



## Carbon Sequestration Potentials of Some Selected Meliaceae Species in a Forest Plantation in Forestry Research Institute of Nigeria, Abia State

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**Abstract:** Meliaceae species are valued not only for their high-quality timber but also for their considerable capacity to accumulate biomass and store carbon. This study assessed aboveground biomass (AGB), carbon stock, and soil organic carbon (SOC) for five species *Cedrela odorata*, *Entandrophragma angolensis*, *Khaya grandifoliola*, *Khaya senegalensis*, and *Lovoa trichilioides* within a 12-year-old plantation in Umuahia, Nigeria. Tree growth variables were measured in 15 m × 15 m sample plots, Newton's formula was used to estimate tree volume, AGB was derived from species-specific wood densities, and carbon stock was estimated using a 0.5 conversion factor. Soil bulk density and SOC were measured at 0–15 cm and 15–30 cm depths. Results showed distinct interspecific differences in growth, volume, and biomass. *C. odorata* (231,976.62 kg ha<sup>-1</sup>) and *L. trichilioides* (130,849.82 kg ha<sup>-1</sup>) exhibited the highest AGB, corresponding to carbon stocks of 231.98 Mg ha<sup>-1</sup> and 130.85 Mg ha<sup>-1</sup>, respectively. In contrast, *K. senegalensis* and *K. grandifoliola* stored greater SOC (8133.75 t ha<sup>-1</sup>) and (6955.95 t ha<sup>-1</sup>) respectively, attributed to substantial fine-root inputs at deeper soil layers. Strong positive correlations among DBH, tree volume, AGB, and carbon stock highlighted the structured nature of carbon allocation. The findings indicate that mixed-species plantations integrating both fast-growing and dense-wood species can enhance short-term biomass carbon gains while supporting long-term soil carbon storage.

**Keywords:** Meliaceae; Aboveground biomass (AGB); Carbon stock; Soil organic carbon (SOC); Wood density.

### INTRODUCTION

Climate change refers to substantial shifts in climatic variables such as precipitation, humidity, wind patterns, drought frequency, and temperature (Malhi *et al.*, 2021; Inanc and Ayaz, 2018). One of its most critical consequences is global warming, an increase in the Earth's average surface temperature caused by the trapping of solar heat due to the accumulation of greenhouse gases, including carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and water vapor (H<sub>2</sub>O) in the atmosphere (Kabir *et al.*, 2023). Among these gases, CO<sub>2</sub> is widely regarded as the most influential contributor to global warming (Nunes, 2023).

The earth natural system particularly the forest has an inherent ability to balance atmospheric CO<sub>2</sub> through processes such as plant photosynthesis that traps large amount of carbon from the atmosphere and store them in plant. However, this equilibrium has been distorted due to anthropogenic CO<sub>2</sub> emission but the forests can still play a crucial role in mitigating emissions (Psistaki *et al* 2024). The capacity of the forest in combating global warming depends on how efficiently trees absorb carbon, convert it into biomass, and store it durably within the forest ecosystem (Chen *et al.*, 2023). Two key components drive this process: biomass carbon in living trees and organisms, and soil organic carbon. Together, they regulate the global carbon

cycle, making forests vital for Earth's climate stability (Koutika et al., 2025).

Carbon stored in form of biomass is known as carbon pool. The aboveground biomass (AGB) pool has been regarded as a vital index of many forest ecosystem processes since approximately half of the AGB is carbon (Luo et al., 2017). Variations in forest above-ground biomass (AGB) could serve as an indicator of forest ecosystem health, revealing impacts from natural disturbance, human influences, and climate change (Li et al 2022).

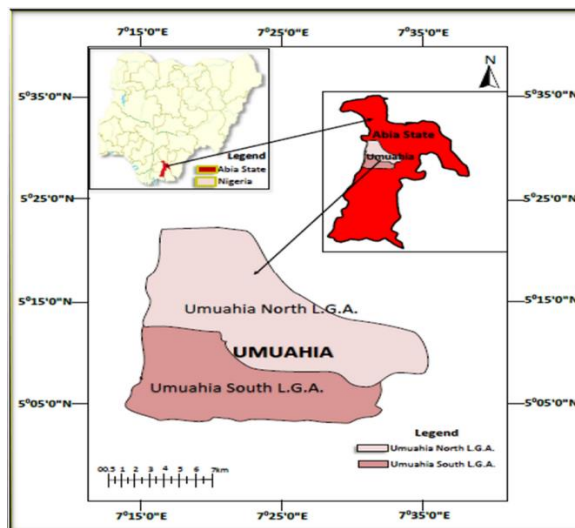
Soil organic carbon, on the other hand, refers to the carbon stored in soil organic matter, which includes decomposed plant and animal residues, microbial biomass, and stable humus (Guan et al 2025; Basiru and Hajri, 2024). In forest ecosystems, SOC is a major carbon pool, storing more carbon than the vegetation and atmosphere combined (Sharma et al., 2023; Buraka et al., 2022). It acts as a long-term storage mechanism for atmospheric CO<sub>2</sub>, helping to mitigate climate change by reducing greenhouse gas concentrations. The accumulation of soil organic carbon is influenced by factors such as tree species, litter quality, and root systems. (Yao et al., 2023).

The Meliaceae family also known as the mahogany family comprises around 50 genera and 600 species of flowering plants (Mukaila et al., 2021), renowned for their valuable timber, medicinal properties, and ecological significance. Notable species include *Entandrophragma*, *Khaya*, *Cedrela*, *Lovoa*, and *Azadirachta indica* (neem) (Cui et al., 2023). These species are not only valuable for their high-quality timber and medicinal properties but also for their significant potential in carbon sequestration due to their large biomass accumulation, fast growth rates, long lifespans and high wood density (Brown et al., 2020; Hornink et al., 2025). Hence, this study estimated the aboveground biomass carbon and soil organic carbon of five selected meliaceae species.

## MATERIAL AND METHODS

### Study Area

The study was conducted at the Forestry Research Institute of Nigeria (FRIN), Humid Forest Research Station, Umuahia, Abia State, south-eastern Nigeria (5°34' N, 7°34' E). The area experiences a humid tropical climate with distinct dry and rainy seasons. Mean annual rainfall is approximately 2,278 mm, occurring mainly between March and October. A short harmattan period characterizes the dry season. The mean annual maximum temperature is about 31 °C, mean daily insolation is 4.8 hours, and relative humidity ranges from 60–90% (Kalu et al., 2012). The vegetation is predominantly tropical rainforest (Ochege and Okpala-Okaka, 2017)



Map of the study area

### Data Collection

The species were planted in 2012 at 3m by 3m spacing. Temporary sample plots (15 m × 15 m) were laid out in each tree species compartment using the quadrat sampling technique. In total, seven temporary sample plots (TSPs) were established for data collection, representing seven species, namely *Cedrela odorata*, *Entandrophragma angolensis*, *Khaya grandifoliola*, *Khaya senegalensis*, *Lovoa trichilioides*, were used for the study. All trees ≥10 cm DBH within each TSP were measured for growth traits.

### Tree growth characteristics

Total height of trees in the TSPs was measured using a Haga altimeter. The diameter at the base (Db), diameter at the middle (Dm) and diameter at the top (Dt) of all sampled trees were measured using spiegel relascope. Wood densities of the species were collected from literature (FAO, 2020). The DBH (diameter at breast height) was determined by measuring the tree girth at a height of 1.3 m from the base of each tree with a measuring tape. The diameter was consequently calculated using the formula:

$$DBH = C/\pi \dots\dots\dots 1$$

where c= circumference of the tree (cm)  
and π = 3.142.

### Tree Volume Estimation

The volume of all sampled trees was calculated using Newton's formula as it gives accurate approximation of the stem's actual shape.

$$TV = \pi H/24 (Db^2 + 4Dm^2 + Dt^2) \dots\dots\dots 4$$

- Where,  
TV = volume (m3);  
H= total height (m);  
π = pi (3.142);  
Db = the sectional area at the base (m2)  
Dm = the sectional area at the middle (m2);  
Dt = the sectional area at the top (m2)

### Aboveground Biomass and Carbon Stock Estimation

AGB was calculated using the formula:

$$\text{AGB} = \text{Tree volume (m}^3\text{)} \times \text{Wood density (kg/m}^3\text{)} \dots\dots\dots 5$$

Where, AGB = Aboveground Biomass;

TV = Tree stem volume;

WD = Wood density

#### Wood density

Wood densities of the individual tree species were obtained from literatures (FAO, 2020).

#### Carbon Stock Estimation

The aboveground carbon stock of individual trees for each species was estimated by multiplying the dry biomass by a carbon fraction (CF) of 0.5. This value is based on the widely accepted assumption that roughly 50% of tree biomass consists of carbon (Hetland et al., 2016; Jew et al., 2016)

$$\text{Carbon Stock (kg)} = \text{AGB} \times \text{CF}$$

#### Data Analysis

The results were analyzed using descriptive statistics. Correlation analysis was conducted to determine the relationships between tree parameters and growth variables, as well as between soil carbon and other assessed soil parameters

## RESULTS AND DISCUSSION

### Results

#### Stand growth characteristics of the species

The growth attributes of the studied Meliaceae species are summarized in Table 1. The maximum height from *C. odorata* stands was 21.60m with a mean height of 18.64m. this was followed by *L. trichiloides* (21.30 m) with a mean height of 17.61m. *E. angolensis*, *K. grandifoliola* and *K. senegalensis* had similar mean height of 8.88m, 8.55m and 8.36m respectively. The largest tree from *C. odorata* stands had a Dbh of 57.67 cm, while the mean dbh of the trees was 15.67 cm, reflecting a significant presence of medium size trees and this was comparable to the mean dbh of *E. angolensis* (16.93 cm), *K. gradifoliola* (15.63 cm) and *K. sensgalensis* (14.34 cm). *L. trichiloides* stands on the other hand had trees with mean dbh of 21.24 cm indicating higher proportion of larger trees.

Across all species examined, the highest concentration of individuals was observed in the 11–20 cm DBH size class (Figure 1), followed by the 21–30 cm class, with all species represented in these categories. In contrast, the lowest number of trees occurred in the  $\geq 51$  cm size class, followed by the 41–50 cm class, in which only *C. odorata* was present.

#### Tree Volume, Aboveground Biomass, and Carbon Storage of Selected Meliaceae Species

The tree volumes of the studied species are presented in Table 2. *C. odorata* had a mean tree volume of 1.10 m<sup>3</sup> and a total volume of 1,220.89 m<sup>3</sup> ha<sup>-1</sup>, while *L. trichiloides* exhibited a mean volume of 0.51 m<sup>3</sup> and a total volume of 568.92 m<sup>3</sup> ha<sup>-1</sup>. *K. grandifoliola* and *K. sengalensis* had relatively comparable mean tree volume of (0.16 m<sup>3</sup>) and (0.18 m<sup>3</sup>) respectively. However, *C. odorata* tree volume was substantially higher than *L. trichiloides*, *E. angolensis*, *K. sengalensis* and *K. grandifoliola* with about 100%, 400%, 500% and 600% respectively.

The trend in aboveground biomass accumulation of the five selected meliaceae species was such that *C. odorata* had the highest total AGB of 231976.62 kg ha<sup>-1</sup> with a mean of 417.55kg, this was followed by *L. trichiloides* with a total of 130,849.82 kg ha<sup>-1</sup> and mean of 235.53 kg, *E. angolensis* (117.33 kg) while *K. grandifoliola* and *K. senegalensis* had relatively similar mean aboveground biomass of 95.23 kg and 97.04 kg respectively, which was four times lower than the value of *C. odorata*.

The carbon stock of the species is presented also in Table 2, revealing a trend similar to that of aboveground biomass (AGB) as carbon stock is 50% of AGB. The carbon stock of the species species rank in descending order as follows: *C. odorata* 208.78 kg/tree, with a total of 231.98 Mg/ha, *L. trichiloides* 117.76 kg/tree, with a total of 130.85 Mg/ha, *E. angolensis* 58.67 kg/tree, with a total of 65.18 Mg/ha, *K. senegalensis* 53.91 kg/tree, with a total of 39.10 Mg/ha and *K. grandifoliola* 47.61 kg/tree, with a total of 52.90 Mg/ha.

#### Relationship between tree growth, stand biomass, and forest carbon stock

The relationships among tree growth parameters, stand biomass accumulation, and forest carbon stock are shown in Table 3. Except for wood density, which showed a negative correlation, all other variables exhibited positive associations. Notably, aboveground biomass and carbon stock were perfectly positively correlated ( $r = 1.000$ ), indicating a direct proportional relationship. Tree volume also showed strong positive correlations with diameter at breast height (DBH) ( $r = 0.961$ ), aboveground biomass ( $r = 0.997$ ), and carbon stock ( $r = 0.997$ ). These results suggest that increases in tree volume are closely linked with enhanced biomass accumulation and greater carbon sequestration potential.

#### Soil bulk density and organic carbon stock

Soil bulk density increases with soil depth across all species stands as shown in Table 4, while soil organic carbon (SOC) concentration decreases with soil depth. At the upper soil surface of 0-15cm, *L. trichiloides* had the lowest soil bulk density (0.96 g cm<sup>-3</sup>), this was followed by *E. angolensis* (1.10 g cm<sup>-3</sup>), while *K. senegalensis* and *C. odorata* had similar and highest bulk density (1.19 g cm<sup>-3</sup>). Similarly, at the subsurface soil depth *L. trichiloides* also had the lowest soil bulk density (1.20g cm<sup>-3</sup>). The SOC concentration of *L. trichiloides* stands declined drastically with depth, from 45.22 g/cm<sup>2</sup> at 0-15cm to 21.42 g/cm<sup>2</sup> at 15-30cm. Meanwhile, *K. senegalensis* (41.06 and 40.28 g/cm<sup>2</sup>), *K. grandifoliola* (36.44 and 33.12 g/cm<sup>2</sup>) and *E. angolensis* (16.17 and 16.69 g/cm<sup>2</sup>) showed minimal variation between the two depths. The total SOC stock (t/ha) decreased in the order of: *K. senegalensis* > *K. grandifoliola* > *L. trichiloides* > *C. odorata* > *E. angolensis*, with values of 8133.75 t ha<sup>-1</sup>, 6955.95 t ha<sup>-1</sup>, 6663.6 t ha<sup>-1</sup>, 5954.70 t ha<sup>-1</sup>, and 3285.75 t ha<sup>-1</sup> respectively (Table 5). *K. senegalensis* recorded the highest total carbon stock (8172.85 t/ha), despite having relatively low biomass carbon (39.10 t ha<sup>-1</sup>) when compared to others, the soil organic carbon (SOC) content at both soil depths

were high (4105.50 and 4028.25 t ha<sup>-1</sup>). Similarly, the SOC of *K. grandifoliola* was high at both depths (3644.25 and 3311.70 t ha<sup>-1</sup>) and this resulted in high TSOC (6955.957 t ha<sup>-1</sup>). On the other hand, *L. trichiloides* had the highest SOC at 1-15cm (4521.60 t ha<sup>-1</sup>) soil depth but its TSOC was lower than those of the Khaya species due to its low SOC (2142.00 t ha<sup>-1</sup>) at 15-30cm soil depth (Table 5).

**Relationships between soil depth, bulk density and organic carbon dynamics**

Table 6 presents the correlation coefficients among soil depth, bulk density, organic carbon, and soil organic carbon. Soil depth showed a moderate positive correlation with bulk density (r = 0.47), indicating an increase in soil compaction with increasing depth. In contrast, soil depth was moderately and negatively correlated with organic carbon (r = -0.52) and soil organic carbon (r = -0.56), suggesting a decline in carbon content with increasing soil depth. Bulk density exhibited negative correlations with both organic carbon (r = -0.43) and soil organic carbon (r = -0.47), implying that higher organic matter content is associated with lower soil compaction and improved soil structure. A very strong positive correlation was observed between organic carbon and soil organic carbon (r = 0.94), reflecting their close interdependence and consistency as indicators of soil carbon status.

**Discussion**

**Growth characteristics and tree volume of the meliaceae species**

The Meliaceae species studied exhibited variations in growth characteristics, which were reflected in their tree volume. As anticipated, species with larger stem diameters and greater heights, including *C. odorata* and *L. trichiloides*, tended to have greater volumes. This outcome was expected due to the allometric relationship between tree volume and diameter (Bradford and Murphy 2019). However, *E. angolensis* achieved a high tree volume despite its relatively low height, due to its substantial diameter at breast height (DBH). This highlights the importance of both diameter and height in determining tree volume (Ciceu et al., 2020). This result aligns with the findings of Ariyo (2020) in Ibadan, Nigeria, who similarly observed that trees with larger stem diameters tend to have greater volumes. It also corroborates the work of Luoma et al. (2021), who reported a comparable positive

relationship between DBH and tree volume in Boreal forests in Finland. The lower tree volumes recorded in the present study compared to those reported by Fatimah et al., (2024) are likely attributable to the smaller DBH values and shorter tree heights observed in our sampled trees.

The diameter-class distribution, characterized by the dominance of individuals in the 11–20 cm and 21–30 cm DBH classes, indicates that the stand is composed mainly of small to medium-sized trees. This pattern is consistent with the findings of Ahmed et al., (2022), who reported a similarly high proportion of smaller diameter trees in a young mangrove plantation in Bangladesh. Likewise, Ureigho and Oyibo (2023) observed a positively skewed DBH distribution in 14 and 15-year-old *C. odorata* plantations in Nigeria, where medium-sized stems were most abundant and large trees were comparatively few.

Conversely, the limited presence of large-diameter individuals particularly within the ≥41 cm class, where *C. odorata* was the only species represented suggests species-specific advantages such as rapid diameter growth that enable this species to dominate the upper size categories. This interpretation aligns with Akowuah et al., (2022), who documented relatively high growth rates in *C. odorata* under favorable site and climatic conditions.

**Table 1: Growth variables of some selected meliaceae species**

Variables	<i>C.odorata</i>	<i>E.angolensis</i>	<i>K.grandifoliola</i>	<i>K.sengalensis</i>	<i>L.trichiloides</i>
<b>Height</b>					
Mean (m)	18.24	8.88	8.55	8.36	17.61
Max	21.60	14.00	13.00	11.25	21.30
Min	14.05	5.10	4.0	5.5	14.35
SE	0.42	0.48	0.55	0.41	0.42
<b>Dbh</b>					
Mean (cm)	15.67	16.93	15.63	14.34	21.24
Max	57.27	31.82	25.45	22.27	31.82
Min	14.32	9.55	9.55	9.86	13.68
SE	2.06	0.96	1.01	0.87	1.07
<b>Wood density</b>					
Mean (kg ha <sup>-1</sup> )	380.00	580.00	600.00	600.00	460.00

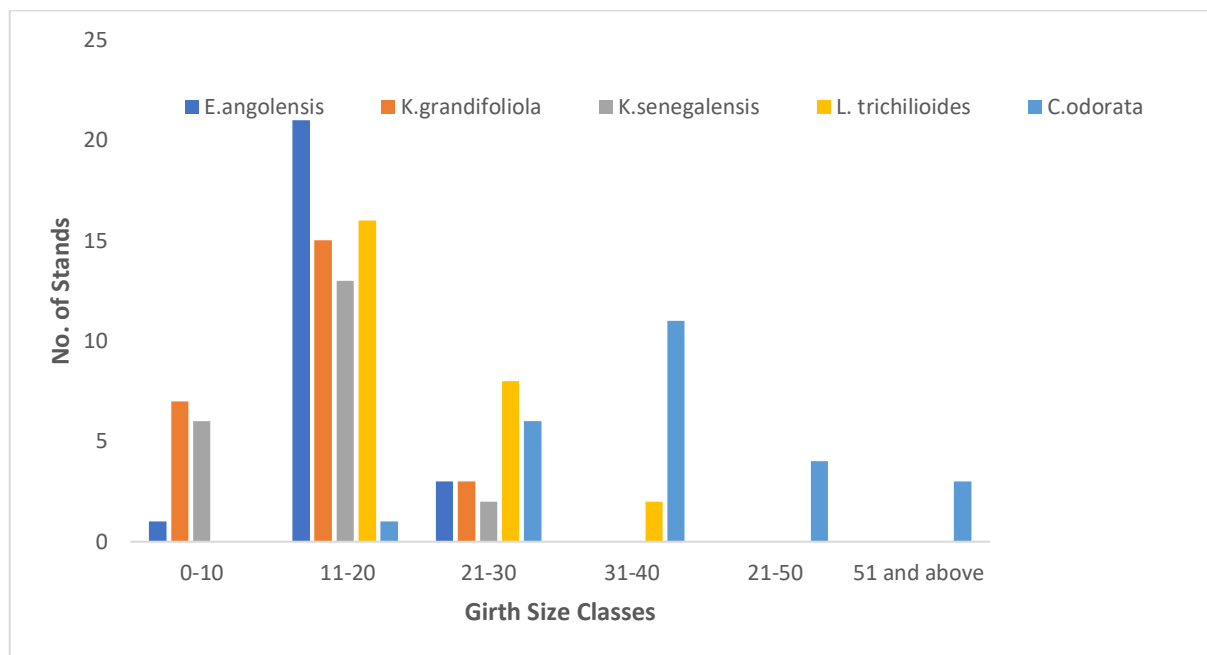


Fig 1: Distribution of tree species across the different girth-size classes

Table 2: Tree volume, aboveground biomass and carbon storage of the selected meliaceae species

Variables	<i>C.odorata</i>	<i>E.angolensis</i>	<i>K.grandifoliola</i>	<i>K.senegalensis</i>	<i>L.trichiloides</i>
<b>Volume</b>					
Total (m <sup>3</sup> ha <sup>-1</sup> )	1220.89	224.77	176.34	159.12	568.92
Mean	1.10	0.20	0.16	0.18	0.51
Max	2.91	0.57	0.35	0.65	1.01
Min	0.13	0.09	0.07	0.06	0.13
SE	0.13	0.02	0.02	0.03	0.09
<b>AGB</b>					
Total (Mg ha <sup>-1</sup> )	463.95	130.37	105.81	78190.67	264676.17
Mean (Kg)	417.55	117.33	95.23	97.04	235.53
Max	1105.34	328.21	210.81	259.20	465.69
Min	56.79	49.55	39.43	35.39	58.78
SE	47.98	12.34	11.66	10.20	22.07
<b>Carbon</b>					
Total (kg ha <sup>-1</sup> )	231,976.62	65,184.08	52,903.04	39,095.33	130,849.82
Mean	208.78	58.67	47.61	48.52	117.76
Max	552.97	164.16	105.40	129.61	232.85
Min	28.40	24.78	19.72	17.69	29.39
SE	23.99	6.17	5.8	5.10	11.03

Table 3: Correlation analysis of the variables

Variables	Height	DBH	Tree volume	Wood density	AGB	Carbon
Height	1					
DBH	0.790	1				
Tree volume	0.876	0.961	1			
Wood density	-0.969	-0.913	-0.966	1		
AGB	0.904	0.960	0.997	-0.981	1	
Carbon	0.904	0.960	0.997	-0.981	1.000	1

**Table 4:** Soil characteristics at different depths under some selected meliaceae plantation

Tree species	Soil depth (cm)	Bulk density (g cm <sup>3</sup> )	Org.C (%)	SOC stock (g cm <sup>-2</sup> )
<i>C.odorata</i>	0-15	1.19	2.17	38.74
	15-30	1.25	1.11	20.81
<i>E.angolensis</i>	0-15	1.10	0.98	16.17
	15-30	1.25	0.89	16.69
<i>K.grandifoliola</i>	0-15	1.13	2.15	36.44
	15-30	1.33	1.66	33.12
<i>K.sengalensis</i>	0-15	1.19	2.30	41.06
	15-30	1.31	2.05	40.28
<i>L.trichiloides</i>	0-15	0.96	3.14	45.22
	15-30	1.20	1.19	21.42

**Table 5:** Soil organic carbon (SOC) stock at different soil depth under some selected meliaceae plantation

Tree species	Soil depth (cm)	SOC stock (t ha <sup>-1</sup> )	Total SOC (t ha <sup>-1</sup> )	Total carbon in biomass (t ha <sup>-1</sup> )	Total carbon (Biomass C + TSOC) (t ha <sup>-1</sup> )
<i>C.odorata</i>	0-15	3873.45			
	15-30	2081.25	5954.70	231.97	6186.67
<i>E.angolensis</i>	0-15	1617.00			
	15-30	1668.75	3285.75	65.18	3350.93
<i>K.grandifoliola</i>	0-15	3644.25			
	15-30	3311.7	6955.95	52.90	7008.85
<i>K.sengalensis</i>	0-15	4105.50			
	15-30	4028.25	8133.75	39.10	8172.85
<i>L.trichiloides</i>	0-15	4521.60			
	15-30	2142.00	6663.6	130.85	6794.45

**Table 6:** Correlation analysis of the variables

Variables	Soil depth	Bulk density	Org. carbon	Soil org. carbon
Soil depth	1			
Bulk density	0.47	1		
Org. carbon	-0.52	-0.43	1	
Soil org carbon	-0.56	-0.47	0.94	1

### Aboveground biomass and carbon stock

The aboveground biomass (AGB) of Meliaceae species showed a trend influenced by the interaction between wood basic density and tree volume, highlighting the importance of wood basic density as a factor in estimating biomass in tropical forests (Phillips *et al.*, 2019). The relatively low aboveground biomass (AGB) of *K. grandifoliola* and *K. senegalensis* was attributed to their low tree volumes, despite having high wood density. In contrast, *C. odorata*, which had the lowest wood density, exhibited the highest AGB due to its substantial tree volume, likely resulting from rapid growth. This is supported with the investigation of Wirabuana *et al.*, (2022) who observed greater biomass in clonal teak as a result of increased height and diameter. Fast growing species like *Cedrela odorata* produces more biomass due to their rapid rate of photosynthesis that results in increased height and diameter (Novor and Abugre, 2020). Carbon stock on the other hand is based on biomass accumulation which is a key indicator of carbon sequestration. Approximately 50% of dry weight of plant biomass is made up of carbon, this implies that species with higher biomass production tend to store more carbon (Akhilesh *et al.*, 2018). Consequently, *C. odorata* and *L. trichiloides* exhibited higher carbon stock values than *E. angolensis*, *K. grandifoliola*, and *K. senegalensis*, primarily due to their greater biomass production. Nonetheless, the carbon stocks recorded for *K. grandifoliola* and *K. senegalensis* in this study were higher than those reported by Gomes *et al.* (2024) for 9-year-old *Khaya* spp. stands in Brazil, who gave the values to be 33.97 and 33.86 Mg/ha respectively. These differences could be as a result of the tree age. The size of a tree as well as its age could influence its carbon stock (Addi *et al.* 2019). Biomass accumulation increases with age in young trees, in the early stages of stand development, trees prioritize root development for efficient water and nutrient absorption, driving rapid foliage growth. As stands mature, foliage biomass and production increase due to the effect of increment in diameter and height (Kohl *et al.* 2017).

### Relationship among growth variables, biomass and carbon stock

The positive associations among growth variables, biomass, and carbon stock have been reported in previous research (Ononyume and Edu 2025; Hasan *et al.*, 2025; Fatimah *et al.*, 2024). These relationships highlight the intrinsic connection between structural growth attributes and the carbon sequestration potential of forest ecosystems. The observed patterns further highlight the structured nature of forest growth dynamics, where primary growth variables such as DBH, height, and volume strongly influence secondary ecological variables including biomass and carbon stock (Kumar *et al.*, 2024; Gebeyehu *et al.*, 2019). The negative relationship between wood density and growth variables likely arises from an allocation constraint between mechanical strength and growth rate. Species allocating more resources to dense wood typically exhibit slower

growth and lower total biomass accumulation. Consequently, tree species with high wood density such as *E. angolensis* and the *Khaya* spp in this study, tend to have lower biomass compared to species with low wood density such as *C. odorata* and *L. trichiloides*.

These findings indicate that fast-growing, high-productivity species can capture and store carbon quickly, boosting short-term sequestration rates, whereas slow-growing species with dense wood contribute to maintaining carbon stocks over the long term. To maximize both rapid carbon uptake and long-term storage, carbon-sequestration initiatives should prioritize mixed-species plantations that combine fast-growing species with slower-growing, dense-wood species.

### Soil bulk density and organic carbon stock

Across all species stands, soil bulk density increased consistently with depth, aligning with the findings of Wasli *et al.* (2022) and Guo *et al.* (2024). Higher soil bulk density indicates greater compaction, which reduces pore space, restricts water and air movement, and limits microbial activity (Gui *et al.*, 2023). Conversely, lower soil bulk density reflects a more porous soil structure that enhances water retention and gas exchange (Kool *et al.*, 2019).

This porosity promotes microbial decomposition, leading to increased soil organic carbon in the *L. trichiloides* stand. However, the *E. angolensis* stand, despite having a similar bulk density, exhibited significantly lower soil organic carbon that was well over 50% less. This difference may result from variations in litter quantity and quality between the two species, illustrating the complex interactions between soil physical properties and biotic processes that govern soil carbon storage

The amount of litter produced plays a crucial role in building soil organic carbon over time while litter quality influences the speed and efficiency of early decomposition and carbon turnover (Zeng *et al.*, 2024; Liu *et al.*, 2023).

Although bulk density increased with depth, soil organic carbon (SOC) decreased, a pattern observed in all species stands and consistent with the reports of Kibet *et al.* (2022); Chepkemoi *et al.*, (2020). The high soil organic carbon (SOC) levels near the surface likely result from substantial litter accumulation, leading to rapid decomposition and, in turn, contributing to the lower soil density observed in the topsoil. Elevated soil organic carbon (SOC) concentrations observed under *Khaya senegalensis* at subsurface depths (15–30 cm) may be attributed to enhanced belowground root activity particularly increased fine-root biomass and turnover which contribute additional organic inputs to deeper soil layers. This agrees with the findings of Djongmo *et al.*, 2019, who reported that fine-root production and renewal are key mechanisms driving soil carbon accumulation in savanna tree species. Similarly, Gomes *et al.*, (2024) reported substantial fine-root biomass for *K. senegalensis* at 20–30 cm depth (2.80 t C ha<sup>-1</sup>).

Roots contribute to soil carbon through rhizodeposition during growth and root litter decomposition (Sokol *et al.*, 2019; Dijkstra *et al.*, 2021). Notably, Yang *et al.* (2023) found that root growth contributes more significantly to SOC than dead root decomposition, suggesting that carbon

released during root growth is more stable. Furthermore, research suggests that root inputs are more effective at stabilizing SOC than aboveground plant inputs (Jackson *et al.*, 2017), highlighting the critical role of roots in building long-term soil carbon stocks.

### Relationships between soil depth, bulk density, and organic carbon dynamics

The correlation analysis demonstrated significant relationships among soil depth, bulk density, organic carbon, and soil organic carbon that are consistent with established soil behavior. Soil depth showed a moderate positive correlation with bulk density ( $r = 0.47$ ), indicating increased compaction with increasing depth. This trend is in agreement with previous studies reporting that deeper soil horizons generally possess fewer macropores and reduced biological activity relative to surface layers, leading to higher bulk density as organic matter content decreases with depth (Mahajan *et al.*, 2025). In contrast, soil depth exhibited negative correlations with both organic carbon ( $r = -0.52$ ) and soil organic carbon ( $r = -0.56$ ), indicating that carbon concentrations are greatest in surface layers and progressively decline with increasing depth. This pattern is widely documented in soil studies, as organic residue inputs, root activity, and microbial biomass are predominantly concentrated near the soil surface (Mahajan *et al.*, 2025). The observed reduction in organic carbon with depth reflects diminished organic inputs and differences in decomposition dynamics between surface and subsoil horizons. Additionally, bulk density showed negative correlations with organic carbon ( $r = -0.43$ ) and soil organic carbon ( $r = -0.47$ ), further reinforcing the inverse relationship between soil compaction and carbon content. High organic carbon content is known to improve soil structure by increasing aggregation and porosity, which reduces bulk density; therefore, soils richer in carbon typically exhibit lower compaction and bulk density values (Khusrizal *et al.*, 2024)

### CONCLUSION

This study reveals clear interspecific differences in growth, biomass, and carbon storage among the examined Meliaceae species. Tree volume and biomass were primarily driven by diameter and height, reflecting the importance of allometric relationships in explaining structural variation. Fast-growing species such as *C. odorata* and *L. trichilioides* accumulated greater biomass and carbon, whereas dense-wood species like *E. angolensis* and the *Khaya* spp. contributed less biomass but may enhance long-term carbon retention.

The diameter-class distribution reflected a stand dominated by small to medium-sized trees, indicating ongoing stand development, while variation in litter quality, root inputs, and soil bulk density influenced belowground carbon distribution. Elevated subsurface SOC under *K. senegalensis* highlights the role of fine-root dynamics in long-term carbon stabilization.

Overall, the positive relationships among growth variables, biomass, and carbon stock emphasize the structured nature

of forest carbon dynamics. These findings suggest that mixed-species plantations that combine fast-growing and dense-wood species may optimize both rapid carbon uptake and long-term storage, providing a strategic approach for climate-focused forest management.

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### Conflict of Interest

The authors report no conflicts of interest related to this research.

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