Original Research Article

Above-ground carbon stocks of *Tectona grandis* and *Gmelina arborea* plantations in Njala University, Southern Sierra Leone

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* and *Gmelina arborea* 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 total tree height. Above-ground biomass (AGB) was estimated using allometric equation, 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}). Above-ground biomass was shown to exhibit a strong positive correlation (0.99) with below-ground biomass, while total carbon stock was also positively correlated (0.99) with total carbon dioxide sequestered, which is indicative that the various attributes can be accurately predicted from each other. 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 > .05) between the tree species and experimental sites.

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

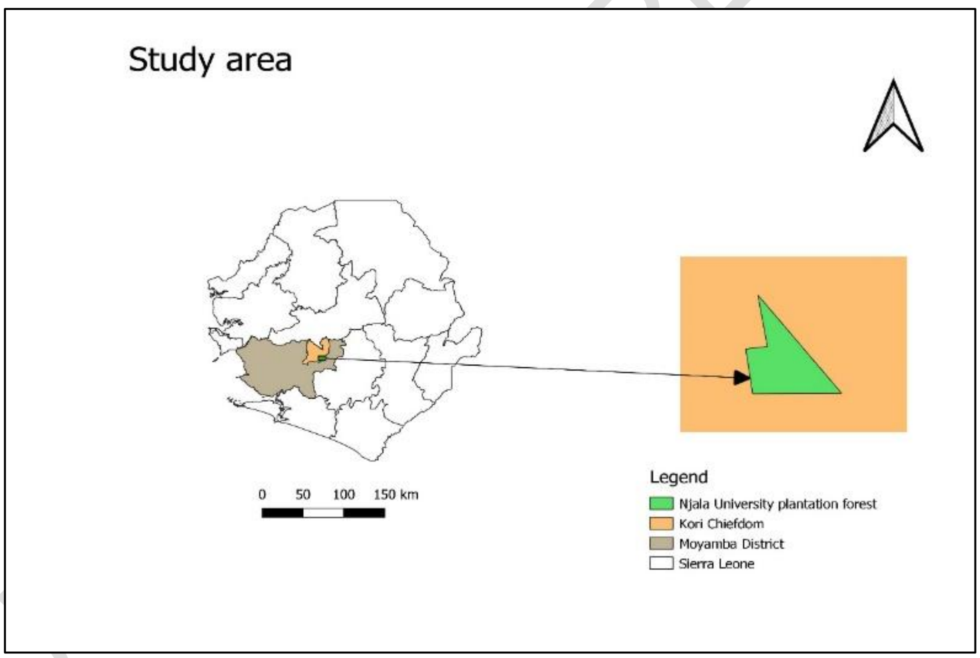
1. INTRODUCTION

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* and *Tectona grandis* 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 will be conducted in Njala University forest plantation. The forest plantation is situated within Njala University campus, Moyamba District, Southern Sierra Leone (Fig. 1). 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 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].



Source: Authors illustration

Fig. 1. Map of the study area showing the plantation forest area

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.

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. 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.

$$AGB = \exp(-2.977 + \ln(\rho D^2 H))$$

$$AGB = 0.0509 \times \rho D^2 H$$

where:

AGB = aboveground biomass (kg).

ρ = species-specific wood density (g/cm^3)

D = 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 (Kanowski and Catterall, 2010).

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].

Above-ground carbon ($t\ ha^{-1}$) = Above-ground biomass * 0.5

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.

Below-ground biomass ($t\ ha^{-1}$) = Above-ground biomass * 0.26

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

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

$$T_{CS} = T_{AGC} + T_{BGC}$$

where:

T_{CS} – total carbon stock [tha^{-1}];

T_{AGC} – total above-ground carbon [tha^{-1}];

T_{BGC} – total below-ground carbon [tha^{-1}]

Carbon dioxide equivalent sequestered (TCO_2) = T_{CS} * 3.67

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 Pearson correlation test was also conducted to study the association between the different variables. 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 < 10.6 t ha^{-1} for *Tectona grandis* to 40.4 t ha^{-1} for *Gmelina arborea* (see Fig. 2). 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*.

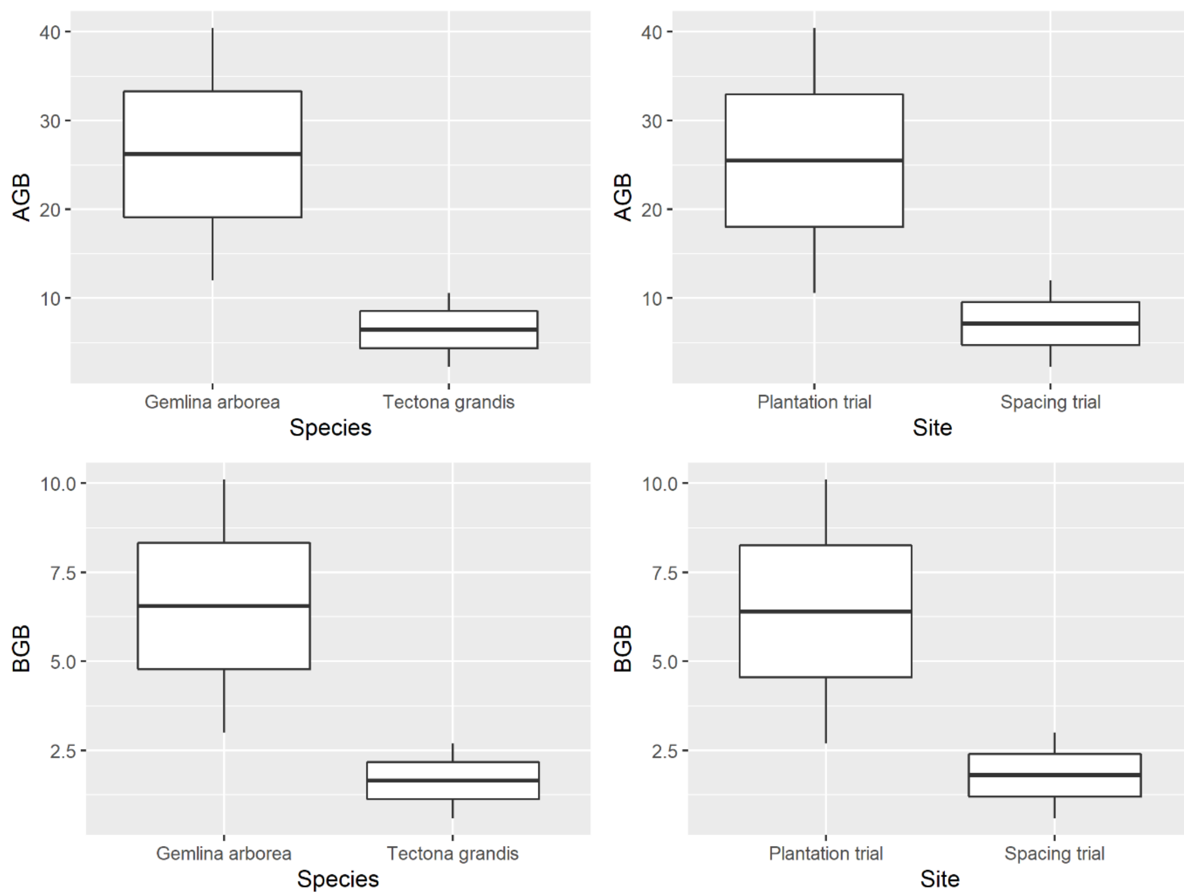


Fig. 2. Above-ground biomass (AGB) and below-ground biomass (BGB) categorized by tree species and experimental sites

3.2 Total carbon stocks (TCS) and total carbon dioxide equivalent sequestered (TCO_2)

The TCS 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. 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. 3). 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.* [19] 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 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 [20] 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.

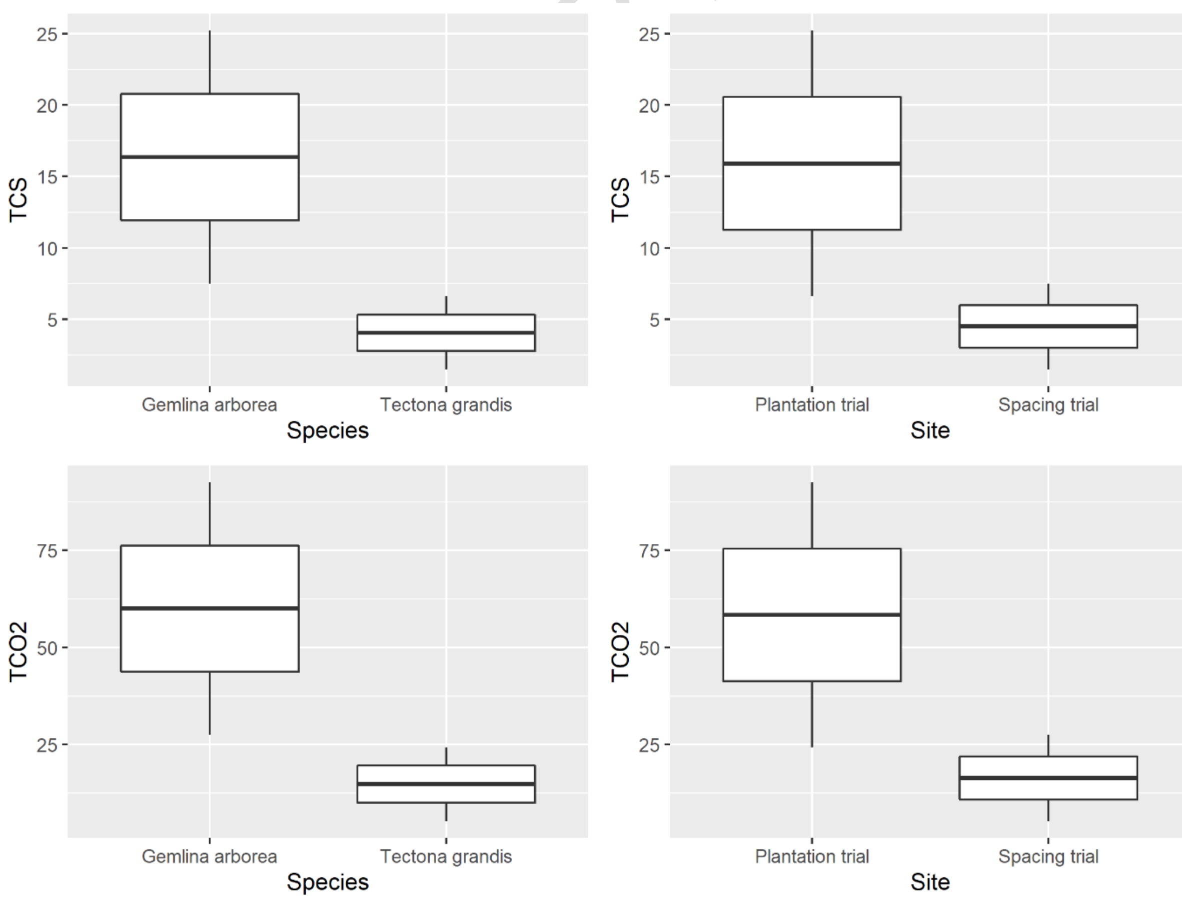


Fig. 3. Total carbon stocks (TCS) and total carbon dioxide sequestered (TCO_2) categorized by tree species and experimental sites

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 Tables 1, 2, 3, and 4). 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.* [21], 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.

Furthermore, the Pearson correlation test found that above-ground biomass and below-ground biomass are significantly correlated with a correlation coefficient of 0.99 and a *P* value less than the significance alpha level of .05. The implication is that the two variables vary in the same direction in which an increase in above-ground biomass will increase below-ground biomass. The test results are similar for the association between total carbon stocks, and total carbon dioxide equivalent sequestered with a correlation coefficient of 0.99, which is similarly significant at $P < .05$. The strong positive correlation is indicative that an increase in the total carbon stock corresponds to an increase in the total carbon dioxide sequestered.

Table 1. Summary of the ANOVA for the influence of species and site on above-ground biomass

	Sum of Squares	df	Mean Square	F value	Pr(>F)

Species	390.1	1	390.1	3.862	0.300
Site	336.7	1	336.7	3.334	0.319
Residuals	101.0	1	101.0		

*no significant difference

Table 2. Summary of the ANOVA for the influence of species and site on below-ground biomass

	Sum of Squares	df	Mean Square	F value	Pr(>F)
Species	24.01	1	24.01	3.842	0.300
Site	21.16	1	21.16	3.386	0.317
Residuals	6.25	1	6.25		

*no significant difference

Table 3. Summary of the ANOVA for the influence of species and site on total carbon stocks

	Sum of Squares	df	Mean Square	F value	Pr(>F)
Species	151.29	1	151.29	3.812	0.301
Site	129.96	1	129.96	3.274	0.321
Residuals	39.69	1	39.69		

*no significant difference

Table 4. Summary of the ANOVA for the influence of species and site on total carbon dioxide equivalent sequestered

	Sum of Squares	df	Mean Square	F value	Pr(>F)
Species	2043	1	2043	3.862	0.300
Site	1764	1	1764	3.335	0.319
Residuals	529	1	529		

*no significant difference

4. CONCLUSION

The potential of forest plantations to sequester carbon in the above-ground pool cannot be underestimated. Considering the results of this present study, it is clear that 5 - 6 years after planting, *Tectona grandis* and *Gmelina arborea* plantations can sequester mean above-ground carbon in the ranges 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 above-ground carbon stock. 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 because tree species, particularly *Gmelina arborea*, could rapidly accumulate carbon in their above-ground biomass within a short time. This reinforces the notion that plantations sequester more carbon in their early growth phase, with carbon storage potential declining as age increases. 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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