevea brasiliensis, Areca catechu* and *Citrus* sinensis in the East Siang district of Arunachal Pradesh, India. The trend is similar for the AGB across the two experimental sites, although the maximum value for AGB in the spacing trial was slightly higher above 10 t ha^{-1}. The BGB estimates were higher for *Gmelina arborea* than *Tectona grandis* across the experimental sites. The differences in above-ground and below-ground biomass for the two experimental sites show higher means for the plantation trial than the spacing trial. The means for AGB were relatively higher than BGB between the species and sites, which agrees with Semere and Gebreyesus [17]. The species performance portrayed *Gmelina arborea* as accumulating a higher AGB and BGB than *Tectona grandis*.

3.2 Total Carbon Stocks (TCS) and Total Carbon Dioxide Equivalent Sequestered (TCO_2)

The total carbon stock of *Gmelina arborea* was substantially higher than that of *Tectona grandis* across the experimental sites, with values ranging between 1.5 t ha^{-1} to 25.2 t ha^{-1}. These values are lower than that reported by Kanowski and Catterall [13]. They found the average carbon stored in the above-ground biomass of young monoculture plantations to be around 62 t ha^{-1} in Australia. However, our estimates for total carbon stock (AGC + BGC) are comparable with those reported by Dabi *et al.* [19], who found total biomass carbon values between the ranges of 0.07 t ha^{-1} to 35.58 t ha^{-1} for selected plantations of *Hevea brasiliensis, Areca catechu* and *Citrus* sinensis in the East Siang district of Arunachal Pradesh, India. The plantation trial was more productive in terms of total carbon stock accumulation than the spacing trial. A similar pattern was observed for the total carbon dioxide equivalent sequestered. The carbon sequestration was higher for *Gmelina arborea*, and the plantation trial's contribution to the total carbon sequestered was greater than the spacing trial (see Fig. 6). This could be because of the previous land use history of the experimental sites. The plantation trial was previously farmland, while the spacing trial was an abandoned grassland; therefore, the site characteristics to support tree growth might be more favourable in the former. This aligns with the findings of Semere and Gebreyesus [17] that the intensity of management can dictate the carbon stock accumulation potential of a site or plantation. Furthermore, the variation in carbon stocks between the two tree species might be accounted for by the planting density used in plantation establishment. The plantation trial had a lower planting density than the spacing trial, so carbon stock accumulation may be higher under low planting densities. This assertion is in line with Vallejos-Barra *et al.* [20] that for plantations of the same age, lower plantation densities seem to correspond to slightly higher carbon absorption rates. However, Semere and Gebreyesus [17] argued that the carbon stock potential of plantations established on the same type of soil is not merely a function of the number of trees planted but depends largely on the dendrometric parameters of the plantation, such as DBH and height. In fact, Dida and Tiburan [21] found that trees with large DBH had the highest AGB estimates on the University of the Philippines Los Baños (UPLB) campus. This also agrees with Kanowski and Catterall [13], who found the contribution of large trees with DBH > 10 cm to AGB higher than smaller DBH trees, as well as Dabi *et al.* [19], who reiterated that the girth of trees influences biomass accumulation.

3.3 Comparison of the Differences in Carbon Stock Variables According to Species and Site

The ANOVA revealed that species and site do not have a statistically significant effect on AGB, BGB, TCS and total carbon dioxide equivalent sequestered (see Table 1). This indicates that the choice of tree species and site does not affect the quantity of carbon stock produced in the above-ground and below-ground biomass. This is similar to the results of Brown *et al.* [22], who reported no significant difference in the mean AGCs between different plantations and primary forest types in Southern Ghana. However, it differs from the results of Kanowski and Catterall [13], who found a significant difference in the above-ground carbon stocks between site types. A possible explanation for this difference might be because the site types in their study were heterogeneous, consisting of both monocultures (pure and mixed species) and environmental restoration plantations, as compared to our study, which reports findings solely for monocultures of *Gmelina arborea* and *Tectona grandis* plantations. However, in our study, similar site conditions between the plantation trial and the spacing trial might account for the lack of significant difference since the two experimental sites are within the same area and hence benefit from the same growing conditions.

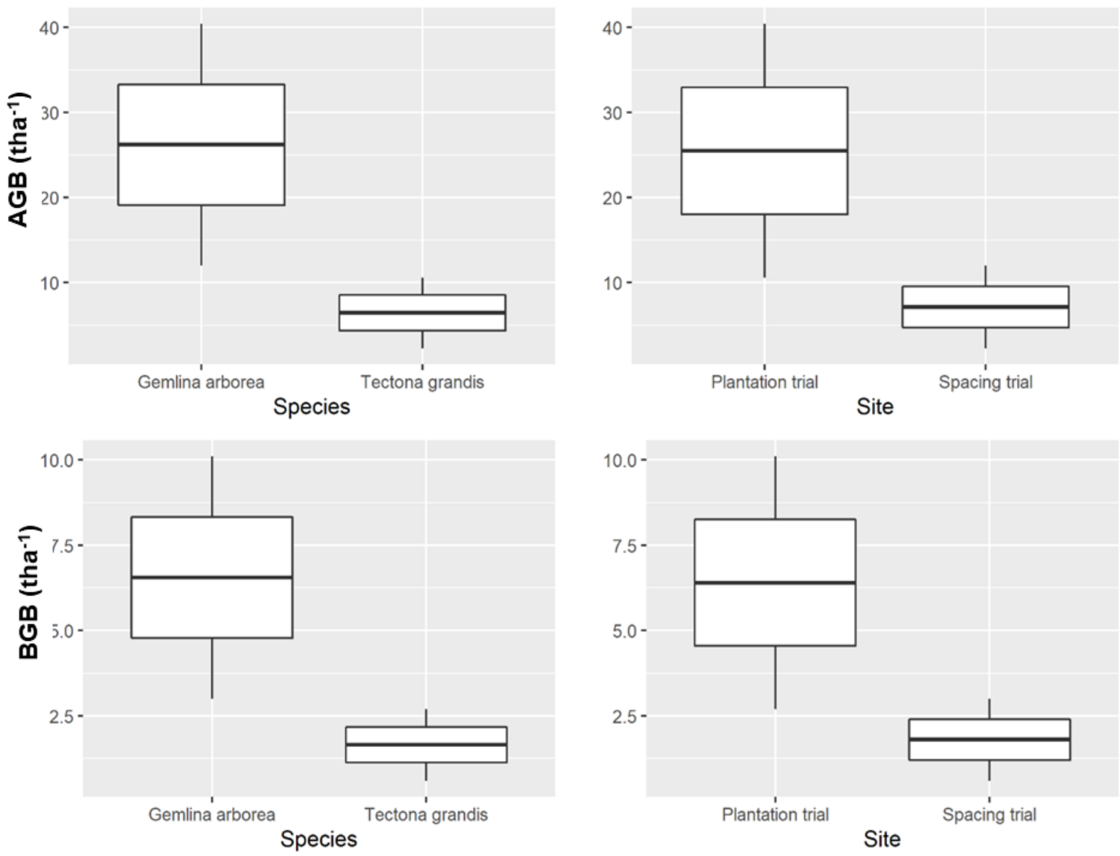

Fig. 5. Above-ground biomass (AGB) and below-ground biomass (BGB) categorized by tree species and experimental sites

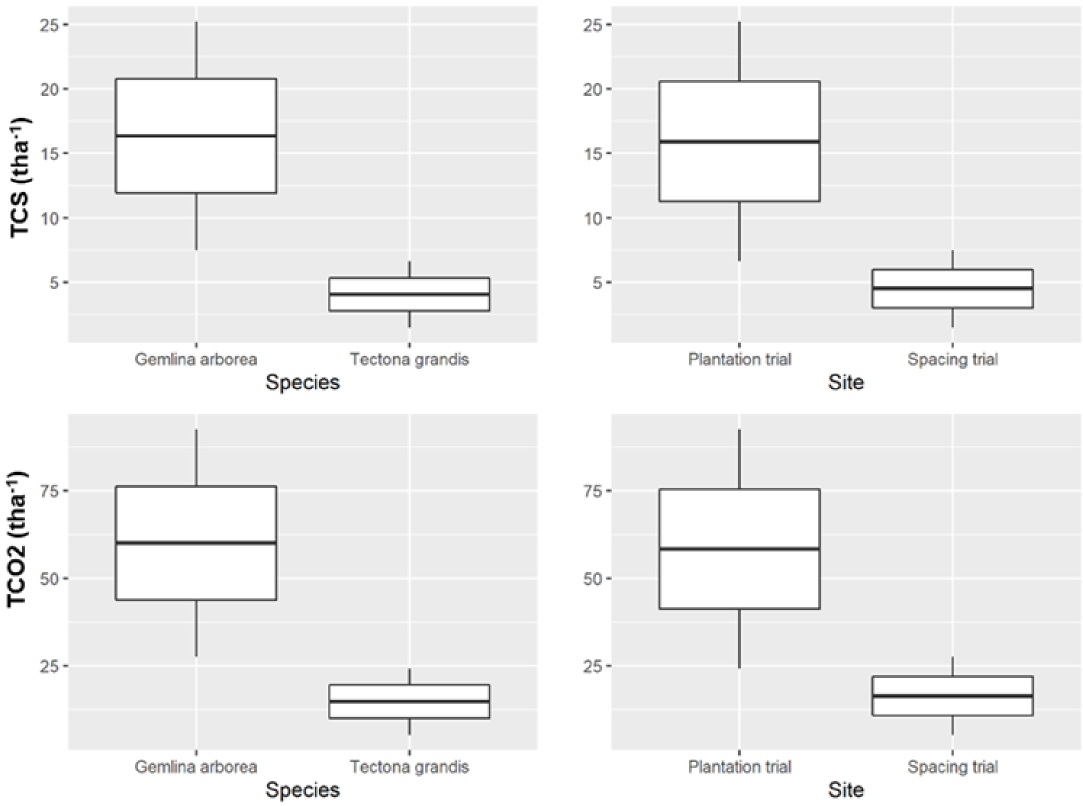

Fig. 6. Total carbon stocks (TCS) and total carbon dioxide sequestered (TCO_2) categorized by tree species and experimental sites

Table 1. Summary of the ANOVA for the influence of species and site on the different variables

	Sum of Squares	df	Mean Square	F value	Pr(>F)
AGB					
Species	390.1	1	390.1	3.862	0.300^{ns}
Site	336.7	1	336.7	3.334	0.319^{ns}
Residuals	101.0	1	101.0		
BGB					
Species	24.01	1	24.01	3.842	0.300^{ns}
Site	21.16	1	21.16	3.386	0.317^{ns}
Residuals	6.25	1	6.25		
TCS					
Species	151.29	1	151.29	3.812	0.301^{ns}
Site	129.96	1	129.96	3.274	0.321^{ns}
Residuals	39.69	1	39.69		
TCO_2					
Species	2043	1	2043	3.862	0.300^{ns}
Site	1764	1	1764	3.335	0.319^{ns}
Residuals	529	1	529		

**, ** $p < 0.05$ and $p < 0.01$ respectively; ns- not significant*

4. CONCLUSION

The potential of forest plantations to sequester carbon in the above-ground pool cannot be underestimated. Considering the results of the present study, it is clear that 5 - 6 years after planting, *Tectona grandis* and *Gmelina arborea* plantations can potentially store total carbon (above-ground and below-ground) between the range of 1.5 t ha^{-1} to 25.2 t ha^{-1} per year respectively. The results also revealed that the type of tree species and the experimental site do not significantly influence the total carbon stock stored in the above and below-ground biomass. Notwithstanding, *Gmelina arborea* plantations accumulated more above-ground biomass and carbon stock than *Tectona grandis* in the study. These findings present plantation forests as a possible option for climate change mitigation through carbon sequestration in their above-ground and below-ground biomass. Therefore, the findings from this research can serve as a baseline for future assessment of above-ground carbon stocks in forest plantations in the region and the country as a whole.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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