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# The Potential of Fast-Growing Tree Species in Biomass and Soil Organic Carbon Stock and Its Implications for Climate Change Mitigation in Western Ethiopia

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**Abstract:** Plantations of fast-growing tree species are important in climate change mitigation efforts because of their enormous potential for carbon storage and the potential affected mainly by tree species type and composition, which influence particular carbon pools in the system. This study estimates biomass and soil organic carbon (SOC) under selected fast-growing tree species in Ethiopia's Diksis district, Oromia region. Major parameters, height (H) and diameter at breast height (DBH), were measured in permanently sampled plots (9mx9m) with three replications to evaluate the biomass carbon stock of selected species. Soil samples (0–15 and 15-30 cm) were also collected to determine soil organic carbon (SOC) and bulk density. Above and below-ground biomass (AGB) and (BGB) were calculated using the site and species-specific allometric equations, and SOC was analysed using appropriate procedures in the laboratory. The results showed that the highest total biomass carbon stock was recorded for *Eucalyptus globulus* (5.7Mg C ha-1), and the lowest was recorded for *Eucalyptus grandis* (1.2 Mg C ha-1). Amongst the studied tree species, the highest and lowest mean total soil organic carbon (SOC) was recorded for *Eucalyptus saligna* (60 Mg C ha-1) and *Eucalyptus viminalis* (35.4 Mg C ha-1), respectively. The study also revealed that plantation sites could enhance carbon stock accumulation in biomass and soil organic carbon. Hence, considering that incorporating fast-growing tree species in plantations is helpful in climate change mitigation strategies is a preeminent approach beyond their economic values.
*Key words: biomass carbon stock, climate change mitigation, fast-growing tree species, soil organic carbon*

## 1. Introduction

In Ethiopia, highland forest cover was about 40% of the total land area some decades ago, delivering a wide range of social, economic, and environmental benefits, including critical components of biodiversity [1]. However, anthropogenic disturbances are causing a dramatic decline in these forests, and the scenario is gradually changing. Today, the area covered by natural high forests is less than 3% of the country's total land [2],[3]. The remaining forests are highly fragmented, and plantations of non-native tree species are modifying them [4],[5],[6]. Manmade plantations of fast-growing exotic tree species are becoming another form of vegetation found in highland regions of Ethiopia. Despite this, different human activities have increased the concentration of greenhouse gases (GHGs) in the atmosphere [7]. This increasing concentration can be caused by the different industrial wastes and the negligent management of the environment, such as degradation, deforestation, and wildfires [8].

To reduce carbon dioxide emissions, Ethiopia relies on existing vegetation, which is decreasing in both area and composition. However, the removal of greenhouse gases from the atmosphere through sinks (i.e. trees and soil) is one way of addressing climate change [9]. In the wake of global efforts to address climate change, considerable interest has been generated in the carbon sequestration potential of trees particularly in plantations of fast-growing trees which are being considered as a mitigation option to reduce atmospheric carbon di oxide and climate change [10]. Thus, understanding the ability of plantation forests to sequester carbon dioxide, especially in Ethiopia where land degradation and deforestation are immense, is therefore of great importance, as the afforestation has been considered, as a cost-effective and environmentally beneficial strategy. [11]. Moreover, tree plantation for carbon sequestration has ecological, environmental, social, and economic values. Forests have a higher carbon density than others [12] While sustainable management, planting, and rehabilitation of forests can conserve or increase forest carbon stocks [13].

Ethiopia relies on existing vegetation to reduce carbon dioxide emissions, which is decreasing in both area and composition. However, removing greenhouse gases from the atmosphere through sinks (i.e. trees and soil) is one way of addressing climate change [9]. In the wake of global efforts to address climate change, considerable interest has been generated in the carbon sequestration potential of trees, particularly in plantations of fast-growing trees, which are considered a mitigation option to reduce atmospheric carbon dioxide and climate change [10]. Thus, understanding the ability of plantation forests to sequester carbon dioxide, especially in Ethiopia where land degradation and deforestation are immense, is therefore of great importance, as af-forestation has been considered a cost-effective and environmentally beneficial strategy. [11]. Moreover, tree plantation for carbon sequestration has ecological, environmental, social, and economic values. Forests have a higher carbon density than others [12], while sustainable management, planting, and rehabilitation of forests can conserve or increase forest carbon stocks [13].

Interest in the broader plantation of exotic trees for climate change mitigation is increasingly receiving attention due to their fast growth and ability to adapt to broader ecology and low-quality and degraded lands. On account of their fast growth and, therefore, short rotation cycle, exotic tree plantations have been reported to have a higher carbon density per hectare compared to the natural high forests [14],[15]; thus, they can be used as a potential source of carbon sink [16] in the country. Despite these, there needs to be more information on the aboveground biomass and carbon storage potential of fast-growing tree species, particularly in the highland areas where the availability of potential plantation species is minimal. Knowledge of the aboveground biomass fast-growing tree species adapted to the highland is a prerequisite for sustainable management [17]. This information would justify investment in the country's fast-growing species plantation for biomass production. To the best of our knowledge, no study has been conducted to compare the biomass and soil carbon stock of evaluated fast-growing tree species i.e. *Cupress lustanica*, *Eucalyptus viminalis*, *Acacia decurrens*, *Eucalyptus saligna*, *Acacia melanoxylon*, *Eucalyptus camaldulensis*, *Eucalyptus grandis*, and *Eucalyptus globulus* grown in plantations in Ethiopia. Therefore, in this study, we evaluated the biomass of carbon and soil organic carbon of fast-growing tree species in Diksis Woreda, Oromia Region. Thus, the information generated from this study could be essential tools in the long-term management of plantation forest systems in the country since they can evaluate the biomass production and carbon accumulation of different fast-growing tree species in the highland part of the country.

## 2. Materials and methods

### *2.1. Study site description*

The study was conducted in Diksis district located in the East Arsi Zone of Oromia Regional State, Ethiopia (Figure 1). Mean temperatures of the area range from 23 and 6 °C. The mean annual precipitation is 1100 mm with peaks in July and August. The soil type of the study area is classified as Nitosols. All data were collected from the plantations established by the Ethiopian Environment and Forest Research Institute in the year 2013 as a part of the comparative growth performance of fast-growing tree species for wood fuel production in the Ethiopian highland research project. The plantation was for about 11 fast-growing tree species with three replications sated in the permanent plot (RCBD) with a plot size of 7.5×7.5m, with a spacing of 1.5 m between trees and plots and 2m between blocks.

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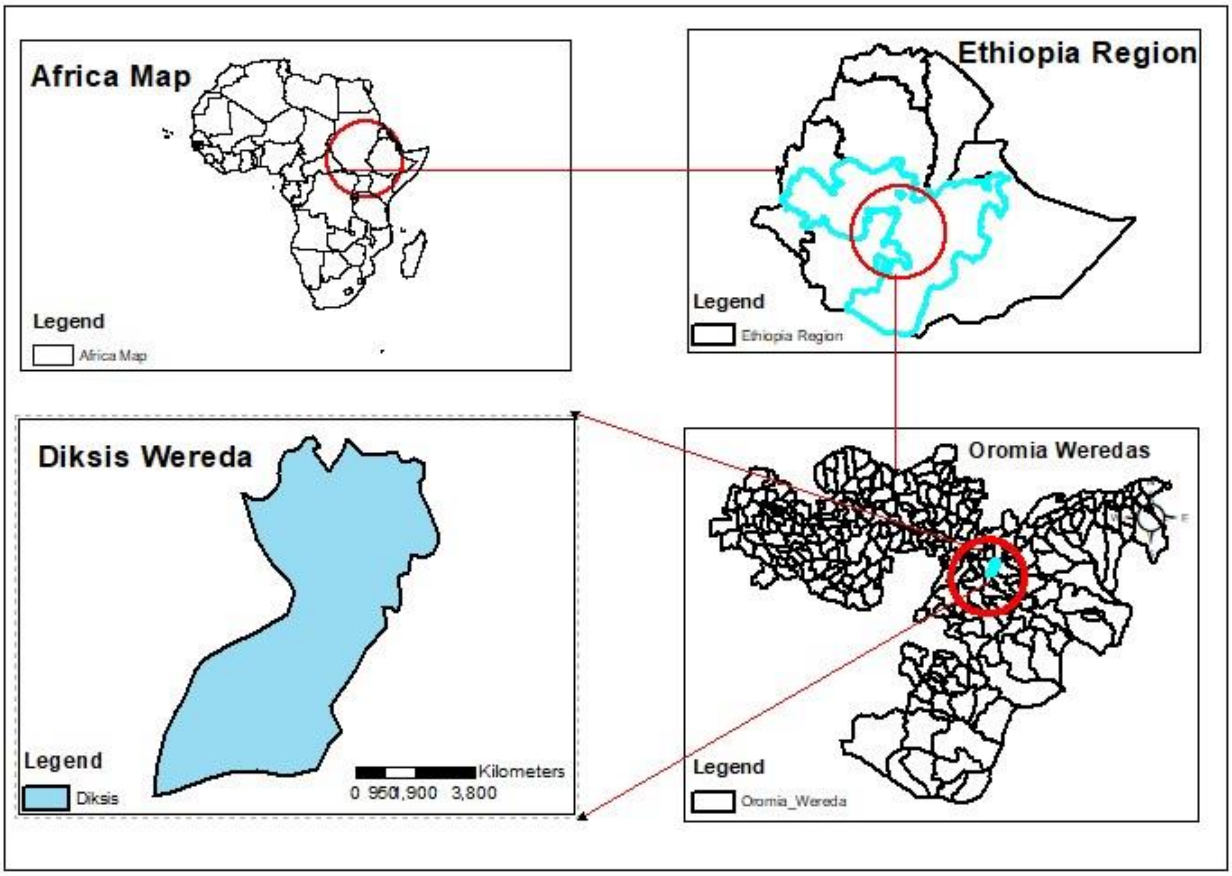


Figure 1: Map showing the location of the study area, Diksis, in East Arsi Zone of Oromia Regional State, Ethiopia.

### *2.2. Data collection methods*

#### *2.2.1. Tree inventory*

The AGB estimation was carried out by a non-destructive sampling method for all woody species found in the plots: Cupress Lusitania, *Eucalyptus viminalis*, *Acacia decurrens*, *Eucalyptus saligna*, *Acacia melanoxylon*, *Eucalyptus camaldulensis*, *Eucalyptus grandis*, *and Eucalyptus globulus*. Biomass was estimated by measuring diameter at breast height (DBH) for plant diameter ≥ 2.5 cm and plant height≥1.5 m for each species. All data relating to biomass were recorded in the field.

Table 1. Scientific and Family Names of Evaluated Fast Growing Tree Species

| No | Species | Family name | Common name | Local name |
|---|---|---|---|---|
| 1 | *Cupressus lustanica* | *Cupressaceae* | *Mexican white cedar* | *Ye ferengi tside* |
| 2 | *Eucalyptus viminalis* | *Myrtaceae* | *The manna gum* | *White Gum* |
| 3 | *Acacia decurrens* | *Fabaceae* | *Black wattle* | *Ye ferengi Gerar* |
| 4 | *Eucalyptus saligna* | *Myrtaceae* | *Sydney blue gum* | *Saligna-Bahirzaf* |
| 5 | *Acacia melanoxylon* | *Fabaceae* | *Australian blackwood* | *Omedella /Ye ferengi Weyera* |
| 6 | *Eucalyptus camaldulensis* | *Myrtaceae* | *River red gum* | *Key-Baherzaf* |
| 7 | *Eucalyptus grandis* | *Myrtaceae* | *Flooded gum* | *Baherzaf* |
| 8 | *Eucalyptus globulus* | *Myrtaceae* | *Tasmanian bluegum* | *Nechi- Bahirzaf* |

#### *2.2.2. Soil sampling methods*

Soil samples were collected under the sample plots established in each fast-growing tree species plantation. After clearing and removing plant matter and debris from the soil surface, five soil cores were extracted from the centre and the four corners of each plot using a core sampler (4 cm diameter, 20 cm deep, and 250 cm3). The soil cores collected from each plot were pooled, and a relatively homogeneous subsample of approximately 500 g from each plot was placed in a plastic bag for analysis. A total of 90 composite soil samples for organic carbon estimation and 90 samples for bulk density determination were separately sampled with three soil depths of 0-10 cm, 10-20 cm, and 20-30 cm. Soil samples for bulk density analysis were collected separately from each soil depth using a core sampler of 5cm diameter [18].

### 2.2.3. Laboratory analysis

The soil samples for bulk density were oven-dried at ± 105 °C for 48 hrs and analysed following the appropriate procedure. The collected soil samples for organic carbon determination were air-dried and sieved for further analysis were applied for SOC determination [19]. The soil samples for bulk density were oven-dried at ± 105 °C for 48 hrs and analysed following the appropriate procedure. The collected soil samples for organic carbon determination were air-dried, sieved for further analysis, and applied for SOC determination [19].

### 2.2.4. Soil bulk density and Soil Organic Carbon (SOC) analysis

#### 2.2.4.1. Soil bulk density

The soil bulk density was determined in the two soil depths from undisturbed soil samples. According to [18] (Pearson et al., 2005) the bulk density of the soil sample plot was calculated using the following formula:

Soil bulk density= Dry mass of soil (g)/volume of core sampler ($cm^3$) ……Eq.1

#### 2.2.4.2. Soil Organic Carbon

SOC was calculated using the formula developed by [18]

SOC = BD x %C x depth x 100………………Eq.2

Where, SOC = Soil Organic Carbon (Mg ha-1), BD = Bulk Density (g cm-3), Depth of the soil sample (cm), % C = Carbon Concentration

### 2.2.5. Above ground biomass carbon estimation

Measured parameters for biomass carbon assessment were estimated using the following species-specific allometric models. Developed allometric equations were used to generate a reliable estimate of AGB for each studied species, and the models were found to be specifically for each species, as the morphology and range of vegetation cover along the tropics are similar with very low environmental and geographic conditions (Table 2).

Table 2. Adopted Allometric Models for Biomass Estimation of Evaluated Fast Growing Tree Species

| No | Species | Allomertic equations | sources |
|---|---|---|---|
| 1 | *Cupressus lustanica* | $Y= 0.0355 + 0.00003*X^2 \times W$ | Henery.M et al., (2000) |
| 2 | *Eucalyptus viminalis* | $Y=0.0155 \times X^{2.5823}$ | Tandon et al. (1989) |
| 3 | *Acacia decurrens* | $Y =3.1582+0.0337x^2 \times W$ | Hailu (2002) |
| 4 | *Eucalyptus saligna* | $Y=0.069413*(X^{2.1472}) *(W^{0.3129})$ | Schubert et al., (1988) |
| 5 | *Acacia melanoxylon* | $Y =3.1582+0.0337x^2 \times W$ | Zewdi et al., (2009) |
| 6 | *Eucalyptus camaldulensis,* | $Y=0.0155 \times X^{2.5823}$ | Henery.M et al., (2000) |
| 7 | *Eucalyptus grandis,* | $Y=0.069413*(X^{2.1472}) *(W^{0.3129})$ | Tandon et al. (1989) |
| 8 | *Eucalyptus globulus* | $Y= 0.45*(X)^{2.01}*W^{3.41}$ | Hailu (2002) |

*Where, X, Height and w, DBH (diameter at Breast height)*

### 2.2.6. Below ground carbon stock estimation

Below Ground Biomass comprises live roots of biomass which are >2mm diameter, estimated by multiplying AGB by 0.26 as the root to shoot ratio, this is appropriate ratio for tropical region almost with similar climatic conditions and species type for this particular study. [20] and [21]. Below-ground biomass comprises live roots of biomass that are >2mm in diameter, estimated by multiplying AGB by 0.26 as the root-to-shoot ratio. This ratio is appropriate for a tropical region with similar climatic conditions and species types for this particular study [20] and [21].

### 2.2.7. Total Carbon Stock Density Estimation

The total carbon stock density from different carbon pools was calculated using the following formula [18].

$C\ Total = C_{AGTB} + C_{BGTB} + SOC$…………..Eq.3

Where, C Total = Total carbon Stock Density (Mg $ha^{-1}$)

$C_{AGTB}$ = Carbon Stock in Above Ground Tree Biomass (Mg $ha^{-1}$)

$C_{BGTB}$ = Carbon Stock in Below Ground Tree Biomass (Mg $ha^{-1}$)

SOC = Soil Organic Carbon (Mg $ha^{-1}$) soil bulk density=Dry mass of soil (g)/volume of core sampler (cm3).

### 2.3. Statistical Analysis

The collected data was analyzed using SPSS version20 software for statistical analysis. One Way Analysis of Variance (ANOVA) was performed to examine the variations in biomass and soil carbon stock among the species. A post hoc test was used to evaluate the mean differences across the estimated species, and mean separation was conducted using the Tukey Kramers test. The collected data was analyzed using SPSS version 20 software for statistical analysis. One-way analysis of Variance (ANOVA) was performed to examine the variations in biomass and soil carbon stock among the species. A post hoc test was used to evaluate the mean differences across the estimated species and mean separation was conducted using the Tukey Kramers test.

### 2.4. *Biomass carbon stock*

The mean total biomass carbon stock (TBC), above-ground biomass carbon stock, and below-ground biomass carbon stock amounts differed significantly among the studied tree species (F = 5.23; *p*= 0.005). Significantly highest TBC was estimation recorded by *Eucalyptus globulus* (5.70 ± 1.50 Mg ha-1) followed by *Eucalyptus saligna* (*p*= 0.002), *Acacia melanoxylon* (*p*=0.004), respectively. However, there was no significant difference in TBC recorded for the *Cupressus lustanica*, *Eucalyptus viminalis*, *Eucalyptus grandis*, *Acacia decurrens*, and *Eucalyptus camaldulensis* tree (p > 0.05; Table 3).

Table 3: Mean (±standard deviation) biomass carbon (AGBC plus BGBC) carbon stocks (Mg ha−1) for evaluated fast growing tree species.

| No | Species | AGBC (Mg ha$^{-1}$) | BGBC (Mg ha$^{-1}$) | TBC (Mg ha$^{-1}$) |
|---|---|---|---|---|
| 1 | *Cupressus lustanica* | 1.30±0.2$^{c}$ | 0.40±0.4$^{a}$ | 1.70±0.5$^{c}$ |
| 2 | *Eucalyptus viminalis* | 1.00±0.1$^{c}$ | 0.40±0.4$^{a}$ | 1.40±0.3$^{c}$ |
| 3 | *Eucalyptus globulus* | 4.30±1.3$^{a}$ | 1.40±1.4$^{a}$ | 5.70±1.5$^{a}$ |
| 4 | *Eucalyptus saligna* | 2.10±0.89$^{b}$ | 0.40±0.4$^{a}$ | 2.50±0.8$^{b}$ |
| 5 | *Eucalyptus grandis* | 1.00±0.2$^{c}$ | 0.20±0.2$^{a}$ | 1.20 ±0.6$^{c}$ |
| 6 | *Acacia decurrens* | 1.10±0.2$^{c}$ | 0.30±0.3$^{a}$ | 1.40± 0.4$^{c}$ |
| 7 | *Eucalyptus camaldulensis* | 1.50 ±0.2$^{c}$ | 0.20±0.3$^{a}$ | 1.70±0.6$^{c}$ |
| 8 | *Acacia melanoxylon* | 1.48±0.1$^{c}$ | 0.52±0.52$^{a}$ | 2.00±0.55$^{b}$ |

*Note: The letter a,b,c shows significantly difference between species in AGB,BGB, and TBC. The same letters represent no significant difference and different letters show significant difference based on Tukey HSD at 5% significant level.*

#### 2.4.1. *Mean SOC (Mg ha-1) among selected species*

The mean SOC stocks for evaluated tree species under three depths (0-10cm), (10-20cm) and (20-30cm) show significant differences (F = 7.79 *p* = 0.01; Fig. 2) similar to our hypothesis with decreasing rates while increasing soil depth. About 40% of the SOC was contributed by upper topsoil (0-10), and the remaining amount was covered by subsoil (10-20) and (20-30). Mean SOC stocks by depth are given in (Figure 2). The highest significant (*p*= 0.07) mean SOC was recorded for *Casuarina equisetifolia* (89Mg ha-1) while the lowest was recorded for Eucalyptus viminalis (34Mg C ha-1) (Figure 2).

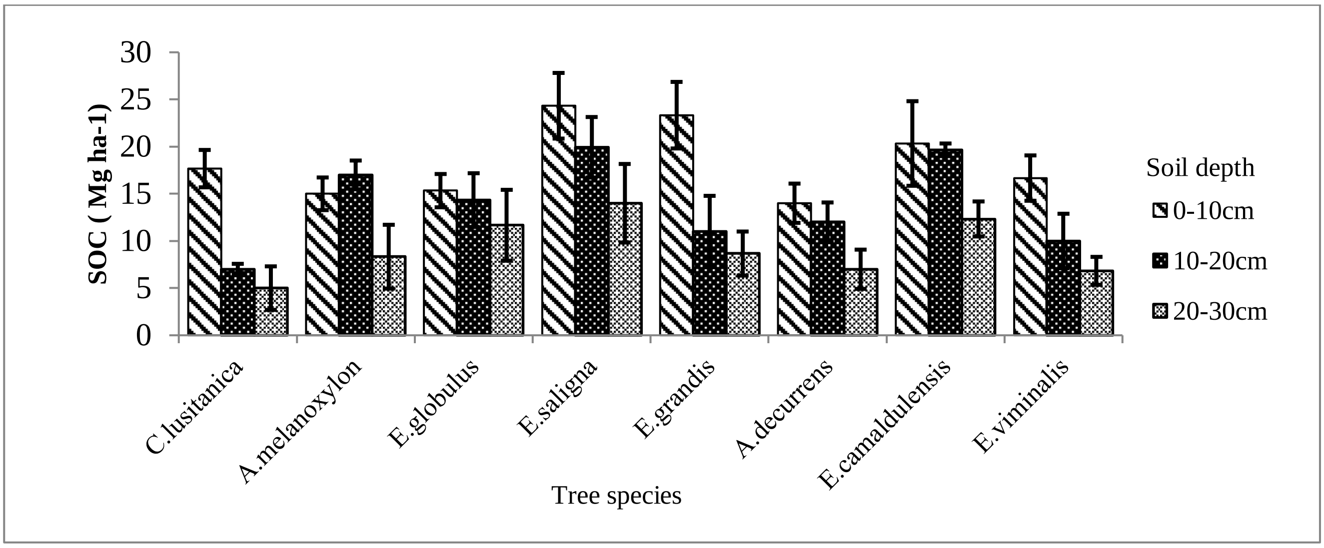


*Figure 2: Mean Soil organic carbon (SOC) (Mg ha-1) under Cupressus lustanica, Eucalyptus viminalis, Eucalyptus globulus, Eucalyptus saligna, Eucalyptus grandis, Acacia decurrens, Eucalyptus camaldulensis, Acacia melanoxylon, fast-growing tree stands along three depths (0-10cm, 10-20cm, and 20-30cm). Error bars represent standard error.*

### 2.5. *Total carbon*

Total carbon stocks (sum of total biomass carbon and SOC 0–30 cm) ranged from 35.4 to 60 Mg ha−1 and the highest mean ecosystem carbon stock was recorded for *Eucalyptus saligna* (62.5Mg C ha$^{-1}$) and the minimum was recorded for *Eucalyptus viminalis* (35.4 Mg C ha$^{-1}$) (Table 3). The mean total carbon density of SOC was significantly higher than biomass carbon stock (p > 0.05) contributing 95.2% for total carbon stock potential of evaluated fast growing tree species.

Total carbon stocks (sum of total biomass carbon and SOC 0–30 cm) ranged from 35.4 to 60 Mg ha−1, and the highest mean ecosystem carbon stock was recorded for *Eucalyptus saligna* (62.5Mg C ha-1), and the minimum was recorded for *Eucalyptus viminalis* (35.4 Mg C ha-1) (Table 3). The mean total carbon density of SOC was significantly higher than biomass carbon stock ($p > 0.05$), contributing 95.2% to the total carbon stock potential of evaluated fast-growing tree species.

Table 4: Mean (±standard deviation) biomass carbon, soil carbon (SOC) and total (total biomass plus SOC 0–60 cm) carbon stocks (Mg ha−1) for evaluated fast growing tree species.

| No | Species | Biomass carbon (Mg $ha^{-1}$) | Total SOC (0-30 cm, Mg $ha^{-1}$) | Total Carbon (Mg $ha^{-1}$) |
|---|---|---|---|---|
| 1 | *Cupressus lustanica* | 1.70±0.5$^{c}$ | 40 ± 1.4$^{b}$ | 41.7 ± 1.9$^{b}$ |
| 2 | *Eucalyptus viminalis* | 1.40±0.3$^{c}$ | 34 ± 2.9$^{b}$ | 35.4 ± 1.8$^{b}$ |
| 3 | *Eucalyptus globulus* | 5.70±1.5$^{a}$ | 41.5 ± 2.6$^{b}$ | 47.2 ± 0.7$^{b}$ |
| 4 | *Eucalyptus saligna* | 2.50±0.8$^{b}$ | 60 ± 10$^{a}$ | 62.5 ± 1.8$^{a}$ |
| 5 | *Eucalyptus grandis* | 1.20 ±0.6$^{c}$ | 44 ± 1.3$^{b}$ | 45.2 ± 4$^{b}$ |
| 6 | *Acacia decurrens* | 1.40± 0.4$^{c}$ | 43.8 ± 1.9$^{b}$ | 45.2± 0.5$^{b}$ |
| 7 | *Eucalyptus camaldulensis* | 1.70±0.6$^{c}$ | 49± 1.3$^{b}$ | 50.7± 1.5$^{b}$ |
| 8 | *Acacia melanoxylon* | 2.00±0.55$^{b}$ | 41.5 ± 1.2$^{b}$ | 43.5 ± 0.9$^{b}$ |

*Note: The letter a,b,c shows significantly difference between species in AGB,BGB, and TBC. The same letters represent no significant difference and different letters show significant difference based on Tukey HSD test at 5% significant level.*

## 3. Discussion

### *3.1. Biomass Carbon Stock*

Estimating the carbon pool is crucial for assessing the role of trees in the global carbon cycle and climate change mitigation. In the present study, results indicate that Eucalyptus globulus, Eucalyptus saligna and Acacia melanoxylon respectively accumulated large amounts of biomass carbon in all plots of the entire experimental trial both in above and below ground biomass, which can be attributed to higher volume and basal area of the species as basal area and volumes positively contributes for biomass expanse [22]. The early growth period of fast-growing tree species is the most critical stage in accumulating high carbon stock; thus, though all species are at the same age in our study trial site, their rate of growing performance and diameter growth rate could be the reason for their variation in their biomass carbon accumulation as all tropical forest tree species extensively differ from one another in their growing property [23]. In the present study, the mean total biomass carbon stock was comparable with some published studies with the same land use system and age of plantation [22].

### *3.2. Soil Organic Carbon Stock*

The mean SOC of species estimated in this study was comparable with other related studies [24],[25]. This study reveals that the SOC among selected tree species showed a remarkably higher carbon stock than other studies in Southern Ethiopia, Wondo genet, [26]. The SOC under *Cupressus lustanica* plantation was lower than our study results [27]. The higher soil organic carbon under mixed stands may be attributed to the higher annual litter fall in mixed stands. This study is in line with [28], [29]. Studies reveal that differences in SOC quantification can be related to sample sizes, sample numbers, and analytical methods. In addition, precise estimation of SOC distributions is further complicated due to variations in SOC contents, poor spatial coverage, and species types. Furthermore, conifer species allocate more total organic matter than fast-growing tree species [30] *Casuarina equisetifolia* accumulate more SOC than the other studied tree species types. The accumulation could be due to the species' different strategies of carbon and nutrient allocation potential [31].

### *3.3. Total carbon stock*

The present study shows that the highest mean total ecosystem carbon stock was recorded for *Eucalyptus saligna*, which is in line with the reports of [32]. Thus, a considerable amount of carbon could be stored in planting fast-growing species by short-term rotation. On the contrary, our study shows lower carbon stock than in India [33]. Tree plantation can significantly promote soil carbon storage in less time than natural vegetation [34]. Therefore, developing countries' specific information is crucial based on plantation contribution to carbon lock [35] (Watson et al., 2000). In addition, plantations can serve as sources of commercial forest products that alleviate the pressure on native forests and sequester carbon. At the same time, they can also be stated as one of the most critical climate change mitigation strategies [36]. In general, this study ascribed the importance of well-managed plantations on the faces of climate change mitigation; carbon stock in different carbon pools could lower atmospheric concentrations of $CO_2$ and increase carbon stock accumulation. Therefore, a well-managed plantation, including site preparation and species selection based on the agroecology of the plantation area, helps in doing so. The plantations in the study area stored a notable amount of carbon stock both in biomass and soil carbon poo contributions of SOC stocks were higher in all studied species than biomass carbon stock proving soil carbon is the largest carbon among all carbon pools. Knowing that Planting fast-growing species has a significant effect on biomass and SOC stock accumulation other than the economic benefit they could provide thus, this study will swell information about the carbon stock potential of plantation of highland areas of Ethiopia.

## 4. Conclusion

This study explored the carbon storage potential of fast-growing tree species in biomass and soil carbon pools under a controlled experimental site in the Northern highland of Ethiopia. The results show that *Eucalyptus globulus*, *Eucalyptus saligna, and Acacia melanoxylon* are recommended species for their high carbon lock potential in biomass and SOC compared to other evaluated fast-growing tree species in the present study. Hence, considering this species while establishing plantations in areas with comparable climatic zones and agroecology would be crucial in their ecological benefit beyond their economic uses. However, additional factors such as site-specific factors, management practices, diseases, pest control methods, and other related aspects need further study before establishing plantations. Furthermore, the present study also ascribed the importance of plantations as carbon management, which in turn contributes to lowering the atmospheric concentration of CO2 and increasing carbon stock accumulation. As a result, selecting fast-growing tree species while designing plantations can store a notable amount of carbon stock, and these potentials should be considered while setting climate change mitigation strategies.

### Author's contribution

Conceptualization, all authors; methodology, M.S. formal analysis, M.S and E.B; writing—review and editing, all authors; visualization, all authors; funding acquisition, T.B. All authors have read and agreed to the published version of the manuscript.

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### Data Availability Statement

Data are available upon request from the corresponding author.

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### Conflicts of Interest

The authors declare no conflict of interest.

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