COMPARATIVE ASSESSMENT OF CARBON STOCKS OF *EUCALYPTUS GRANDIS* AND *EUCALYPTUS CAMALDULENSIS* STANDS AT KIBRIT PLANTATION FOREST , AWI ZONE, AMHARA REGION, ETHIOPIA

M.Sc. THESIS

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HAWASSA UNIVERSITY, WONDO GENET, ETHIOPIA

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A THESIS SUBMITTED TO THE

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FOREST RESOURCE ASSESSMENT AND MONITORING

JUNE, 2018

APPROVAL SHEET-I

This is to certify that the thesis entitled "Comparative Assessment of Carbon Stocks of *Eucalyptus grandis* and *Eucalyptus camaldulensis* stands at Kibrit Plantation Forest, Awi Zone, Amhara Region, Ethiopia" is submitted in partial fulfilment of the requirements for the degree of Master of Science with specialization in Forest Resource Assessment and Monitoring, Wondo Genet College of Forestry and Natural Resources, has been carried out by Sewagegn Sahilu Taye ID No. MSc/FrAm/Rooo14/09, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence here by can submit the thesis to the department.

Dr.Yemiru Tesfaye ____________________ ____________

Name of main supervisor signature date

APPROVAL SHEET-II

We, the undersigned, members of the board of examiners of the final open defense by Sewagegn Sahilu Taye have read and evaluated his thesis entitled "Comparative Assessment of Carbon Stocks of *Eucalyptus grandis* and *Eucalyptus camaldulensis* stands at Kibrit Plantation Forest, Awi Zone, Amhara Region, Ethiopia" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfilment of the requirements for the degree of Master of Science in Forest Resource Assessment and Monitoring.

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DECLARATION

I, Sewagegn Sahilu Taye hereby declare that this M.Sc. thesis entitled "Comparative Assessment of Carbon Stocks of *Eucalyptus grandis* and *Eucalyptus camaldulensis* stands at Kibrit Plantation Forest, Awi Zone, Amhara Region, Ethiopia" is my original work and has not been presented for a degree in any other university, and all resources material used in this thesis have been duly acknowledged.

Sewagegn Sahilu Taye ______________________ Date_______________________

ABBREVIATIONS /ACRONYMS

AGB	Aboveground Biomass
AGBC	Aboveground Biomass Carbon
AGC	Aboveground Carbon
BEF	Biomass Expansion Factor
BGB	Belowground Biomass
BGBC	Belowground Biomass Carbon
BGC	Belowground Carbon
C	Carbon
CDM	Clean Development mechanism
CRGE	Climate Resilience Green Economy
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization
GHGs	Greenhouse Gases
GIS	Geographic Information System
GPS	Global Positioning System
IPCC	Intergovernmental Panel on Climate Change
LB	Litter Biomass
LBC	Litter Biomass Carbon
LOI	Loss on Ignition

SOM	Soil Organic Matter
SPSS	Statistical Package for Social Science
TBC	Total Biomass Carbon
TCS	Total Carbon Stock
UNFCCC	United Nation Framework Convention on Climate Change
UNREDD	United Nations Reducing Emissions from Deforestation and Degradation
WBISPP	Woody Biomass Inventory Strategic Planning Project

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Comparative Assessment of Carbon Stocks of *Eucalyptus grandis* and *Eucalyptus camaldulensis* stands at Kibrit Plantation Forest, Awi Zone, Amhara Region, Ethiopia

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ABSTRACT

*In Ethiopia, plantation forests have been widespread in different diverse agro-ecologies of the country and known to provide various products and ecosystem services especially for smallholder farmers. While a few studies have been conducted on carbon stock of plantation forests in different regions of Ethiopia, there is no such study on Eucalyptus camaldulensis and Eucalyptus grandis stands at Awi Zone, Amhara Region, Ethiopia, where those stands are common plantation species. The overall objective of this study was to estimate the carbon stock of Eucalyptus grandis and Eucalyptus camaldulensis stands at Kibrit Plantation Forest, Awi Zone, Amhara Region, Ethiopia. For this study, to collect field data systematic random sampling method was applied. A total of 60 plots (10m*20m) were systematically established for inventory of trees in both plantation stands. All trees ≥5cm DBH and height were measured. Within each sample plot, (1m*1m) designed subplots were used to collect litter and soil samples. Species specific allometric equations were used to estimate the tree biomass and belowground biomass was estimated using root to shoot ratio default value. Soil organic carbon content analysis, Bulk density and litter moisture content determination was done at laboratory. To analyze the data, Statistical Package for Social Science (SPSS) version 20 was used and all statistics were evaluated at 95% confidence level. In this study, the mean total carbon stock (biomass plus soil organic carbon, 0-60 cm) was significantly higher in Eucalyptus grandis (351.76±71.2 t/ha) than in adjacent Eucalyptus camaldulensis stand (192.24±27.9 t/ha). The mean total biomass carbon stock was significantly higher in Eucalyptus grandis (267.82±73.1t/ha) than (105.52±22.8 t/ha) in Eucalyptus camaldulensis stand. While, the mean total soil organic carbon stock of Eucalyptus grandis stand was (83.94±1.7t/ha) and for Eucalyptus camaldulensis stand (86.72±6.6 t/ha). This study indicated that, presence of great significant difference in carbon storage potential between both stands and estimation of biomass carbon stock using species specific equation gives better estimates. Finally, data of current study can be used as a baseline data to make inferences about the carbon storage potential of Eucalyptus grandis and Eucalyptus camaldulensis species in areas where the study was conducted.*

Key words*: Biomass carbon, Chagni district, Eucalyptus plantation, Soil Organic Carbon,*

1. INTRODUCTION

1.1 Background

Nowadays, protecting the carbon stock in existing forests and getting the new through plantation forests becomes important measure to enhance the carbon sequestration capacity in the terrestrial ecosystems and to reduce the concentration of CO_2 from the atmosphere (Lal, 2005). According to Kooten (2000), forests offer two main options to reduce the concentration of carbon dioxide; First volume of atmospheric carbon dioxide may be reduced by increasing forest biomass and achieved through an expansion of forests either by planting currently un-forested land, or by allowing the existing forests to accumulate higher biomass. Second main approach is to utilize forests directly as a source of raw materials for energy production which is considered as carbon neutral energy source.

Plantation forests have been promoted as a strategy for carbon sequestration under afforestation and reforestation programs as well as under the Clean Development Mechanisms of the Kyoto Protocol (Smith *et al.*, 2007). According to Carle and Holmgren (2008), plantation forests are defined as “those forests predominantly composed of trees established through planting and/or after deliberate seeding of native or introduced species”. Plantation forests can make a very significant contribution to a low-cost global climate change mitigation and provides synergy for adaptation and sustainable development, including extending the carbon retention in harvested wood products, product substitution, and biomass production to meet society’s needs for timber and energy (Smith *et al*.,2007).

In Ethiopia, plantation forestry is an old-aged practice, which is widespread in different forms in the diverse agro-ecologies of the country. Existing common plantation forest types include industrial plantation, home and farm plantations, agroforestry plantation and environmental plantations (Kanninen, 2010). These plantation forests are dominated by

Eucalyptus species and known to provide mainly fuel wood, construction material and income generation for smallholder farmers (Teketay, 2000). Eucalyptus plantations in Ethiopia are common particularly as smallholder woodlots and farm boundaries, since they are fast growing, require minimum care, grow in wide ecological zones and poor environments, coppices after harvest, and resist environmental stress and diseases (Mekonnen *et al*., 2007). Eucalyptus species are superior in their performance to other exotic and native species, thus farmers plant large numbers on small areas of land and manage them to yield a variety of products (Teketay, 2000).

In Amhara region, particularly Awi zone owns large quantity of eucalyptus plantations. Some of the common eucalyptus species which are well adapted and widely planted in this area includes; *Eucalyptus globulus, Eucalyptus camaldulensis* and *Eucalyptus grandis.* Most of the community in Awi zone is dependent on eucalyptus plantations for fuel wood, construction material and income generation especially for poor farmers.

1.2 Statement of the problem

Plantation forests are one of the climate change mitigation strategies which Ethiopia proposed on its readiness preparation proposal (Wehkamp *et al*., 2015). Properly to understand the significance of plantation forests for climate change mitigation requires, quantification of reliable biomass estimates using species specific allometric equations as well as identification of carbon storage potential species among the existing plantation forests. In Ethiopia there is no well-organized and documented carbon stock study of plantation forests at species level, except a few general studies as a whole using generic equations. But, using of generic allometric equation as a whole gives unreliable carbon stock estimates, due to tree species and forest stand differ in architecture, wood gravity and silvicultural management system (Henry *et al*., 2011).

In Amhara Region particularly in Awi zone, *E.camaldulensis* and *E. grandis* are some of the common species which are well adapted and widely planted by farmers and governmental organizations. If these species are supported by research activities, they have a potential value in bringing individual households into current emerging carbon credit marketing system in addition to their direct economical contribution. However in this area, there is no research activity conducted on quantification of carbon stocks of such plantation species using species specific equations. Therefore, this study was intended to estimate the carbon stock of *E. camaldulensis* and *E. grandis* stands at Kibrit Plantation Forest, Awi Zone, Amhara Region, Ethiopia.

1.3 Objectives of the study

1.3.1 General objective

The general objective of the study was to estimate the carbon stock of *Eucalyptus grandis* and *Eucalyptus camaldulensis* stands at Kibrit Plantation Forest, Awi Zone, Amhara Region, Ethiopia

1.3.2 Specific objectives

- To estimate the biomass carbon stock of *Eucalyptus grandis* and *E.camaldulensis* stands at Kibrit Plantation Forest
- To estimate the soil organic carbon stock of *Eucalyptus grandis* and *E.camaldulensis* stands at Kibrit Plantation Forest
- To compare the biomass and soil organic carbon stocks of *Eucalyptus grandis* and *E.camaldulensis* stands at Kibrit Plantation Forest

1.4 Research questions

- How much is the current biomass carbon stock of *E. grandis* and *E.camaldulensis* stands at Kibrit Plantation Forest?
- How much is the current soil organic carbon stock of *E. grandis* and *E.camaldulensis* stands at Kibrit Plantation Forest?
- Is there a significant difference between *E. grandis* and *E.camaldulensis* stands of current biomass and soil organic carbon stocks at Kibrit Plantation Forest?

1.5 Significance of the study

This study investigated the carbon stock of *E.grandis* and *E. camaldulensis* stands at Kibrit Plantation Forest, in Awi Zone, Amhara Region, Ethiopia. So, it provides information for researchers and stake holders to understand the role of carbon storage potential of *E.grandis* and *E.camaldulensis* species in climate change mitigation. From this study, quantified reliable carbon stock may be used as important source of data for regional and global data sets such as: CDM (Clean Development Mechanism), REDD+ (Reducing Emission from Deforestation and Forest Degradation and through forest conservation, sustainable forest management and enhancement of carbon stocks) and voluntary carbon markets. The study has also a contribution to the conservation of forest resources and promotes the ecosystem services they provide to the local communities in addition to their direct economic benefit.

2. LITERATURE REVIEW

2.1 Definition and components in plantation forestry

Many researchers have struggled to define plantation forest at different times due to some ambiguous terms such as; afforestation, plantation, man-made, Artificial (Evans, 1992). Del Lungo and Carle (2006) defines plantation forests as 'forests of introduced species and in some cases native species, established through planting or seeding, with few species, even spacing and/or even aged stands'. This definition includes industrial plantations, small-scale home and farm plantations, agroforestry plantations and plantations established to achieve ecological objectives, such as soil protection and wildlife management (Kanninen, 2010). The all-inclusive and widely accepted definition of plantation forest is the definition which is given by Carle and Holmgren (2008) "those forests predominantly composed of trees established through planting and/or after deliberate seeding of native or introduced species". The main components of plantation forests are industrial plantation, Home and farm plantations, Agroforestry plantation, Environmental plantations and Managed secondary forests with planting (Kanninen, 2010).

2.2 Plantation forest in the tropics and Ethiopia

Plantation forest has intensified in recent years and continues to do so, especially in tropical countries. In these regions plantation forest shows faster growth and rotation age is as short to give high yield as compared to other regions (Paquette and Messier, 2010). Globally, area of plantation forests has increased over the past decade, representing 7% of the global forest area, and the relative rate of annual expansion has been 2% (Harvey *et al*., 2014). Most of the plantation forests in the tropics have been planted in the form of industrial monocultures involving a limited number of species which are exotic to most of the areas where they are cultivated (Plath *et al*., 2011).

Plantation forestry in Ethiopia is an old-aged practice, which is widespread in different forms in the diverse agro-ecologies of the country. Common plantation forest types include industrial plantation, home and farm plantations, agroforestry plantation and environmental plantations (Nune *et al*., 2013). Most of the plantation forests are dominated by eucalyptus species and known to provide mainly fuel wood, construction material and income generation for smallholder farmers (Teketay, 2000). Main species composition in these plantations are, *Eucalyptus* species covering 56% and *Cupressus lusitanica* covering 32 % of the total area, followed by *Juniperus procera* (2%), *Pinus patula* (1.8 %), and other species (8 %). Eucalyptus are fast-growing and preferred species plantations; they are widely grown in Ethiopia and thus are of great commercial importance (Teketay, 2000).

2.3 Historical back ground of Eucalyptus introduction to Ethiopia

Eucalyptus is one of the diverse genuses of flowering plants in the world. It belongs to the Family Myrtaceae (subfamily Myrtoideae) and comprises about 800 species. The term eucalyptus is derived from the two Greek words, "eu" meaning "well," and "kaluptos" meaning covered. Thus, eucalypts means true cover, well-covered (Liu *et. al*, 2010).

In Ethiopia, planting of eucalyptus has a long history dating back to extensive plantations surrounding urban centers in the late 1800s (Jagger and Pender, 2000). In Ethiopia Eucalyptus was introduced during the reign of Emperor Menilek II in 1895 (Edwards *et al.*, 1995). Since then, eucalyptus has expanded over large parts of Ethiopia, becoming an integral part of most of the Ethiopian farming system and one of the Ethiopian most important tree resources (Pohjonen and Pukkala, 1987).

Jagger and Pender (2000) also pointed out that planting of eucalyptus trees in Ethiopia has expanded from State owned plantations to community woodlots, and households suffering from severe wood shortages, water scarcity, erosion and land degradation. The fast growing and resilient eucalyptus species perform well than most indigenous woodland and forest tree species and most crops. In Ethiopia, growing eucalyptus helps local communities to diversify and increase their farm income, and hence, farmers prefer to plant eucalyptus for household use, sell, soil conservation and gully stabilization, to drain marshy land, and ensure land tenure security (Mekonnen *et al.* 2007).

2.4 Eucalyptus plantation in Ethiopia

The genus Eucalyptus (common name Eucalyptus) are widely planted all across Ethiopia including on large areas of land previously allocated to food production (Liang *et al*., 2016) and it covers about 506,000 ha (Teketay, 2000). According to Edwards *et al*. (1995), in Ethiopia there are about 55 species of Eucalyptus and from these most widespread are *Eucalyptus globulus, Eucalyptus camaldulensis, Eucalyptus citriodora, Eucalyptus grandis and Eucalyptus saligna.*

The major factors driving farmers to plant Eucalyptus in Ethiopia are: increasing demand for fuel wood and construction material, unavailability of wood on farm, its high rate of biomass production, ease to cultivate and wider adaptability, non-palatability to livestock (Mekonnen *et al.* 2007). According to Hailu *et al*. (2003), Eucalypts are highly preferred and appreciated by local people than other indigenous or exotic species, because Eucalyptus perform a high biomass production and a rapid growth, produce valuable construction poles and fuel wood in a reasonable short period of time for the local market, thus providing cash income for local village communities.

This being the reality, there are arguments for and against planting Eucalyptus in Ethiopia which are mounting from time to time (Teketay, 2000). Arguments for planting of Eucalyptus include: Eucalyptus appears to fill the gap created by the indigenous forest species (Zegeye, 2010); Availability and easy propagation of seeds, tolerance to wide environmental conditions, fast growth, high coppicing ability, good economic returns, and tolerance to pests and diseases (Teketay, 2000); Eucalyptus can supply wood in good quantities within 4-5 years from comparatively small areas of land (Teketay, 2000); Eucalyptus plantations can help to control soil erosion and improve soil fertility (Teshome ,2009) and foster the regeneration of native woody species provided that there is ample seed source in the vicinity (Lemeneh and Teketay, 2004).

Arguments against planting Eucalyptus include: Depletion of soil water and nutrients, allelopathic effects on native flora, provision of inadequate food and habitat for wildlife and unsuitability for erosion control (Zegeye, 2010). But these negative impacts can be minimized provided that the choice of species and site as well as the management of the stands are appropriate (Moges, 1998).

2.5 Plantation forests for climate change mitigation

Carbon dioxide (CO_2) is a major GHG and its concentration in the atmosphere is believed to be accelerated by human activities such as burning of fossil fuels and deforestation (Metz *et al*., 2007). To reduce CO_2 from the atmosphere, the two key activities are: reduction of anthropogenic emissions of CO_2 and storing of the atmospheric carbon in the biosphere using land use systems such as reforestation and afforestation (Nair *et al*., 2009). Globally forests are storing more than 650 billion tons of carbon, 44% in the biomass, 11% in dead wood and litter, and 45 % in the soil (Feng *et al.*, 2016). 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 (Kooten, 2000). According to Kooten (2000), plantation forests offer two main options to climate change mitigation: first the volume of atmospheric CO_2 may be reduced by increasing forest biomass (above and below-ground biomass, deadwood and litter) and achieved through an expansion of forests either by planting currently un-forested land, or by allowing the existing forests to accumulate higher biomass. Second main approach is to utilize plantation forests directly as a source of raw materials for energy production which is considered as carbon neutral energy source. According to Harvey *et al*. (2014), plantation forestry is the important practice for climate change mitigation especially in the tropics, where the carbon sequestration potential is high and successful implementation requires knowledge of the role of species identity and diversity on the carbon accumulation of plantations. However, there is a large variation in the carbon sequestration potential of different plantation species and there are varying estimates of the carbon sequestration rates of common plantation species (Sharma *et al*., 2011).

Plantation forests can make a very significant contribution to a low-cost global climate change mitigation portfolio that provides synergy with adaptation and sustainable development, including extending carbon retention in harvested wood products, product substitution, and biomass production to meet society's needs for timber, fiber, and energy (Smith *et al*.,2007). Since plantation forests are a cost-effective means of sequestering carbon and countries that have a large forest sector are interested in C credits related to reforestation, and those with large tracts of agricultural land are interested in afforestation as a means for achieving some of their agreed upon carbon dioxide emissions reduction (Sedjo *et al*.,1995). According to Fearnside (1999), plantation forest 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.

2.6 Carbon stock potential of plantation forests

Carbon stock is defined as total carbon stored (absolute quantity) in terrestrial ecosystems at specific time, as living or dead plant biomass (above and below-ground) and in the soil, along with usually negligible quantities as animal biomass (Moges *et al*., 2010). Various studies have shown that different forest ecosystems have different biomass and carbon stock potentials (Nair *et al.*, 2009). This variability is mainly due to the species composition, growth speed, age, geographical location of the system (Jose, 2009), previous land use (Mutuo *et al*., 2005), climate, soil characteristics, crop-tree mixture, site productivity and management practices (Montagnini and Nair, 2004).

Tropical plantation forests have important role for carbon stock in a much higher quantity than any other biome (Bracmort and Gorte, 2009). Studies on carbon stock in tropical forests have been carried out by several researchers, either measured directly based on destructive sampling in experimental plots (Miyamoto *et al*., 2007) or estimated based on volume data of forest inventories at one occasion (Brown *et al*., 1989). However, forest biomass and carbon stock may be dynamic and changes occur continuously at individual tree and stand levels throughout time due to loss of carbon during deforestation caused by human activities and accumulation of carbon during regrowth of forests (Miyamoto *et al*., 2007). It is estimated that, the carbon stored globally in the forest biomass amounts to 2,40,439 Mega ton with an average carbon density of 71.5 ton/ha and a recent estimate indicates that tropical forests account for 247 Giga ton vegetation carbon, of which 193 Giga ton is stored above ground (Saatchi *et al*., 2011). According to Moges *et al*. (2010), Ethiopia's forest resource store an estimated 2.76 billion tons of carbon, which playing a significant role in the global carbon balance. Among the plantation forests, Eucalyptus plantations are very efficient at carbon sequestration with average annual fixation rates of 10 ton of carbon per hectare and even when considering the CO_2 produced when Eucalypts are used for energy in the form of charcoal, they have a positive net carbon balance (Marcolin *et al.,* 2002).

In Ethiopia, according to WBISPP (2005) study, the mean aboveground carbon stock of plantation forest is 123 t/ha. But, estimation was done using global level generic allometric equation which is developed by Brown (1997). In Ethiopia, according to the Metz *et al*. (2007), the total carbon stock of plantation forest is 114.48 t/ha (AGC=74.41, BGC=20.09 and SOC=19.78). From this amount, Eucalyptus plantation forests share excluding the dead wood and litter biomass the mean biomass carbon stock is 92.26 t/ha (AGC = 68.34 and BGC=23.92) (Metz *et al*. (2007). According to Fantu *et al.(*2007) study in Oremia region Degaga and Kofele districts, the aboveground biomass carbon stock of *Eucalyptus grandis* plantation at the developmental age of 14 years, DBH and height ranged from 12 to 40 cm and 13.9 to 47.1 m is 194.5 t/ha. *Eucalyptus grandis* is generally the best species in volume production when planted on suitable sites and considered it to be among the most productive Eucalypts in the world (Eldridge *et al*., 1994). According to the Omoro *et al.(*2013) in high elevation forested areas of Taita Hills in south-eastern Kenya, the mean aboveground biomass carbon stock of *Eucalyptus grandis* ranges from 102.5 to 481.5 t/ha. In Nigeria, the total above ground biomass carbon stock production of *Eucalyptus camaldulensis* stand at the developmental age of 25 years is 256 t/ha (Akindele *et al*.,2010). According to the Du *et al*. (2015) in Guangxi Province of southern China, the total carbon stock of Eucalyptus plantation at five different developmental age is 112.9 t/ha at 1year, 172.5 t/ha at 2 years, 203.8 t/ha at 3years, 161.1 t/ha from 4-5 years and 162.7 t/ha. From 6 to 8 years respectively. Biomass carbon stock of the plantation forests may be expected to increase with increasing of plantation age (Guo and Gifford, 2002). According to Keith *et al*.(2009) study at moist highlands of Victoria in southeastern Australia, biomass carbon stock of *Eucalyptus reganans* ranges up to 1053 t/ha in living aboveground biomass and 1867 t C ha^{-1} in living plus dead total biomass in stands at the developmental age which is greater than 100 years. According to this study, the reason mentioned for high biomass carbon stocks in *Eucalyptus reganans* is due to a prolonged absence of direct human land use activity. In Brazil, the mean annual increment of *Eucalyptus grandis* plantation is commonly between 2.8 to19.6 t/ha) on rotation from 5 to 21 years. But, intensive breeding and silviculture activities can raise 18.48-39.2 t/ha (Turnbull, 2000).

According to George (2014), whatever the importance of Eucalyptus plantation in carbon sequestration and storage potential is already accepted and well documented in many countries, there is no sufficient research done on carbon storage potential of many species.

2.7 Factors influencing the forest carbon stock

Identifying the factors which influencing carbon stock of forest is very important for the management of forest resource sustainably (Houghton, 2005). Carbon stock of a given forest can be influenced by many factors like inherent potential of the tree and the physical ecosystem in which the tree exists (Houghton, 2005). The most important being the species composition, stand age, origin of stand establishment (seed source or coppice), site quality, genetic variation, stand density, management regime, previous land use and environmental factors such as elevation, slope and aspect gradients (Fahey *et al.,* 2010). Intensive silviculture, with shorter harvesting intervals and more intensive logging generally reduces net carbon storage rates and carbon storage at the stand level, when compared with low-intensity silviculture (e.g., the selection system) (McKinley *et al*., 2011). In addition, low intensity silviculture may create stand structures and a composition more suitable for storing carbon, and disturbance resistance that may prevent catastrophic events such as wildfires. According to McKinley *et al*. (2011), high-severity fire can increase soil erosion, alter nutrient cycling, and decrease post-fire seedling recruitment, thus leading to long-term losses of carbon stocks of forest. In general management activity can affect the net carbon exchange with the atmosphere to a large extent, by both affecting the amount of carbon stored in the vegetation and soil, and altering the local productivity pathway of the forest (Bellón *et al*., 1993). According to the Keith *et al*. (2009), study the overall factors controlling the biomass carbon stocks are: environmental conditions, life history and morphological characteristics of each tree species, natural disturbance, and land use activity.

2.8 Forest carbon stock estimation

Biomass carbon stocks of forests can be estimated using destructive or non-destructive methods (Vashum and Jayakumar 2012). Destructive methods done harvesting of individual trees on plot area basis (Gibbs *et al*. 2007). Nondestructive biomass estimation method doesn't require harvesting of trees and it can be done using existing biomass equations or biomass expansion factors to extrapolate biomass to a given unit areas (Pearson *et al.* 2007). Nondestructive methods use readily measurable proxies, such as diameter at breast height, height, or other vegetation indices that can be converted to biomass based on statistical relationships established by destructive sampling methods (Massada *et al*., 2006). According to Solomon *et al*. (2007), equations which are used to estimate the aboveground tree biomass are differ depending on the type of species, geographical location, type of forest, climate and other factors i.e., why using of species-specific equations is preferred to estimate the aboveground biomass of trees. There are different types of generic allometric equations which are developed to estimate the aboveground tree biomass of tropical, temperate and boreal natural forests as a general (Solomon *et al*., 2007). But, there are no well-defined and organized plantation forest specific equations except a few species specific equations (Solomon *et al*., 2007). Due to this, most of the researchers use generic allometric equations which are developed for natural forests to estimate the aboveground tree biomass of plantation forests (Solomon *et al*., 2007). According to Henry *et al*. (2011), most of the carbon stock assessment in Africa has high uncertainty due to the lack of proper techniques of inventory and lack of site and species specific allometric equations. Due this most of the carbon stock assessments use generic allometric equations despite the high degree of variability in site and growth characteristics of species (Henry *et al*., 2011). According to Engleston *et al*.(2006), in plantation forests, carbon is located in five main carbon pools namely, living aboveground biomass, living belowground biomass, dead wood biomass, litter biomass and soil carbon. But, most of the total carbon in plantation forests is stored in aboveground biomass of trunk, branches and foliage (Sharma *et al*., 2011).

Below Ground Biomass carbon pool consists of all the biomass of living roots of trees, and the biomass in tree stems below 1% height (stump height) (Nadelhoffer and Raich, 1992). Estimation of BGB is relatively expensive and time consuming as compared to aboveground biomass estimation due to wide variability in the way that roots are distributed in the soil (Pearson *et al*., 2007). Therefore, in the absence of measured values many researchers use root to shoot ratio to estimate below ground living biomass (Pearson *et al*., 2007). The ratio ranges from 18% to 30%, with tropical forests in the lower range and the temperate and boreal forests in the higher range (Pearson *et al*., 2007). There are also different regression models (with less data) that are existing for estimation of BGB as a function of AGB for different regions (Pearson *et al*., 2007). However, according to MacDicken (1997), for cases in which more accurate estimates of belowground biomass are economically feasible using locally established methods is important.

Forest litter layer is defined as all dead organic surface material that includes dead leaves, twigs, flowers and dead wood with a diameter of less than 10 cm on the floor of the land (Brown *et al*., 2004). The primary method for assessing carbon stock in the litter pool is to sample and assess the wet-to-dry mass ratio and biomass is oven dried and finally, the carbon content in the litter biomass is estimated by multiplying with the default carbon fraction 0.47 as recommended by (Hiraishi *et al*., 2013).

Soil is the most effective sequestration reservoir for carbon in many ecosystems because of the long turnover time of soil organic matter compared with most plant tissues, and because of less inter-annual variability or disturbance-driven losses (Lal, 2005). The most common method of estimating the amount of carbon stock in soils is based on soil analysis and expressed usually in tons per hectare (Pearson *et al.,* 2005). Globally, soil organic carbon stock increases with precipitation and clay content and decreases with temperature, which has been confirmed on regional and local scales (Yang *et al*., 2007). According to Hiederer (2009) due to the presence of lower accumulation of organic matter resulting from lower belowground root biomass in the sub-surface layer, soil organic carbon decreases in the soil profile. However, net increases in soil carbon might be highly variable owing to differences in climate, age, tree type, and soil depth across sites, and only modest gains in soil carbon could be expected in most locations for several decades (McKinley *et al.,* 2011). Soil represents the most significant pool of carbon storage in terrestrial ecosystems which is accounting about 75% of total stored Carbon (Lal, 2005). Soil carbon sequestration depends on edaphic and climatic conditions, which may enhance or reduce the organic matter inputs (Nieder *et al*., 2003). The accumulation of soil organic carbon depends on the quantity of litter (Lemma *et al*., 2007) and root activity such as rhizo-deposition and decomposition (Rees *et al*., 2005). According to Nair *et al*.(2009) carbon stock up to 1m depth for the agroforestry systems globally ranges (30−300 ton of carbon per hectare and in Ethiopia (49.41−256.3 ton of carbon per hectare (Gebeyehu *et al*., 2017). On the other hand, other related studies were reported the increment of soil carbon stocks in the ecosystem as the number of plant species and aboveground biomass increases (Lemeneh *et al*., 2005). Tropical soils are less capable to store carbon than other biomes. This is mainly due to the rapid decomposition of dead biomass in the warm, humid climatic conditions which leads to rapid carbon and nutrient leaching (Trumper *et al.,* 2009). The type of tree species found in the system also play an indirect role on the SOC accumulation through their production and allocation of above and belowground biomass (Lemenih *et al*., 2004). However, the turnover of the litter to SOM will depend on the quality of the litter. Litter rich in phenolic and lignin will have higher C/N values and contribute to slower decomposition rates leading to less SOM found in short term (Jandl *et al*., 2007).

2.9 Importance of carbon stock estimation in a forest

Estimation of forest carbon sock is useful in assessing the forest structure and condition, forest productivity and carbon fluxes based on sequential changes in biomass, sequestration of carbon in biomass components and can be used as an indicator of site productivity (Chavé *et al*., 2003). Estimation of carbon stocks of a forest is crucial to quantify the environmental services provided by trees and the management of carbon resources in relation to the environment (Niu and Duiker (2006). According to Schwartzman *et al*.(2008), estimates of carbon stocks enable also economic valuation of forests to explore possibilities of financial gains through mechanisms such as the United Nations Reducing Emissions from Deforestation and Degradation in Developing Countries Programmed (UNREDD). Organizations such as $REDD^+$, CDM and other voluntary organizations for carbon credit allocation based on carbon stocks performance requires accurate estimates of carbon stocks of land use system and can only be harnessed if estimation of carbon stock is accurate and reliable (Gurney and Raymond, 2008). Indeed, trading carbon credits offers a new hope to resource poor and small land holder farmers of the region that are prone to climate change and variability by creating another important income stream that would make the local livelihoods resilient to climate change (Gurney and Raymond, 2008). Measurement of carbon stocks of forest species wise distribution in different geographical regions enables to identify regions which are rich or deficient in Carbon stocks while providing information on specific tree species and which species are greater carbon sequestration potential under their respective climatic and soil conditions (Pearson *et al.,* 2007). Furthermore, comparative carbon stock estimates provide indications of the condition of forest resource in a given climatic zone and an indirect estimate of site quality (Houghton and Goodale, 2004). According to Houghton and Goodale (2004), there is a variation between carbon storage potential of species and land use types and due to this, carbon stock measurement is important to provide essential data which enable the extrapolation of biomass stocks to ecosystems and allow reliable emission estimates from land use and land cover change scenarios.

3. MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location of the study area

The study was conducted in Chagni district, Awi Zone, Amhara Region, Ethiopia. Chagni district is located at 509 km Northwest of Addis Ababa and 57 km West of Injibara town. Geographically, it is situated between 10°56'40"N and 10°59'10" N latitude and 36°31'50"E and 36°33'20"E longitude (Figure 1). It is one of the 12 administrative districts in Awi Zone and bordered in all directions by Gongua district. The administrative center of Chagni district is Chagni town. Kibrit Plantation Forest is found in this district at 2.5 km distance to the East of Chagni town and geographically, located between 10°56'40"N and 10°57'10"N latitude and 36°31'50"E and 36°32'20"E longitude. Kibrit Plantation Forest is bordered by Ardi River to the South, Chagni 01 kebele to the West, Chagi Injibar road to the North and Sigadi kebele to the East.

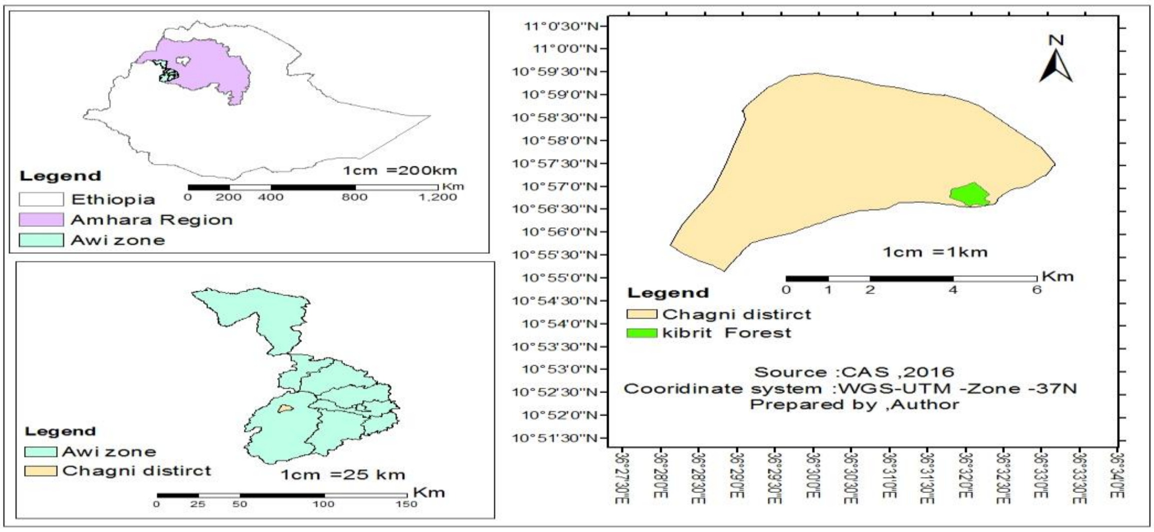

Figure 1: The map of Ethiopia showing Amhara Region and the study area

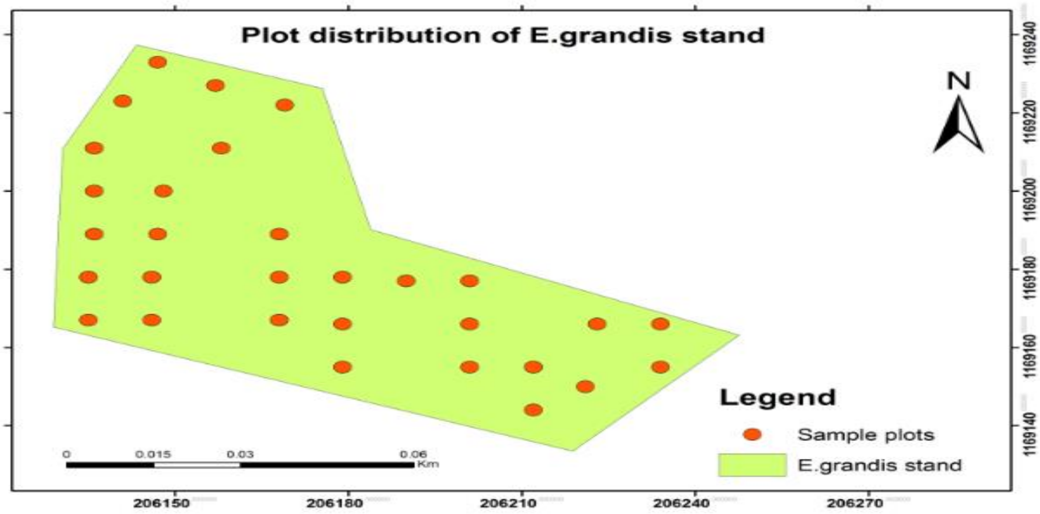

Figure 2: Sample plots of *E. grandis* stand at Kibrit Forest Plantation

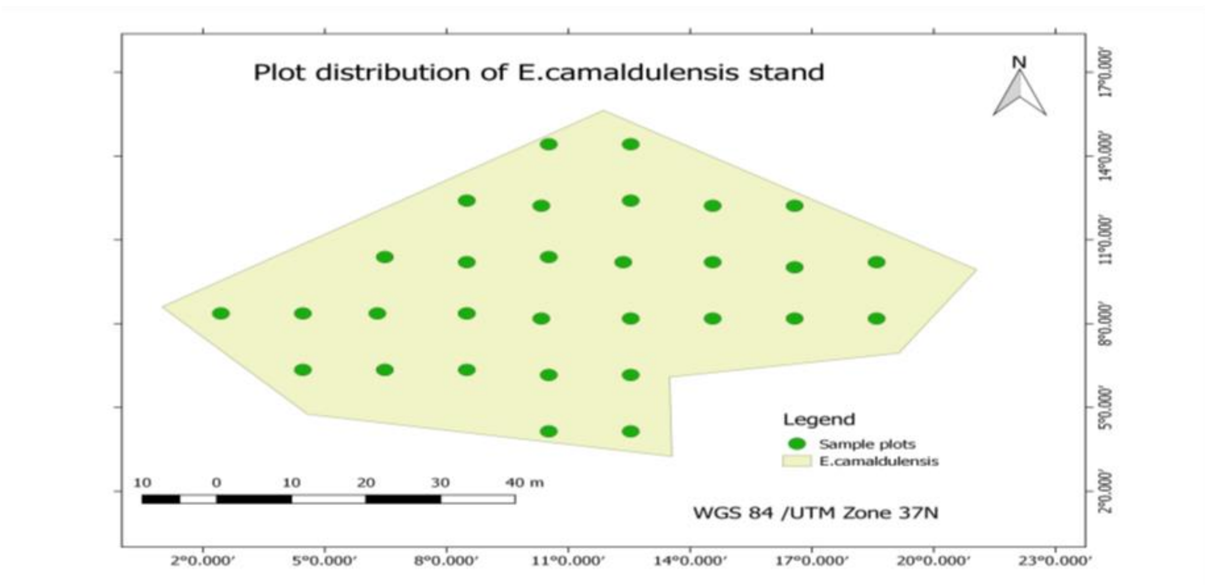

Figure 3: Sample plots of *E. camaldulensis* stand at Kibrit Forest Plantation

3.1.2 Agro-ecological zone

The study area is characterized by a unimodal rainfall distribution with a main wet season from June to September usually continued with a less pronounced wet period up to October. Based on long term weather data obtained from Chagni Meteorological Station, the mean annual rainfall and monthly temperature of the study area ranges from 1300 mm to 1800 mm and from 18.6°C to 28°C, respectively. Elevation range extends from 1627m to 1793 m above sea level.

3.1.3 Soil

According to the FAO (1984) geomorphology and soils map classification of Ethiopia used in the development of a master land use plan for the country the major soil type of the study area is grouped under the Nitosols. Generally, the soil type of the study area is characterized as reddish brown to red soils which have high moisture storage capacity and a deep rooting volume. According to the Gongua Agricultural Office, before the establishment of Kibrit plantation forest, the site where *Eucalyptus grnadis* growing was farm land for many years and *E.camaldulensis* stand growing was pasture land.

3.1.4 Vegetation

3.1.4.1 Natural vegetation of the study area

Most of the natural vegetation of the study area is grouped under the Dry evergreen afro-montane type (Demissew *et al*., 2010). Some of the remnant Dry evergreen afro-montane vegetation types in this area include; Gongua Elalla natural forest, Degera Abo natural forest and Tiru Birhan natural forest. In these forests main dominant plant species are; *Albizia gummifera, Croton macrostachyus, Cordia africana, Prunus Africana, and Syzygium giuneense.*

3.1.4.2 The Kibrit plantation Forest

Kibrit Plantation Forest is established by the species of *Eucalyptus grandis, Eucalyptus camaldulensis, Grevilia robusta* and *Pinus patula in* 1990 by the government of Ethiopia for the purpose of industrial plantation. The total area of the forest is 57ha (*Eucalyptus grandis* 10 ha, *Eucalyptus camaldulensis* 8 ha, *Pinus patula* 11ha, *Grevilia robusta* 12 ha and 16 other species). *E.grandis* and *E.camaldulensis* stands are established (2mx2m) spacing on the gentle sloppy area which is less than 1%. Silvicultural management system is the same for both stands from the time of establishment to now. Currently both stands age is 28 years and they are still not harvested.

According to Bekele-Tesema (2007) *Eucalyptus grandis* grows best in humid subtropical conditions, but has been widely planted all over the world. In Ethiopia it grows successfully in Moist and Wet Weyna Dega agro climatic zones. It performs well on light and medium neutral to acid soils that are free draining and moist up to 1700-2500 masl. It is an evergreen tree 40-55m, to a diameter of 2m; with an excellent straight trunk and wide spreading thin crown, self-pruning of branches in plantations.

Eucalyptus camaldulensis is widely distributed in its native Australia and 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 meters above sea level. It is tall evergreen tree to 30 m, deeply branched but with a long straight bole (Bekele-Tesema, 2007).

3.2 Methodology

The methodology and procedures used to estimate the carbon stocks for this study were based on the standard carbon inventory principles and techniques. In detail it was based on the predictor variable (tree diameter at breast height) and Samples (soil and litter) data collection and analysis of carbon which is accumulating in aboveground biomass, belowground biomass, soil carbon and litter fall carbon pools of the *Eucalyptus grandis* and *E.camaldulensis* stands using verifiable methods and appropriate equations.

3.2.1 Study site selection

Study site selection was decided purposively. The reason why study site selection was decided purposively was, due to the two species (*E. grandis* and *E.camaldulensis*) are established in adjacent sites with similar condition of climatic, topographic, edaphic, time of plantation (age) and similarity in silvicultural management intervention systems for both stands were appropriate for the study. Therefore, Kibrit plantation forest has provided the best site in this respect and thus selected for the study.

3.2.2 Delineation of the study site

Study site delineation is the first activity of the forest carbon measurement area boundaries (Bhishma *et al.*, 2010). Unless the spatial boundaries of the study site were not separated and properly recognized it is difficult to get accurate measurement and effective work. Therefore, study site delineation was done taking the geographic coordinates of the forest boundary using GPS 60 at each turning point. Then after, all the recorded way-points from the field were used to produce the sketch map of the study site using Arc GIS 10.3.1 software.

3.2.3 Sampling Technique

For this study, to collect the data systematic sampling technique was selected. The reason why systematic random sampling technique was selected is that, it yields more precise results and it is easily applied in the field for forest data collection. To decide the required number of sample plots, pragmatic approach was followed on the basis of available resources (Woldemariam, 2015). Accordingly, a total of 60 sample plots (30 for each stand) were selected based on this approach. Totally 16 transect lines (10 for *E.camaldulensis* and 6 for

E.grandis stand) were estabulished by the specing of 45m between them. The sample plots which were used to collect the tree data (DBH and total height) were single rectangular in shape and designed by (10m*20m) (figure 2. All of the 60 sample plots which were prepared on the sketch map of the study site using gridlines were distributed on the ground regularly at 45m distance beteween each sample plot following the systematic sampling method. To collect the litter and soil samples, square shaped sub-sample plots were designed 1m x1m within all sample plots' center and corners.

Since, slope gradient of the study site was less than 10%, correction of sample plot dimension was not performed (Walker *et al*., 2018). According to Walker *et al*, (2018), when the slope gradient of sample plot is less than 10%, the impact of slope distorting the true horizontal projection is insignificant.

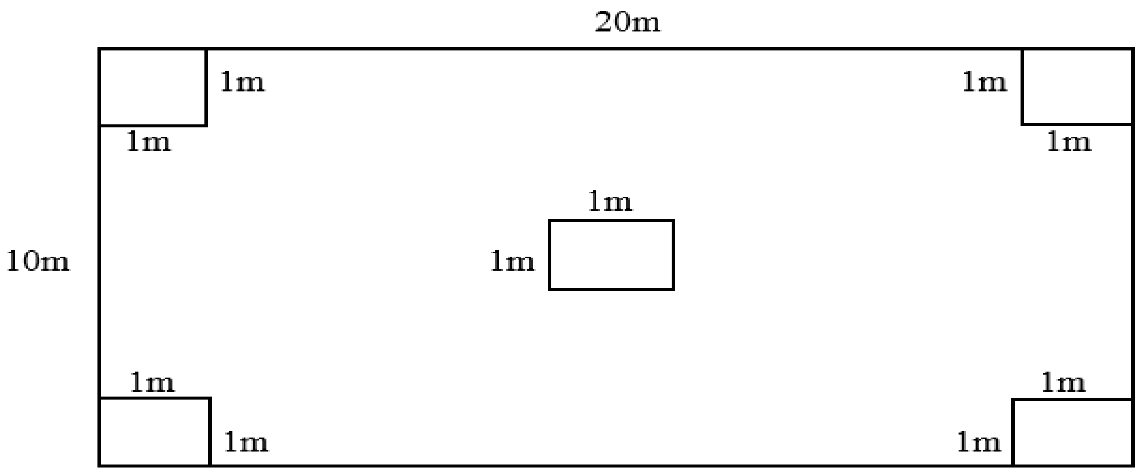

Figure 4: Design of sample and subsample plots

3.3 Field data collection

3.3.1 Woody species inventory

All trees of *E. grandis* and *E. camaldulensis* with DBH ≥5 cm within all sample plots were measured at breast height (1.3m) using 50cm graduated caliper and total tree height by Laser Ace 1000 Rangefinder. The reason why tree diameter measured is that, it is the main tree biomass carbon predictor variable for allometric equations which are selected for this study. It also uses to develop stand characteristics together with total tree height. Trees on the border >50% of their DBH fall within the plot were included and trees >50% of their DBH fall outside the plot were excluded from the inventory (Karky and Banskota, 2007). Similarly, those trees 50% of their DBH fall within or outside the plot were decided using lottery method. Trees whose trunk is outside but inclined into the plot area were excluded from the inventory. Trees whose trunk is inside the sampling plot and inclined to the outside were included to the inventory. All trees diameter at breast heght was recorded from two perpendicular directions and average value was taken for further calculation. In the case of multi-stemmed trees (more than 2 stems per plant), each stem was measured and the equivalent diameter of the tree was calculated as the square root of the sum of diameters of all stems (Snowdon *et al*., 2002).

3.3.2 Litter sampling

In this study collected litter samples were include only the *E. camaldulensis* and *E. grandis* species dead leaves, branches, twigs, flowers, and dead wood with a diameter of less than 10 cm. Totally, 180 litter samples of *E. camaldulensis* and *E. grandis* (90 for each stand) were collected from 3 sub-samples which were chosen randomly using lottery method from 4 sub-samples designed (1m*1m) at the corner of sample plots. The reason why litter samples collected from 3 sub-sample plots only, while there were 4 sub-samples was to minimize the labour and laboratory cost. All samples wet mass was weighed at the field using 0.1g precision balance. After weighed and coded, all samples were evenly mixed per sample plot to prepare totally 60 composite samples (30 for each stand). From the prepared composite samples, 100g from each sample was taken to the laboratory for the determination of oven dry mass (Pearson *et al*., 2007).

3.3.3 Soil sampling

For carbon content analysis soil samples were collected based on the specified soil depths (0–20, 20–40 and 40–60) cm using soil Auger. Totally, 540 samples (270 for each stand) were collected from 3 sub-samples which were chosen randomly using lottery method from 4 sub-samples which were designed (1m*1m) at the corner of sample plots. The reason why soil samples collected from 3 sub-sample plots only, while there were 4 sub-samples was to minimize the labor and laboratory cost. All samples wet mass was weighed at the field using 0.1g precision balance. After weighed and coded, all samples were evenly mixed per sample plot to prepare totally 180 composite samples (90 for each stand). From the prepared composite samples, 500g from each sample was taken to Debre-Markos Soil Laboratory Center for the analysis of carbon content.

For bulk density determination, soil sample was collected from sub-samples which were designed at the center of each sample plot (1m*1m). Soil samples for bulk density were collected using 392.5cm^3 (20cm length and 5cm diameter) Core sampler based on the specified soil depth (0-20, 20-40 and 40–60)cm. Totally,180 samples (90 for each stand) were collected and weighed at field using 0.1g precision balance. All of the collected 180 samples were taken to laboratory for the determination of soil bulk density.

3.4 Laboratory analysis

All laboratory work for this study was done at Debre-Markos Soil Laboratory Center. In this laboratory, composite litter samples were air dried for one day and then, oven-dried at 70°C for 24 hours to determine the constant oven dry mass. Then the samples were weighed, grinded using mortar and pesto, then sieved by 2mm mesh. The loss on ignition (LOI) method was used to estimate percentage of carbon in the litter. 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 with ash were weighed and litter organic matter fraction was calculated according to the Allen *et al*. (1986).

Soil samples for bulk density were oven-dried at 105 °C for 48 hours and weighed (Pearson et al., 2007). Bulk density was determined by the core method (Blake and Hartge,1986). Soil organic carbon content analysis of soil samples were also done in this laboratory following the Walkley and Black method (Schnitzer, 1982).

3.5 Carbon stock estimation

3.5.1 Aboveground biomass carbon stock estimation

To estimate the biomass of *E. grandis* stand trees, species specific allometric equation which is developed by Fantu *et al*. (2007) in Ethiopia was used (Eq.1). Similarly, to estimate the aboveground biomass of *E.camaldulensis* stand trees, species specific allometric equation developed by Hailu Z. (2002) in Ethiopia was used (Eq. 2).

$LogY = -1.381+2.893 (logDBH)$ …………………………..…………..………………… Eq. 1

$AGB = 0.0155*(DBH^{(2.5823)})$ ………………………………………………………..… Eq. 2

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

The reason why these equation were selected for this study were; first, the general criteria described by the authors of these equations were similar to the criteria of the study area. Second, these equation were only species specific allometric equations in Ethiopia to estimate the *E. grandis* and *E.camaldulensis* tree biomass. Third, using of species specific allometric equation gives reliable biomass estimate than using of generic equation, and fourth reason is that, for this study selected equations (Eq.1 and Eq.2) use the most important tree biomass predictor variable (diameter at breast height).

For (Eq.1) before the estimation of *E. grandis* tree biomass directly, correction factor was used to convert the log transformed predictor variable (DBH) in to anti-logarithm as suggested by (Baskerville, 1972). Conversion of aboveground biomass to carbon stock was done using 0.5 carbon fraction following the Pearson *et al*. (2007) method.

3.5.2 Belowground biomass carbon stock estimation

Belowground biomass of *E.grandis* and *E.camaldulensis* stand trees was estimated multiplying the aboveground tree biomass of each stand by 0.26 root to shoot ratio default value (IPCC, 2006).

BGB = AGB * 0.26 ……………………………………………...……………..…. Eq. 3

Where: BGB = belowground biomass (kg/tree), AG = aboveground biomass (kg/tree) and 0.26 = conversion factor (26 % of AGB).

Conversion of belowground biomass to carbon stock was done using 50% carbon fraction following the Pearson *et al*. (2007) method.

3.5.3 Litter biomass and carbon stock estimation

The amount of biomass in the litter was calculated according to Pearson *et al*. (2005).

$$\mathrm{LB} = \frac{\mathrm{Wfield}}{\mathrm{A}} \times \frac{\mathrm{Wsubsample(dry)}}{\mathrm{Wsubsample(fresh)}} \times \frac{1}{10{,}000} ----------- .---- Eq.4$$

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 ovendry subsample of litter taken to the laboratory to determine moisture content (g) and 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 ……………………………………..…………………..……..…. Eq. 5

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

3.5.4 Soil organic carbon stock estimation

Soil organic carbon stock was calculated following the Pearson *et al*. (2007) method after the analysis of soil organic carbon content and bulk density determination by the formula of:

SOC = BD * SD * %C * 100 ………………………..…………………………….. Eq. 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.

3.5.5 Total Carbon stock estimation

Total carbon stocks of *E.grandis* and *E. camaldulensis* stands was calculated summing the carbon stock of individual carbon pools of both stands separately following the (Pearson *et al.*,2005) method.

TCS = AGBC+BGBC+LBC+SOC ……………………………………………………. Eq .7

Where: TCS = total carbon stock (t/ha), AGBC = aboveground biomass carbon (t/ha), BGC = belowground biomass carbon (t/ha), LBC = litter biomass carbon (t/ha) and SOC = soil organic carbon (t/ha).

3.6 Data analysis

Tree diameter at breast height, total tree height, wet and oven dry mass of soil and litter samples were organized using Microsoft excel 2013 and analyzed by Statistical Package for Social science (SPSS version 20). Prior to statistical test, all data were subjected to the Kolmogorov–Smirnov test to check the normality. To test difference in biomass carbon stock between *Eucalyptus grandis* and *Eucalyptus camaldulensis* stands, one-way ANOVA statistical test was used. Two-way ANOVA was used to test the difference of soil organic carbon stock in relation to stand species and soil depth (cm). All of the necessary statistics were evaluated at a 95% confidence level.

4. RESULTS

4.1 Characteristics of *E. grandis* and *E. camaldulensis* stands

In this study, while there is no significant difference (p= 0.052) in mean diameter at breast height, the mean height of *E.grandis* stand trees was larger (p=0.037) than the *E. camadulensis* stand trees by a factor of 1.4 (Table1). Though, the two stands were established at the same time, stem/ha of *E.camaldulensis* stand was greater (P = 0.000) than the *E. grandis* stand. But, basal area of *E. grandis* stand was greater than the *E.camaldulensis* stand by a factor of 1.1.

Table 1: *E. grandis* and *E.camadulensis* stand characteristics (Mean ±SD) of study site

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(m^2ha^{-1})	35 ± 0.3	32 ± 0.1	0.023
Stem/ha	1507 ± 18	1555 ± 16	0.000

n =number of sample plots, DBH = Tree diameter, BA=basal area and H= Tree height

4.2 Biomass Carbon Stocks of *E. grandis* and *E. camaldulensis* stands

This study indicated that, the total mean biomass carbon stock of the current study was significantly higher (p = 0.000) in *E. grandis* than the *E. camaldulensis* stand (Table 2). That means, the total mean biomass carbon stock of *E. grandis* stand was greater by a factor of 2.5 *E.camaldulensis* stand. Trees accounted 99.99% of the total mean aboveground biomass carbon stocks in *E. grandis* and 99.98% in *E. camaldulensis* stand. While the contribution of trees to the total mean belowground biomass carbon stock was 100% in both stands (*E. grandis* and *E.camaldulensis*). Contribution of litter for aboveground biomass carbon stock in both stands was statistically very insignificant, i.e., 0.01% for *E. grandis and* 0.02% for *E. camaldulensis* stand.

Table 2: (Mean±SD) of aboveground biomass carbon (AGBC), belowground biomass carbon (BGBC) and total biomass carbon (TBC) for each of the two stands and results of One way ANOVAs (at α=0.05).

Carbon stock	Plantation stands	Trees	Litter	Total	P-value
AGBC (t/ha)	*E. grandis*	212.5±58	0.02±0.00	212.52±58	0.000
	E. camaldulensis	83.7±18.1	0.02±0.00	83.72±18.1	0.000
BGBC (t/ha)	*E. grandis*	55.3±15.1	-	55.3±15.1	0.000
	E. camldulensis	21.8±4.7	-	21.8±4.7	0.000
TBC (t/ha)	*E. grandis*	267.8±73.1	0.02±0.00	267.82±73.1	0.000
	E. camldulensis	105.5±22.8	0.02±0.00	105.52±22.8	0.000

n = 30 for each stands

4.3 Soil Organic Carbon Stocks in *E. grandis* and *E.camaldulensis* stands

The total mean SOC stock of the current study site was significantly higher (p = 0.000) in *E. camaldulensis* than the *E. grandis* stand (Table 3). In both stands, more soil organic carbon was stored in the top layer (33.8 %) of the total soil organic carbon stock in *E. grandis* and (34.7%) in the *E. camaldulensis* stand. While, the bottom layer (40-60) cm accounted 32.9% of the total soil organic carbon stocks in *E. grandis* and 31.9% in the *E. camaldulensis* stand.

Table 3: (Mean±SD) of soil organic carbon (SOC) in *E. grandis* and *E. camaldulensis* stands

Variables	Soil depth (cm)	Plantation stands		P-value
		E. grandis (n=30)	*E. camaldulensis* (n=30)	
SOC (t/ha)	0−20	28.4±0.5	30.1±1.9	0.000
	20−40	27.9±0.6	28.9±2.3	0.000
	40−60	27.6±0.6	27.7±2.4	0.000
	(0−60)	83.94±1.7	86.7±6.6	0.000

n= number of sample plots

4.4 Total Carbon Stocks of *E. grandis* and *E. camaldulensis* stands

This study indicated that, statistically there was a great significant difference (p = 0.000) between *E. grandis* and *E. camaldulensis* stands in total mean carbon stocks (biomass carbon plus soil organic carbon) (Table 4). Biomass carbon stock of *E. grandis* stand was 2.5 times as large as the biomass carbon stock of *E.camaldulensis* stand. Similarly, the total carbon stock of the *E. grandis* stand was 1.8 times as large as that of the total carbon stock of the *E. camaldulensis* stand. Contribution of the biomass carbon stock from the total carbon stock in *E. grandis* stand was 76.12 % and 54.9 % for *E. camaldulensis* stand. Soil Organic Carbon stock accounted 23.9% of the total carbon stock in *E. grandis* and 45.1% in *E. camaldulensis* stand.

Table 4 :(Mean±SD) of total biomass carbon, soil organic carbon (SOC) and stand total (total biomass plus SOC 0-60 cm) carbon stocks (t/ha) for each stand

Carbon stocks	Plantation stand		P-value
	E. grandis (n=30)	*E. camaldulensiss* (n=30)	
BC (t/ha)	267.82±73.1	105.52±22.8	0.000
SOC (t/ha)	83.94±1.7	86.72±6.6	0.000
TC (t/ha)	351.76±71.2	192.24±27.9	0.000

Results of one-way ANOVAs (at α=0.05); n is number of samples

5. DISCUSSION

5.1 Characteristics of *E.grandis* and *E. camaldulensis* stands

In this study, the total mean height of the *E. grandis* stand was larger (34.4m) than the *E. camadulensis* stand total mean height (24.7m).The mean diameter at breast height of *E.grandis* stand (29.6m) was also greater than the (28.3m) of *E. camadulensis* stand. Though, the two stands were established at the same time, stem/ha of *E.camaldulensis* stand was greater (1555 trees/ha) than the *E.grandis* stand (1507trees/ha). But, basal area of *E. grandis* stand ($35m^2$/ha) was greater than the ($32m^2$/ha) *E.camaldulensis* stand. This difference might be, due the difference of species characteristics while they are similar in plantation time, silvicultural management system and agro-ecological location. According to Bekele-Tesema (2007) in Ethiopia, *E.grandis* grows in height 40-55m and to a diameter of 2m, while *E. camaldulensis* tree grows up to 30m at suitable environmental condition.

5.2 Biomass Carbon Stocks of *E. grandis* and *E. calmaldulensis* stands

In this current study, *E. grandis* stand was stored substantially high amount of biomass carbon than *E. camaldulensis* stand. This difference might be, due to the presence of larger trees in diameter at breast height in *E. grandis* than *E. camaldulensis* stand and due to difference in aboveground tree biomass estimator (allometric equation). Most of the biomass carbon stock was stored in trees of *E. grandis* and *E. camaldulensis* stands. But, *E. grandis* stand trees storage was very high when compared to with *E. camaldulensis* stand trees. In this study, belowground biomass carbon stock of *E. grandis* stand was also very high when compared to *E. camaldulensis* stand. This difference might be, due to trees biomass carbon stock of *E. camaldulensis* stand was very low as compared to *E. grandis* stand trees. This study indicated that, there is no significant difference between litter biomass carbon stocks of *E. grandis* and *E. camaldulensis* stands. In both stands, its contribution to the mean total biomass carbon stock was statistically insignificant when compared to the other above ground biomass carbon pools. This low contribution might be, due to the consumption of litter fall for fuel by the local community where it is common in that area. The current study, mean biomass carbon stock (267.82 t/ha) of *E. grandis and E.camaldulensis* stand (105.52t/ha) was substantially higher than the mean biomass carbon stock (92.26t/ha) of the Eucalyptus plantations in in Ethiopia (Metz *et al*., 2007).

The current study mean biomass carbon stock (212.5t/ha) of E. *grandis* and *E.camaldulensis* trees (83.7 t/ha) was significantly higher than the mean total aboveground biomass carbon stock (68.34 t/ha) of Eucalyptus plantations in Ethiopia (Metz *et al*., 2007). In this case difference might be, most of the plantation forest carbon stocks in Ethiopia is estimated by generic allometric equations without considering the species difference and importance of species specific equations as a whole. But, estimation of carbon sock using species specific allometric equation, especially in less diverse plantation forests gives better and relatively reliable result than generic equation. The current study mean biomass carbon stock (212.5t/ha) of *E.grandis* stand trees was even greater than the mean biomass carbon stock of *E.grandis* stand trees (194.5 t/ha) which is reported in Oremia region, Degaga and Kofele districts, at the developmental age of 14, diameter at breast height and height ranging from 12 to 40 cm and 13.9 to 47.1 m, respectively (Fantu *et al*. (2007). In this case difference might be, due to the difference of stand age. i.e., currently studied *E. grandis* stand age was 28 years which is greater by 14 years. Another reason might be, due to difference in structural parameter of tree diameter, stem density, climate and soil type of the plantation stands where they are growing. The current study, mean aboveground biomass carbon stock (212.52 t/ha) of *E. grandis* stand was substantially higher than the mean aboveground biomass carbon stock of plantation forests (123 t/ha) which is reported by (WBISPP, 2005) in Ethiopa. But, the mean aboveground biomass carbon stock (83.72 t/ha) of *E. camaldulensis* stand was less than this report. In this case difference might be, due to the difference of species composition, age, silvicultural management system and difference of allometric equations (functions) which were used to estimate the carbon stock, establishment of stand origin (seed or coppice). Obviously, using of species specific allometric equation gives better carbon stock estimate than generic equation.

Outside Ethiopia, the mean aboveground biomass carbon stock (212.52 t/ha) of *E. grandis* stand was within the range of mean aboveground biomass carbon stock (102.5 to 481.5 t/ha) of the *E. grandis* stand at high elevation forested areas of the Taita Hills in South-Eastern Kenya (Omoro *et al.,* 2013). But, the current study mean aboveground biomass carbon stock of *E. camaldulensis* stand (83.72 t/ha) while it is at the age of 28 years was less than the mean aboveground biomass carbon stock of *E.camaldulensis* stand in Nigeria at the age of 25 years 256 t/ha (Akindele *et al*., 2010). In this case difference might be, due to the difference of allometric equations used to estimate the carbon stock, age of the stands, climate and edaphic factors, silvicultural management. But, the mean biomass carbon stock of *E.grandis* (267.82t/ha) and *E. camaldulensis* stand (105.52 t/ha) of the current study site was less than the mean biomass carbon stock of the world's highest biomass carbon sock (1053 t/ha) of *Eucalyptus reganans* in moist highlands of Victoria, southeastern Australia (Keith1 *et al.,* 2009). Variability in this case might be, due to difference in climate, location, age of the stand, silvicultural management system, species and type of equations used to estimate the biomass carbon stock.

5.3 Soil Organic Carbon Stocks of *E. grandis* and *E. caldulensis* stands

The soil organic carbon stock of both stands was significantly (P = 0.000) affected by the soil depth ranges. The overall mean soil organic carbon stock at (0-60) cm soil depth was higher in *E. camaldulensis* stand (86.72 t/ha) than *E. grandis* stand (83.94 t/ha). In both plantation stands, soil organic carbon stock was significantly higher in the top layer than in the lower layer. This difference might be, due the land use history of the stands where they are growing. According to the Gongua District Agricultural Office, the place where *E. camaldulensis* stand growing was pasture land, while *E. grandis* stand growing was farm land for many years. Another reason might be, due to the lower organic carbon turnover rate as a result of minimum soil disturbance as compared to *E. grandis* stand which was relatively disturbed by livestock and human intervention.

The mean soil organic carbon stocks (86.7 t/ha) of *E.camaldulensis* and (83.94 t/ha) of *E. grandis stand* at soil depth (0−60cm) were within the range of soil organic carbon stock up to 1m depth which is reported for the agroforestry systems in Ethiopia (49.41−256.3 t/ha) (Gebeyehu *et al*., 2017) and globally (30−300 t/ha (Nair *et al*., 2009). Variability in this case might be, due to difference in ecosystem type (plantation forest versus agroforestry), rate of mineralization by soil micro-organisms, climate and soil type (Lal, 2004), silvicultural management system (spacing, pruning, thinning), and land-use history (Nair *et al*., 2009).

5.4 Total Carbon Stocks of *E. grandis* and *E. caldulensis* stands

This study indicated that, *E. grandis* stand was stored substantial amount of mean total carbon stock (351.76 t/ha) than in *E. camaldulensis* stand (192.24 t/ha). As reported in (Sharma *et al*., 2011) more carbon stock was stored in tress of both plantation stands (*Eucalyptus grandis* and *E. camaldulensis*). But greater amount of biomass carbon stock (212.5 t/ha) was stored in *E. grandis* stand trees than in *E. camaldulensis* (83.7 t/ha). In this case variability might be, due to the presence of larger diameter trees at breast height in *E.grandis* and allometric equation used to estimate the carbon stock.

Outside Ethiopia, the total mean carbon stock of *E. grandis* (351.76 t/ha) was greater than the total mean carbon stock (203.8 t/ha) of Eucalyptus plantations in Guangxi province of southern China at the stage of three years (Du *et al.,* 2015). But, the current study, mean total carbon stock (192.24 t/ha) of *E. camaldulensis* stand was less than from this report. However, the current study, mean total carbon stock of *E. grandis* (351.76 t/ha) and (192.24 t/ha) *E. camaldulensis* stand was less than the mean biomass carbon stock of (1053 t/ha) *Eucalyptus reganans* stand which is greater than 100 years of age at moist highlands of Victoria, southeastern Australia (Keith *et al*.,2009). Variability in this case might be, due to the difference in climate, location, age of stands, silvicultural management system, species characteristics and type of allometric equation used to estimate the biomass carbon stock (Montagnini and Nair, 2004).

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Results from this study indicate that, *E. grandis* and *E. camaldulensis* stands are important in storing carbon in aboveground tree biomass, in soil and belowground biomass. The total mean carbon stock (biomass carbon plus soil organic carbon) was substantially higher in *E. grandis* than in *E.camaldulensis* stand. High amount of carbon stock was stored in *E. grandis* stand biomass than in *E. camaldulensis* stand. But, mean soil organic carbon stock at 0-60 cm soil depth was greater in *E. camaldulensis* than in *E. grandis* stand. Relatively in both stands, larger amount of soil organic carbon was concentrated in 0-20 cm soil depth. In both stands (*E. grandis* and *E.camaldulensis*), tree diameter at breast height was the determinant variable for the increment of biomass carbon stock. Finally, it could be concluded that, *E. grandis* stand has stored enormous amount of carbon than the *E. camaldulensis* stand. Hence, it has a considerable role in mitigating the climate change by sequestering carbon dioxide and to generate income from the current carbon marketing system in addition to its direct economic benefit.

6.2 Recommendations

Based on the findings of the study the following recommendations are forwarded:

Since, large amount of carbon accumulated in the biomass and soil of *E. grandis* and *E. camaldulensis* stands should be seen as an opportunity and need to be integrated with Reduced Emission from Deforestation and Degradation (REDD+) and other carbon related incentive mechanisms such as Clean Development Mechanism (CDM) and thereby, benefits smallholder famers in their efforts to expand plantation of these species.

Further study is important to assure the biomass carbon stock, especially in *E.grandis* stand due to the contribution of its trees for the aboveground biomass carbon stock which is extremely high as revealed in this study.

Contribution of the *E. grandis* and *E.camaldulensis* species plantations to the climate change mitigation plus the role different management systems for sequestering and retaining more carbon haven't addressed in this study, so, this study results suggest as further study will be carried out in this regards.

Within plantation forests carbon can be stored in fine roots in addition to aboveground, belowground and soil. So, in this study carbon stock in fine root was not included. Therefore, further research should focus on quantifying carbon in this carbon pool. This will help us to fully map the existing biomass carbon dynamic in the area.

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APPENDICES

Appendix 1: Trees and belowground biomass carbon stock of *E. grandis* stand

Plot No.	Trees				Belowground		
	Biomass (kg/ha)	Biomass (t/ha)	Biomass carbon (t/ha)	CO_2 (t/ha)	Biomass (t/ha)	Biomass carbon (t/ha)	CO_2 (t/ha)
1	641718.4	641.7	320.9	1177.6	166.8	83.4	306.2
2	360818.3	360.8	180.4	662.1	93.8	46.9	172.1
3	486607.0	486.6	243.3	892.9	126.5	63.3	232.2
4	458085.4	458.1	229.0	840.6	119.1	59.6	218.6
5	519895.3	519.9	259.9	954.0	135.2	67.6	248.0
6	483654.9	483.7	241.8	887.5	125.8	62.9	230.8
7	360316.3	360.3	180.2	661.2	93.7	46.8	171.9
8	360316.3	360.3	180.2	661.2	93.7	46.8	171.9
9	562774.0	562.8	281.4	1032.7	146.3	73.2	268.5
10	561253.3	561.3	280.6	1029.9	145.9	73.0	267.8
11	555943.5	555.9	278.0	1020.2	144.5	72.3	265.2
12	450424.4	450.4	225.2	826.5	117.1	58.6	214.9
13	774385.0	774.4	387.2	1421.0	201.3	100.7	369.5
14	332723.9	332.7	166.4	610.5	86.5	43.3	158.7
15	356602.5	356.6	178.3	654.4	92.7	46.4	170.1
16	309069.8	309.1	154.5	567.1	80.4	40.2	147.5
17	320229.4	320.2	160.1	587.6	83.3	41.6	152.8
18	417870.0	417.9	208.9	766.8	108.6	54.3	199.4
19	435049.6	435.0	217.5	798.3	113.1	56.6	207.6
20	311835.9	311.8	155.9	572.2	81.1	40.5	148.8
21	378981.2	379.0	189.5	695.4	98.5	49.3	180.8
22	377247.4	377.2	188.6	692.2	98.1	49.0	180.0
23	297420.6	297.4	148.7	545.8	77.3	38.7	141.9
24	342271.4	342.3	171.1	628.1	89.0	44.5	163.3
25	303872.9	303.9	151.9	557.6	79.0	39.5	145.0
26	300584.3	300.6	150.3	551.6	78.2	39.1	143.4
27	353951.4	354.0	177.0	649.5	92.0	46.0	168.9
28	517930.8	517.9	259.0	950.4	134.7	67.3	247.1
29	326051.4	326.1	163.0	598.3	84.8	42.4	155.6
30	492713.5	492.7	246.4	904.1	128.1	64.1	235.1
Mean	425019.9	425.0	212.5	779.9	110.5	55.3	202.8

Appendix 2: Trees and belowground biomass carbon stock of *E.camaldulensis* stand

Plot No.	Trees				Belowground		
	Biomass (kg/ha)	Biomass (t/ha)	Biomass carbon (t/ha)	CO_2 (t/ha)	Biomass (t/ha)	Biomass carbon (t/ha)	CO_2 (t/ha)
1	89127.3	89.1	44.6	163.6	23.2	11.6	42.5
2	117921.7	117.9	59.0	216.4	30.7	15.3	56.3
3	144063.1	144.1	72.0	264.4	37.5	18.7	68.7
4	201526.8	201.5	100.8	369.8	52.4	26.2	96.2
5	211415.0	211.4	105.7	388.0	55.0	27.5	100.9
6	112323.4	112.3	56.2	206.1	29.2	14.6	53.6
7	149480.5	149.5	74.7	274.3	38.9	19.4	71.3
8	145009.9	145.0	72.5	266.1	37.7	18.9	69.2
9	172374.9	172.4	86.2	316.3	44.8	22.4	82.2
10	132604.8	132.6	66.3	243.3	34.5	17.2	63.3
11	171839.8	171.8	85.9	315.3	44.7	22.3	82.0
12	129552.3	129.6	64.8	237.7	33.7	16.8	61.8
13	180610.8	180.6	90.3	331.4	47.0	23.5	86.2
14	194293.1	194.3	97.2	356.5	50.5	25.3	92.7
15	118207.9	118.2	59.1	216.9	30.7	15.4	56.4
16	159732.7	159.7	79.9	293.1	41.5	20.8	76.2
17	143831.1	143.8	71.9	263.9	37.4	18.7	68.6
18	150087.3	150.1	75.0	275.4	39.0	19.5	71.6
19	170244.3	170.2	85.1	312.4	44.3	22.1	81.2
20	191222.5	191.2	95.6	350.9	49.7	24.9	91.2
21	173132.3	173.1	86.6	317.7	45.0	22.5	82.6
22	218064.3	218.1	109.0	400.2	56.7	28.4	104.0
23	220961.5	221.0	110.5	405.5	57.5	28.7	105.4
24	137379.5	137.4	68.7	252.1	35.7	17.9	65.5
25	199586.5	199.6	99.8	366.2	51.9	26.0	95.2
26	166039.6	166.0	83.0	304.7	43.2	21.6	79.2
27	194342.5	194.3	97.2	356.6	50.5	25.3	92.7
28	195739.5	195.7	97.9	359.2	50.9	25.5	93.4
29	232261.1	232.3	116.1	426.2	60.4	30.2	110.8
30	200813.5	200.8	100.4	368.5	52.2	26.1	95.8
Mean	167459.6	167.5	83.7	307.3	43.5	21.8	79.9

Appendix 3: Litter biomass carbon stock of *E. grandis* stand

Plot No.	Wet mass(g)	Sample mass(g)	Oven dry Mass (g)	Oven dry /sample mass	LB (t/ha)	LBC (t/ha)	CO_2 (t/ha)
1	871.50	100.00	91.05	0.91	0.03	0.01	0.05
2	801.50	100.00	91.77	0.92	0.02	0.01	0.04
3	826.60	100.00	92.19	0.92	0.03	0.01	0.04
4	1071.26	100.00	89.33	0.89	0.03	0.02	0.06
5	1131.10	100.00	93.48	0.93	0.04	0.02	0.06
6	1136.30	100.00	91.73	0.92	0.03	0.02	0.06
7	1173.50	100.00	91.50	0.92	0.04	0.02	0.06
8	1244.50	100.00	91.27	0.91	0.04	0.02	0.07
9	1078.30	100.00	92.87	0.93	0.03	0.02	0.06
10	1203.10	100.00	90.82	0.91	0.04	0.02	0.06
11	866.60	100.00	94.07	0.94	0.03	0.01	0.05
12	1072.90	100.00	89.81	0.90	0.03	0.02	0.06
13	1215.10	100.00	92.20	0.92	0.04	0.02	0.06
14	1335.40	100.00	90.96	0.91	0.04	0.02	0.07
15	1420.20	100.00	91.25	0.91	0.04	0.02	0.07
16	940.30	100.00	94.55	0.95	0.03	0.01	0.05
17	1106.60	100.00	90.31	0.90	0.03	0.02	0.06
18	933.82	100.00	94.61	0.95	0.03	0.01	0.05
19	1117.10	100.00	90.15	0.90	0.03	0.02	0.06
20	939.10	100.00	93.08	0.93	0.03	0.01	0.05
21	1186.90	100.00	89.60	0.90	0.04	0.02	0.06
22	1274.80	100.00	91.16	0.91	0.04	0.02	0.07
23	966.80	100.00	93.76	0.94	0.03	0.01	0.05
24	1208.50	100.00	89.71	0.90	0.04	0.02	0.06
25	1002.00	100.00	93.18	0.93	0.03	0.01	0.05
26	1272.60	100.00	89.55	0.90	0.04	0.02	0.07
27	1201.60	100.00	92.23	0.92	0.04	0.02	0.06
28	1072.80	100.00	92.65	0.93	0.03	0.02	0.06
29	1217.30	100.00	90.66	0.91	0.04	0.02	0.06
30	911.10	100.00	93.84	0.94	0.03	0.01	0.05
Mean	1093.31	100.00	91.78	0.92	0.03	0.02	0.06

Appendix 4: Litter biomass carbon stock of *E. camaldulensis* stand

Plot No.	Wet mass (g)	Sample mass(g)	Oven dry Mass (g)	Oven dry /sample mass	LB (t/ha)	LBC (t/ha)	CO_2 (t/ha)
1	962.20	100.00	94.29	0.94	0.03	0.01	0.05
2	1443.30	100.00	87.19	0.87	0.04	0.02	0.07
3	1009.10	100.00	93.98	0.94	0.03	0.01	0.05
4	1450.40	100.00	91.39	0.91	0.04	0.02	0.08
5	913.10	100.00	92.21	0.92	0.03	0.01	0.05
6	1344.30	100.00	87.40	0.87	0.04	0.02	0.07
7	902.30	100.00	94.22	0.94	0.03	0.01	0.05
8	1135.10	100.00	89.17	0.89	0.03	0.02	0.06
9	951.80	100.00	94.29	0.94	0.03	0.01	0.05
10	1146.70	100.00	89.63	0.90	0.03	0.02	0.06
11	949.90	100.00	94.35	0.94	0.03	0.01	0.05
12	1009.70	100.00	90.85	0.91	0.03	0.01	0.05
13	962.71	100.00	91.79	0.92	0.03	0.01	0.05
14	1343.70	100.00	87.98	0.88	0.04	0.02	0.07
15	1426.50	100.00	90.86	0.91	0.04	0.02	0.07
16	946.60	100.00	94.29	0.94	0.03	0.01	0.05
17	1132.90	100.00	88.90	0.89	0.03	0.02	0.06
18	940.12	100.00	94.35	0.94	0.03	0.01	0.05
19	1123.40	100.00	89.71	0.90	0.03	0.02	0.06
20	945.40	100.00	92.75	0.93	0.03	0.01	0.05
21	1193.20	100.00	89.13	0.89	0.04	0.02	0.06
22	1281.10	100.00	90.76	0.91	0.04	0.02	0.07
23	973.10	100.00	93.46	0.93	0.03	0.01	0.05
24	1214.80	100.00	89.25	0.89	0.04	0.02	0.06
25	1008.30	100.00	92.85	0.93	0.03	0.01	0.05
26	1278.90	100.00	89.08	0.89	0.04	0.02	0.07
27	1207.90	100.00	91.87	0.92	0.04	0.02	0.06
28	1079.10	100.00	92.31	0.92	0.03	0.02	0.06
29	1223.60	100.00	90.24	0.90	0.04	0.02	0.06
30	917.40	100.00	93.54	0.94	0.03	0.01	0.05
Mean	1113.89	100.00	91.40	0.91	0.03	0.02	0.06

Appendix 5: Soil organic carbon stock of *E. grandis* stand

Plot No.	Soil depth (cm)	Volume (cm^3)	BD (gcm^{-3})	Oven dry mass(g)	% SOC	SOC (t/ha)	CO_2 (t/ha)
1	20	392.5	0.66	272.6	1.99	78.80	96.86
2	20	392.5	0.68	257.0	2.04	83.23	101.54
3	20	392.5	0.67	280.0	2.02	81.20	99.26
4	20	392.5	0.66	251.5	2.15	85.14	103.17
5	20	392.5	0.66	259.0	2.15	85.14	103.17
6	20	392.5	0.65	255.6	2.17	84.63	103.77
7	20	392.5	0.66	265.7	2.16	85.54	103.47
8	20	392.5	0.66	272.7	2.17	85.93	103.77
9	20	392.5	0.65	277.6	2.19	85.41	104.37
10	20	392.5	0.65	277.7	2.13	83.07	102.57
11	20	392.5	0.65	269.3	2.20	85.80	104.67
12	20	392.5	0.66	267.4	2.11	83.56	101.97
13	20	392.5	0.66	272.7	2.10	83.16	101.77
14	20	392.5	0.65	276.0	2.18	85.02	104.07
15	20	392.5	0.67	253.0	2.04	82.01	100.06
16	20	392.5	0.65	270.5	2.14	83.46	102.87
17	20	392.5	0.66	281.1	2.12	83.95	102.47
18	20	392.5	0.65	287.1	2.22	86.58	105.47
19	20	392.5	0.66	269.0	2.10	83.16	101.77
20	20	392.5	0.65	266.3	2.14	83.46	103.07
21	20	392.5	0.66	289.0	2.09	82.76	101.57
22	20	392.5	0.65	266.2	2.18	85.02	104.07
23	20	392.5	0.65	291.3	2.16	84.24	103.57
24	20	392.5	0.66	243.5	2.13	84.35	102.77
25	20	392.5	0.66	291.1	2.12	83.95	102.57
26	20	392.5	0.66	273.2	2.13	84.35	102.67
27	20	392.5	0.65	238.4	2.17	84.63	103.87
28	20	392.5	0.66	264.6	2.10	83.16	102.57
29	20	392.5	0.65	268.8	2.15	83.85	103.27
30	20	392.5	0.66	278.2	2.11	83.56	102.17
Mean	20	392.5	0.66	272.6	2.18	83.94	102.64

Appendix 6: Soil organic carbon stock of *E. camaldulensis* stand

Plot No.	Soil depth (cm)	Volume (cm^3)	BD (gcm^{-3})	Oven dry mass(g)	% SOC	SOC (t/ha)	CO_2 (t/ha)
1	20	392.5	0.70	274.75	2.10	88.20	323.69
2	20	392.5	0.66	262.98	1.95	77.22	283.40
3	20	392.5	0.70	277.37	1.98	83.16	305.20
4	20	392.5	0.66	257.75	1.89	74.84	274.68
5	20	392.5	0.67	264.29	1.90	76.38	280.31
6	20	392.5	0.67	261.67	1.94	77.99	286.22
7	20	392.5	0.68	265.59	1.92	78.34	287.49
8	20	392.5	0.69	269.52	2.14	88.60	325.15
9	20	392.5	0.71	277.37	2.12	90.31	331.45
10	20	392.5	0.70	273.44	2.17	91.14	334.48
11	20	392.5	0.68	268.21	2.10	85.68	314.45
12	20	392.5	0.69	269.52	1.99	82.39	302.36
13	20	392.5	0.71	277.37	2.13	90.74	333.01
14	20	392.5	0.69	272.13	2.11	87.35	320.59
15	20	392.5	0.67	262.98	2.10	84.42	309.82
16	20	392.5	0.68	265.60	2.04	83.23	305.46
17	20	392.5	0.71	279.98	2.16	92.02	337.70
18	20	392.5	0.73	283.89	2.17	95.05	348.82
19	20	392.5	0.67	262.98	2.24	90.05	330.48
20	20	392.5	0.67	262.98	2.22	89.24	327.53
21	20	392.5	0.70	274.75	2.22	93.24	342.19
22	20	392.5	0.67	264.28	2.15	86.43	317.20
23	20	392.5	0.71	277.24	2.21	94.15	345.52
24	20	392.5	0.60	236.81	2.30	82.80	303.88
25	20	392.5	0.71	277.37	2.22	94.57	347.08
26	20	392.5	0.71	278.68	2.13	90.74	333.01
27	20	392.5	0.64	252.51	2.00	76.80	281.86
28	20	392.5	0.74	291.76	1.96	87.02	319.38
29	20	392.5	0.66	260.36	2.29	90.68	332.81
30	20	392.5	0.70	273.44	2.34	98.28	360.69
Mean	20	392.5	0.69	269.25	2.11	86.70	318.20

Appendix 7: Summary of biomass and SOC stock of *E.grandis* stand

Plot No.	Standing trees		Belowground		Litter		SOC (t/ha)	TBCS (t/ha)
	Biomass (t/ha)	Biomass carbon (t/ha)	Biomass (t/ha)	Biomass carbon (t/ha)	Biomass (t/ha)	Biomass carbon (t/ha)		
1	641.7	320.9	166.8	83.4	0.03	0.01	78.8	483.11
2	360.8	180.4	93.8	46.9	0.02	0.01	83.2	310.51
3	486.6	243.3	126.5	63.3	0.03	0.01	81.2	387.81
4	458.1	229.0	119.1	59.6	0.03	0.02	85.1	373.72
5	519.9	259.9	135.2	67.6	0.04	0.02	85.1	412.62
6	483.7	241.8	125.8	62.9	0.03	0.02	84.6	389.32
7	360.3	180.2	93.7	46.8	0.04	0.02	85.5	312.52
8	360.3	180.2	93.7	46.8	0.04	0.02	85.9	312.92
9	562.8	281.4	146.3	73.2	0.03	0.02	85.4	440.02
10	561.3	280.6	145.9	73.0	0.04	0.02	83.1	436.72
11	555.9	278.0	144.5	72.3	0.03	0.01	85.8	436.11
12	450.4	225.2	117.1	58.6	0.03	0.02	83.6	367.42
13	774.4	387.2	201.3	100.7	0.04	0.02	83.2	571.12
14	332.7	166.4	86.5	43.3	0.04	0.02	85.0	294.72
15	356.6	178.3	92.7	46.4	0.04	0.02	82.0	306.72
16	309.1	154.5	80.4	40.2	0.03	0.01	83.5	278.21
17	320.2	160.1	83.3	41.6	0.03	0.02	84.0	285.72
18	417.9	208.9	108.6	54.3	0.03	0.01	86.6	349.81
19	435.0	217.5	113.1	56.6	0.03	0.02	83.2	357.32
20	311.8	155.9	81.1	40.5	0.03	0.01	83.5	279.91
21	379.0	189.5	98.5	49.3	0.04	0.02	82.8	321.62
22	377.2	188.6	98.1	49.0	0.04	0.02	85.0	322.62
23	297.4	148.7	77.3	38.7	0.03	0.01	84.2	271.61
24	342.3	171.1	89.0	44.5	0.04	0.02	84.4	300.02
25	303.9	151.9	79.0	39.5	0.03	0.01	84.0	275.41
26	300.6	150.3	78.2	39.1	0.04	0.02	84.4	273.82
27	354.0	177.0	92.0	46.0	0.04	0.02	84.6	307.62
28	517.9	259.0	134.7	67.3	0.03	0.02	83.2	409.52
29	326.1	163.0	84.8	42.4	0.04	0.02	83.9	289.32
30	492.7	246.4	128.1	64.1	0.03	0.01	83.6	394.11
Mean	425.0	212.5	110.5	55.3	0.03	0.02	83.94	351.7

Appendix 8: Summary of biomass and SOC of *E. camaldulensis* stand

Plot No.	Standing trees		Belowground		Litter		SOC (t/ha)	TBCS (t/ha)
	Biomass (t/ha)	Biomass carbon (t/ha)	Biomass (t/ha)	Biomass carbon (t/ha)	Biomass (t/ha)	Biomass carbon (t/ha)		
1	89.1	44.6	23.17	11.59	0.03	0.01	88.3	144.42
2	117.9	59.0	30.66	15.33	0.04	0.02	76.7	151.03
3	144.1	72.0	37.46	18.73	0.03	0.01	83.2	173.99
4	201.5	100.8	52.40	26.20	0.04	0.02	74.5	201.46
5	211.4	105.7	54.97	27.48	0.03	0.01	76.8	209.96
6	112.3	56.2	29.20	14.60	0.04	0.02	77.5	148.32
7	149.5	74.7	38.86	19.43	0.03	0.01	78.0	172.20
8	145.0	72.5	37.70	18.85	0.03	0.02	88.2	179.52
9	172.4	86.2	44.82	22.41	0.03	0.01	90.6	199.24
10	132.6	66.3	34.48	17.24	0.03	0.02	90.8	174.39
11	171.8	85.9	44.68	22.34	0.03	0.01	86.1	194.33
12	129.6	64.8	33.68	16.84	0.03	0.01	81.9	163.54
13	180.6	90.3	46.96	23.48	0.03	0.01	90.2	204.02
14	194.3	97.2	50.52	25.26	0.04	0.02	87.9	210.32
15	118.2	59.1	30.73	15.37	0.04	0.02	84.5	158.98
16	159.7	79.9	41.53	20.77	0.03	0.01	83.0	183.66
17	143.8	71.9	37.40	18.70	0.03	0.02	92.3	182.91
18	150.1	75.0	39.02	19.51	0.03	0.01	94.6	189.16
19	170.2	85.1	44.26	22.13	0.03	0.02	90.1	197.39
20	191.2	95.6	49.72	24.86	0.03	0.01	89.1	209.53
21	173.1	86.6	45.01	22.51	0.04	0.02	93.2	202.34
22	218.1	109.0	56.70	28.35	0.04	0.02	86.7	224.12
23	221.0	110.5	57.45	28.72	0.03	0.01	93.8	233.03
24	137.4	68.7	35.72	17.86	0.04	0.02	83.1	169.69
25	199.6	99.8	51.89	25.95	0.03	0.01	94.0	219.72
26	166.0	83.0	43.17	21.59	0.04	0.02	90.7	195.35
27	194.3	97.2	50.53	25.26	0.04	0.02	77.3	199.77
28	195.7	97.9	50.89	25.45	0.03	0.02	87.4	210.78
29	232.3	116.1	60.39	30.19	0.04	0.02	91.0	237.33
30	200.8	100.4	52.21	26.11	0.03	0.01	97.8	224.32
Mean	167.5	83.7	43.54	21.77	0.03	0.02	86.7	192.24

Appendix 9: Location of *E. grandis* stand plots in relation to elevation, latitude and longitude

Plot No	Elevation (m)	Latitude (UTM)	Longitude (UTM)
1	1683	206147	1169233
2	1684	206169	1169222
3	1685	206136	1169211
4	1684	206158	1169211
5	1683	206136	1169200
6	1684	206136	1169189
7	1684	206147	1169189
8	1685	206168	1169189
9	1684	206135	1169178
10	1685	206146	1169178
11	1685	206168	1169178
12	1683	206179	1169178
13	1684	206190	1169177
14	1684	206201	1169177
15	1681	206223	1169166
16	1683	206234	1169166
17	1685	206234	1169155
18	1681	206212	1169155
19	1683	206201	1169166
20	1685	206179	1169166
21	1680	206168	1169167
22	1683	206146	1169178
23	1684	206135	1169178
24	1680	206135	1169167
25	1681	206146	1169167
26	1683	206168	1169167
27	1679	206179	1169155
28	1680	206201	1169155
29	1682	206212	1169155
30	1680	206212	1169144

Appendix 10 : Location of *E. camaldulensis* stand plots in relation to elevation, latitude and longitude

Plot No.	Elevation (m)	Latitude (UTM)	Longitude (UTM)
1	1627	206764	1169715
2	1691	206775	1169715
3	1691	206786	1169726
4	1693	206797	1169737
5	1693	206808	1169748
6	1692	206819	1169748
7	1691	206830	1169736
8	1692	206819	1169737
9	1693	206808	1169726
10	1691	206897	1169726
11	1690	206797	1169715
12	1688	206775	1169704
13	1686	206775	1169693
14	1688	206786	1169704
15	1690	206797	1169715
16	1691	206819	1169714
17	1690	206830	1169725
18	1689	206841	1169736
19	1686	206852	1169725
20	1688	206852	1169714
21	1688	206830	1169714
22	1687	206819	1169703
23	1687	206797	1169704
24	1686	206786	1169704
25	1683	206782	1169250
26	1685	206808	1169692
27	1685	206808	1169703
28	1685	206819	1169692
29	1686	206830	1169703
30	1684	206841	1169714

BIOGRAPHIC SKETCH

The author, Sewagegn Sahilu Taye was born in Awi Zone of Amhara Region in 1972. He attended his education at Ankesha Elementary School from grade 1-8 and then grade 9 - 12 at Ankesha Seniour Secondary School, Ankesha Gogusa Woreda of Awi Zone. After completing his primary and secondary school, he attended diploma in Plant science at Jima College of Agriculture from 1990 to1993. Since his graduation of diploma, he has worked as Natural Resourece Protection and Forest Development Junior expert at Benishangul Gmuz Regional State. He then attended B.Sc. degree in Forestry at Hawassa University, Wondo Genet Collage of Forestry and Natural Resource from 2001 to 2004. After graduation of B.Sc. Degree, he has worked as Natural Resource Protection and Forest Development Team Leader at Benishangul Gmuz Regional State from 2005 to 2009. Since 2010 until he joined the School of Graduate Studies of Hawassa University, Wondo Genet College of Forestry and Natural Resource to pursue his M.Sc. study, he has been working as Branch Manager at Amhara Forest Enterprise.