COMPARATIVE ASSESSMENT OF CARBON STOCK UNDER *EUCALYPTUS GRANDIS* AND *EUCALYPTUS CAMALDULENSIS* STANDS AT KIBRIT PLANTATION FOREST, NORTHWESTERN ETHIOPIA

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ABSTRACT: *Eucalyptus* species are the dominant plantation species with greater economic and environmental values in Ethiopia. Nevertheless, little is known about the carbon stock of *Eucalyptus* species and hence, this study was aimed at estimating the carbon stock of *Eucalyptus grandis* and *Eucalyptus camaldulensis* stands under Kibrit plantation forest. Systematic random sampling was used and a total of 60 plots (10 m×20 m size) were systematically established. Trees ≥ 5 cm Diameter at Breast Height (DBH) were measured. Within each sample plot, (1 m×1 m) subplots were designed for litter and soil sample collection. Species specific allometric equations were used to estimate the tree biomass. Soil organic carbon determination was done using the Walkley Black method. The mean total carbon stock (biomass plus soil organic carbon) was significantly higher ($P< 0.05$) in *E. grandis* (351.72 ± 72.72 t/ha) compared to the adjacent *E. camaldulensis* stand (192.16 ± 24.9 t/ha). The mean total biomass carbon stock was also significantly higher in *E. grandis* (267.78 ± 73.1t/ha) than in *E. camaldulensis* stand (105.52 ± 22.8 t/ha). The mean total soil organic carbon stock was 83.94 ± 1.5 t/ha and 86.64 ± 6.2 t/ha for *E. grandis* and *E. camaldulensis* stands respectively. This study indicated the presence of significant difference in carbon storage potential between the two stands and, therefore, planting *E. grandis* is rewarding in terms of climate change mitigation.

Keywords: Biomass carbon, *Eucalyptus* plantation, Kibrit plantation, Soil organic carbon

INTRODUCTION

Forests store more than 650 billion tons of carbon, 44% in the aboveground biomass, 11% in dead wood and litter, and 45% in the soil globally (Feng et al., 2016). The carbon stock of plantation forest varies with stand age and species. A study by Du et al. (2015) reported a tree biomass carbon stock of 70.1 t/ha in six to eight-year-old eucalyptus stands. Scalenghe et al. (2015) estimated that 550 t/ha, stored in the 50-year-

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old *Eucalyptus camaldulensis* stand in Italy. Plantation forests in Ethiopia store a total of 114.48 t/ha carbon (Metz et al., 2007). Eucalyptus plantations are very efficient at carbon sequestration with average annual fixation rates of 10 ton of carbon per hectare (Marcolin et al., 2002). Plantation forests can make a very significant contribution to a low-cost global climate change mitigation and provide synergy for adaptation and sustainable development, including extending the carbon retention in harvested wood products. Plantation forest has been promoted as a strategy for carbon sequestration under afforestation and reforestation programs as well as Clean Development Mechanisms of the Kyoto Protocol (Smith, 2007). United Nations Framework Convention on Climate Change (UNFCCC) has recognized the importance of plantation forests as a greenhouse gas mitigation options, as well as the need to monitor, preserve and enhance terrestrial carbon stocks (van Kooten, 2000). Carbon sequestration projects in developing nations could receive investments from companies and governments wishing to offset their emissions of greenhouse gases through the Kyoto Protocol's Clean Development Mechanism (Fearnside,1999).

Plantation forestry is an age-old practice widespread in different forms across the diverse agro-ecology of Ethiopia. Plantation forest includes industrial/commercial, wood-lots and peri-urban plantation (Tadesse et al., 2019). Eucalyptus is the dominant genus among plantations in Ethiopia and it is a source of fuelwood, construction material, and income generation for smallholder farmers. According to (FAO, 2011), there are about 55 species of Eucalyptus in the country of which *E. globulus, E. camaldulensis, E. citriodora, E. grandis* and *E. saligna* are widely distributed across the country. Eucalyptus covers 58% (500,000 ha) of the total plantation followed by *Cupressus* (29%), *Juniperus procera* (4%) and *Pinus patula* (2%) (Gil et al., 2010). *Eucalyptus* species are superior in their growth performance compared to other exotic and native species which encourages farmers to plant large numbers on small areas of land and manage to yield a variety of products (Dessie et al., 2019; Tesfaw et al., 2021).

Although extensive studies have been done on the importance and management of eucalyptus in Ethiopia (Mekonnen et al., 2007; Gil et al., 2010; Dessie et al., 2019), information on its carbon stock potential is lacking. Moreover, prior studies have indicated that carbon stock potential of eucalyptus varies among species (Madeira et al., 2002; Keith et al., 2012). To understand the significance of eucalyptus species for climate change mitigation, carbon stock quantification needs to be considered. Therefore, this study was initiated with the objective to estimate and compare the carbon stock in *E. camaldulensis* and *E. grandis* stands of Kibrit Plantation Forest.

MATERIALS AND METHODS

Study area

This study was conducted in Kibrit Plantation Forest Awi Zone, Amhara Region, Ethiopia (Figure 1). It is situated between 10°56'40"N and 10°57'10"N latitude and 36°31'50"E and 36°32'20"E longitude.

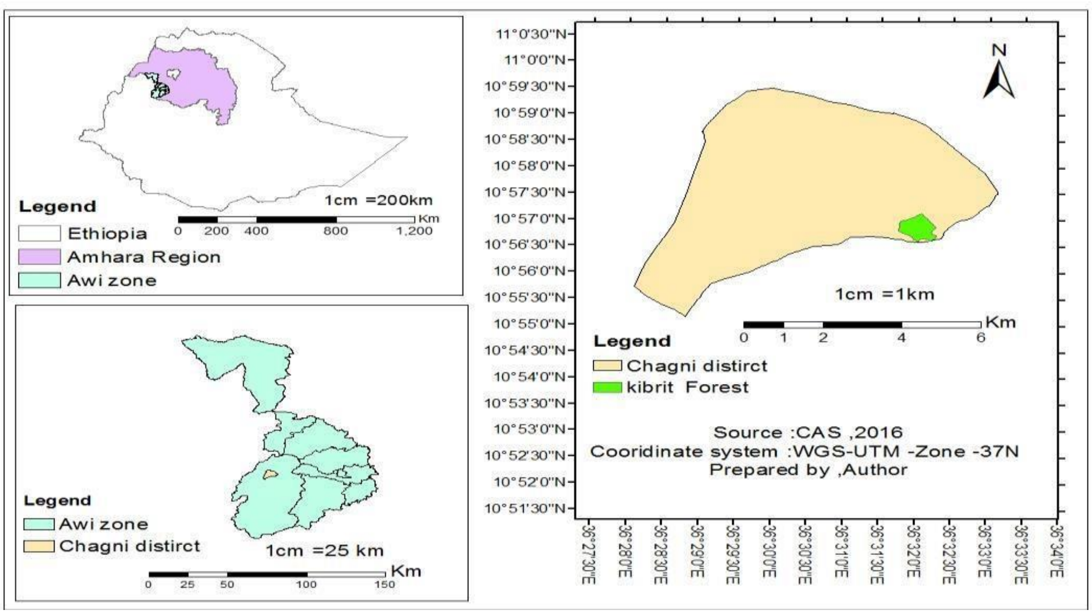

Figure 1. Map of Ethiopia showing the study area.

The study area is characterized by a unimodal rainfall distribution with the rainy season occurring from June to September and often continuing usually continued with a less pronounced wet period up to October. According to the weather data obtained from Chagni Meteorological Station, the mean annual rainfall and monthly temperature of the study area range from 1300 mm to 1800 mm and from 18.6°C to 28°C, respectively. Elevation ranges from 1627 m to 1793 m.a s.l The soil type of the study area is grouped under

Nitosols. Kibrit Plantation Forest covers an area of 57 ha and consists of *Eucalyptus grandis* (10 ha), *E. camaldulensis* (8 ha), *Grevillea robusta* (12 ha), and *Pinus patula* (11 ha) stands. Both *E. grandis* and *E. camaldulensis* are 28-year-old stands and were selected for this study due to similar climatic, topographic, edaphic, age and similar silvicultural management intervention systems.

Eucalyptus grandis is an evergreen tree 40-55 m tall, growing to a diameter of 2 m; with an excellent straight trunk and wide-spreading thin crown, and self-pruning of branches in plantations. It grows successfully in Moist and Wet *Weyna Dega* Agro climatic zones of Ethiopia and performs well on light and medium neutral to acid soils that are free draining and moist up to 1700-2500 m above sea level (Tesema, 2007).

Eucalyptus camaldulensis is a tall evergreen tree to 30 m, deeply branched but with a long straight pole. It is widely distributed in its native Australia and is one of the first Eucalyptus species used elsewhere. It grows well in semi-arid regions and tolerates a long dry season as well as some salinity. It does well in deep silt or clay soil in Dry and Moist *Kolla* Agro climatic zones up to 1,200 - 2,800 m a.s.l. (Tesema, 2007).

Sampling techniques

Systematic random sampling technique was employed and a total of 60 sample plots (30 for each stand) with 45 m distance between plots were selected using pragmatic approach. Considering the shape of the two stands, 16 transect lines (10 for *E. camaldulensis* and 6 for *E. grandis* stand) were laid with the space of 45 m between stands. Rectangular sample plots with an area of 200 m^2 (10 m×20 m) were used for the measurement of DBH and total height. Moreover, 1 m×1 m sub-plots were used for litter and soil sample collection. Soil samples were collected from the center and corners of each sub-plot (Figure 2).

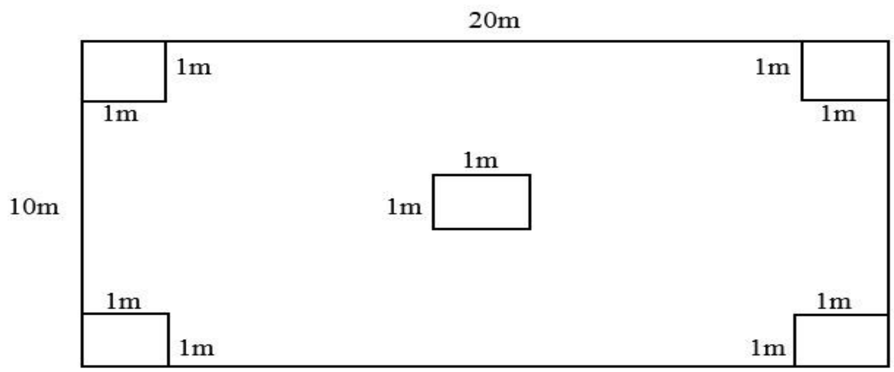

Figure 2. Sample plot design.

All trees of *E. grandis* and *E. camaldulensis* with DBH ≥5 cm in main plots were measured using 50 cm graduated caliper and Laser Ace 1000 rangefinder for DBH and height, respectively. DBH was measured from two perpendicular directions and an average value was recorded (Snowdon et al., 2002).

Litter sampling

The dead leaves, branches, twigs, flowers, and dead wood with a diameter of less than 10 cm was considered as litter and a total of 180 litter samples (90 for each stand) were collected from 3 sub-plots chosen randomly using the lottery method out of 4 sub-plots. Samples were weighed, coded and then evenly mixed to prepare composite samples. From each sample 100 g of composite samples were taken to the laboratory for the determination of oven dry mass (Pearson et al., 2007). Composite litter sub-samples, were air-dried for one day and then, oven-dried at 70°C for 24 hours to determine constant oven dry mass (Ullah and Al-Amin, 2012; Negash and Starr, 2015). The samples were weighed, grinded using mortar and pestle, then sieved by 2 mm mesh. The Loss on Ignition (LOI) method was used to estimate the percentage of carbon in the litter (Pearson et al., 2005). From the oven dried grinded sample, 3.00 g of each litter subsamples were taken in pre-weighed crucibles, and then put in the furnace for two hours to ignite. Then, the crucibles were cooled slowly for two hours inside the furnace. After cooling, the crucibles along with ash were weighed and litter organic matter fraction was calculated (Allen et al., 1986).

Soil sampling

Soil samples from three sub-plots were chosen randomly using the lottery method from four sub-plots at the corners of sample plots and the center. A total of 540 soil samples were collected across the study plots from three soil depths (0–20 cm, 20–40 cm, and 40–60 cm) using soil Auger. All wet soil samples were coded and evenly mixed per sample plot to prepare 180 composite samples. From each sample 500 g was taken to Debre-Markos Soil Laboratory Center for the analysis of carbon content. Bulk density samples were collected using core sampler with a volume of 392.5 cm^3 (20 cm length and 5 cm diameter) and samples were taken to the laboratory for the determination of soil bulk density. Soil samples were oven-dried at 105°C for 48 hours and weighed (Pearson et al., 2007) and bulk density was determined following the core method (Blake and Hartge,1986). Soil organic carbon content analysis was done following the Walkley and Black method (Schnitzer, 1982).

Carbon stock estimation

Aboveground biomass carbon stock estimation

Locally developed allometric equations give reliable biomass estimate than generic equation and hence the aboveground biomass of *E. grandis* stand was calculated using species specific allometric equation developed by Fantu et al. (2007) (Equation 1) and that of *E. camaldulensis* stand was calculated using an allometric equation developed by Hailu (2002) (Equation 2).

$$logY = -1.381 + 2.893(logDBH) \ldots\ldots\ldots\ldots\ldots\ldots \ Equation\ 1$$

$$AGB = 0.0155 * (DBH^{2.5823}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots. \ Equation\ 2$$

Where, logY = aboveground biomass (kg/tree), AGB = aboveground biomass (kg/tree), DBH = diameter at breast height (1.3 m).

Belowground biomass was estimated using IPCC root –to- shoot ratio value of 0.26 for tropical dry forests (IPCC, 2006) as follows.

$$BGB = AGB * 0.26 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 3$$

Where, BGB = belowground biomass (kg/tree), AGB = aboveground biomass (kg/tree) and 0.26 is conversion factor.

The biomass was converted to units of carbon stock by multiplying by a carbon fraction of 0.5 (Pearson et al., 2007).

Litter biomass and carbon stock estimation

According to Pearson et al., (2005), estimation of the amount of biomass in the litter is calculated as:

$$LB = \frac{Wfield}{A} * \left(\frac{Wsubsampledry}{Wsubsamplefresh}\right) * \frac{1}{10000} \quad ---- \quad Equation\ 4$$

Where, LB = Litter biomass (t/ha); Wfield = mass of wet field sample of litter sampled within an area of size 1m^2 (g);

A = size of the area in which litter samples were collected (ha);

Wsubsample (dry) = mass of the oven-dry subsample of litter taken to the laboratory to determine moisture content (g)

Wsubsample (fresh) = mass of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g).

Carbon stock of litter was then calculated by multiplying the biomass of litter per unit area with the percentage of carbon determined for each sample.

$$LBC = LB * \%C \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. Equation\ 5$$

Where, LBC= total carbon stocks in the litter (t/ha) and %C = carbon fraction which was determined in the laboratory.

Soil organic carbon stock estimation

According to Pearson et al. (2007), the soil organic carbon was calculated as follows:

$$SOC = BD * SD * \%C * 100 \ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots Equation\ 6$$

Where: SOC = soil organic carbon (t/ha), BD = bulk density (gcm^{-3}), SD = soil depth (cm) and %C = carbon fraction and expressed as a decimal fraction.

The total carbon stock density was calculated by adding the carbon stock densities of the individual carbon pools using Pearson et al. (2005) formula as follows;

$$CT = AGC + BGC + CL + SOC \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Equation\ 7$$

Where,

CT= Carbon stock density for all pools (ton/ ha),

AGC= Carbon in above -ground tree biomass (ton C/ ha),

BGC = Carbon in below-ground biomass (ton C/ ha)

CL= Carbon in dead litter (ton C/ ha) and

SOC = Soil organic carbon (ton C/ha).

Data analysis

Tree DBH, total tree height, wet and oven dry mass of soil and litter samples were analyzed using Statistical Package for Social science (SPSS version 23). Prior to the statistical test, all data were subjected to the Kolmogorov–Smirnov test to check normality. Independent sample t- test was used to compare the mean carbon stock of the two plantation stands. A 95% confidence level was used to evaluate the statistical tests.

RESULTS

Stand characteristics

The mean DBH was insignificant between stands whereas height, basal area and stem per hectare were significant ($P< 0.05$). The mean basal area of *E. grandis* was higher than *E. camadulensis* by a factor of 1.1 while its number of stems per hectare was relatively lower (Table 1).

Table 1. Stand characteristics of *E. grandis* and *E. camadulensis* (Mean ± standard deviation)

Stand characteristics	*E. grandis* (n=30)	*E. camaldulensis* (n=30)	*P-value*
DBH (cm)	29.6 ± 2.3	28.3 ± 2.3	0.052
H (m)	34.4 ± 1.0	24.7 ± 1.7	0.037
BA (m2ha-1)	35 ± 0.3	32 ± 0.1	0.023
Stem/ha	1507 ± 18	1555 ± 16	0.000

Carbon stock

There were significant differences in total carbon, AGC, BGC and SOC between the stands with significantly higher values of total carbon, AGC and BGC in *E. grandis* and a significantly higher value of SOC in *E. camadulensis*. On the other hand, there is no significant difference between the stands for litter carbon stock (Table 2).

Table 2. Mean ± standard deviation carbon stock of the different carbon pools of *E grandis* and *E camaldulensis* stands (30 plots each)

	Mean C (t/ha) of the different Carbon pools				
Plantation stands	AGC	BGC	LC	SOC	Total
E. grandis	212.50 ± 58	55.26 ± 15.1	0.02 ± 0.00	83.94 ± 1.52	351.72 ± 72.72
E. camaldulensis	83.73 ± 18.1	21.77 ± 47	0.02 ± 0.00	86.64 ± 6.23	192.16 ± 24.9
P value	0.000	0.000	0.079	0.000	0.000

DISCUSSION

Although the two stands belong to the same age, similar silvicultural management system and agro-ecology, their height, basal area and stem number were different. This difference might be, due to the difference in species characteristics. Silvicultural management system and agroecology could result in differences in the same species. Alem et al. (2015) recorded a height of 16.9 ± 5.3, basal area of 5.3 ± 0.03 and stem/ha of 822 ± 244 for a 27-year-old *E. camadulensis* stand in southwest Ethiopia which is quite smaller compared to our results.

Eucalyptus grandis stand stored a substantial amount of carbon than *E. camaldulensis* stand. The variation may be due to difference in aboveground tree biomass allometric equation used. There was no significant difference in litter carbon stocks between the two stands. The mean biomass carbon stock of *E. grandis* (267.78 t/ha) and *E. camaldulensis* (105.52 t/ha) was higher than the mean biomass carbon stock of Eucalyptus plantations (92.26 t/ha) in Ethiopia (Metz et al., 2007). Moreover, the mean aboveground carbon stock of *E. grandis* stand was higher than the mean aboveground carbon stock of plantation forests reported in Woody Biomass Inventory Strategic Planning Project (WBISPP) in Ethiopia (WBISPP, 2004). However, the mean aboveground carbon stock of *E. camaldulensis* stand was less than that reported in WBISPP (2004). This variation may be attributed to the difference in the allometric equations applied, silvicultural management system, climate and soil type of the plantation stands. Carbon sock estimation using species specific- allometric equation provides better and relatively reliable results than generic equation.

CONCLUSION

This study indicated that *E. grandis* and *E. camaldulensis* species stored substantial amount of carbon in their biomass (aboveground, belowground, litter and soil). *E. grandis* had stored enormous amount of total carbon than *E. camaldulensis*. Thus, planting *E. grandis* would be encouraging compared to *E. camaldulensis*. Overall, the species can be considered in plantation developments for climate change mitigation.

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