ASSESSMENT OF BIOMASS AND SOIL CARBON STOCK IN *EUCALYPTUS GLOBULUS* AND *CUPRESSUS LUSITANICA* PLANTATIONS IN BULE DISTRICTS, SOUTHERN ETHIOPIA**.**

M.Sc. THESIS

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OCTOBER, 2019

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M.Sc THESIS SUMMATED TO:

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MONITORING)

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APROVAL SHEET - 1

This is to certify that the thesis entitled "Assessment of biomass and soil carbon stock in *E. globulus* and *C. lusitanica* plantation forest in Bule district, South Nation Nationalities and peoples Regional state" is submitted in partial fulfillment of the requirements for the degree of Master of Science in Forest Resource Assessment and Monitoring, Wondo Genet College of Forestry and Natural Resource, and is a record of original research carried out by Teshome Daka Wedo, ID No. MSc/R021/10, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistances and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend that it be accepted as fulfilling the thesis requirements.

Mulugeta Zewdie (PhD)	____________________	________________
Major advisor	Signature	date

APROVAL SHEET – 2

We the undersigned members of the Board of Examiners of the final open defense by Teshome Daka Wedo have read and evaluated his thesis entitled “Assessment of Biomass and Soil carbon stock in *E. globulus* and *C. lusitanica* plantation forest in Bule district, Southern Ethiopia” and examined the candidate. Accordingly this is to certify that the thesis has been accepted in partial fulfillment of the requirement for the degree of Master of Science in Forest Resource Assessment and Monitoring.

Name of the Chairperson Signature Date

Name of Major Advisor Signature Date

Name of Internal Examiner Signature Date

Name of External Examiner Signature Date

Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the CGS through the DGC of the candidate’s department.

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Above all I thank the “Almighty God” that shepherded me and made this event to be possible. My special thanks go to my advisers Dr. Mulugeta Zewdie for their unreserved support and encouragement from the beginning of my study to its completion. I really appreciate Dr. Mulugeta Zewdie for this professional support, friendly approach, shape the manuscript and patience from the planning stage to the research work to the production of this thesis. I would like to express sincere thanks to the MRV project for providing funding for this study as a student for MSC and thesis research work. The South Region and Gedeo zone Environment protects and Forest Development office acknowledge for giving me the chance for my graduate study. In addition, Bule woreda Agricultural office very acknowledge for supporting field data collection materials and field work during my study. I am also indebted to the Herede farmers associated kebele for allowing me to take sample in their forest land and giving me the information during their forest field data measurements and collections. My besides standing me support my friends thanks from heart for their valuable contribution and encouragement to my success.

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DECLARATION

I, Teshome Daka Wedo, hereby declare that this thesis entitled "Assessment of Biomass and Carbon Stock of *E. globulus* and *C. lusitanica* tree plantation in Bule Districts SNNPs Ethiopia" submitted for the partial fulfillment of the requirements for the Master of Science in Forest Resource Assessment and Monitoring, is the original work done by me under the supervision of Dr. Mulugeta Zewdie. This thesis has not been published or submitted elsewhere for the requirement of a degree program to the best of my knowledge and belief. Materials and ideas of other authors used in this thesis have been duly acknowledged and references are listed at the end of the main text.

Teshome Daka Wedo	------------------------	------------------------------
Name of student	signature	Date

DEDICATION

This piece of work is dedicated to my wife, Beletech Toga, my brother Shitahun Daka and my son Yeabsira and Karlot for their endless love, me since studies supporting and encouraging to my success through death come ahead of their revels a bit before my success in joining of the university.

List of Abbreviations and Acronyms

ABTS	Above Biomass Tree Section
AGB	Aboveground Biomass
AGCD	Aboveground Carbon Density
ANOVA	Analysis of Variance
BGC	Belowground Carbon
BGB	Belowground Biomass
CO_2	Carbon Dioxide
DBH	Diameter at Breast Height
FAO	Food and Agricultural Organization of the United Nations
GHG	Green House Gases
GPS	Geographical Positioning System
Gt	Giga Tone
Ha	Hectare
H	Height
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilo gram

LC	Litter Carbon
Masl	Meter Above Sea Level
NASA GISS	National Aeronautics on Space Administration Goddard institute for Space studies
NOAA NCDC	National oceanic & Atmospheric Administration National Climate Data Center
NTVC	Non Tree Vegetation Carbon
^{O}C	Degree Celsius
Ppm	Parts Per Million
SBD	Soil Bulk Density
SNNPR	South Nation Nationalities Peoples Region
SHT	Soil Horizon Thickness
SOC	Soil Organic Carbon
TCo_2e	Tone Carbon Dioxide Equivalent
WD	Wood Density
WMO	World Meteorological Organization

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ABSTRACT

Forest plays vital role in their living biomass and soil by is if only through establishing forest on non-forest and carbon sequestrate. Biomass and soil carbon stock density estimation enables us to understand the current status of carbon stocks and to derive its near next changes. The occurrence of CO_2 as main greenhouse gas in atmosphere, it has ability to influence the global climate change. Fast growing tree species it helps to mitigation climate change. This study was carried out to estimate the amount of carbon stock in both stand of *C. lusitanica* and *E. globulus* plantation in the Bule district southern, Ethiopia. The data were collected by using systematic sampling method, with the sampling plots were selected by dropping a regular interval of 75 m and 100 m depending on the size of forest area. A total of 60 plots rectangular quadrates having a size of 10m x 20m were used to measured DBH and total tree height parameters. Within these plots five $1m^2$ subplots, four at the corners and one at the centre were laid out to collect soil and litter samples. The biomasses of trees in the forest were estimated by using species specific allometric equation developed in Ethiopia. The mean total carbon density of the forest was 260.23 and 265.37 (t C ha^{-1}) for *C. lusitanica* and *E. globulus* respectively. This is equivalent to 955.04 and 973.9 t C ha^{-1} of CO_2 gas. The mean carbon stocks at the stand of *E. globulus* were estimated at more than in all carbon pools. The carbon density of Bule district forest can be considered as medium when compared with other studies done elsewhere in the tropics.

KEY WORDS: Community plantation forest, biomass and soil carbon density.

1. INTRODUCTION

1.1. BACK GROUND

Increasing the extent of plantation forests has been optional as an effective measure to mitigate elevated atmospheric carbon dioxide (CO_2) concentrations and contributes towards the reduction of global warming (Watson *et al*., 2000 and IPCC, 2001). Climate change is the long term shift in average weather patterns across the world. The recent review shows carbon stocks in forest biomass declined by an estimated 0.5 Gt annually for the duration of the period 2005–2010 (FAO, 2010). In the course of deforestation and forest degradation makes up 12 to 20 % of yearly greenhouse gas emission, which is more than all forms of transport combined (Saatchi *et al*., 2011). The increment of carbon in the atmosphere is a concern worldwide; since it is the main important causal factor for global warming (Lal, 2001), and has direct cost on the economy, environments, aquatic resources and sea level rise (IPCC, 2001a). Causing great challenges on environmental norms and populations are happening globally due to climate change.

Global climate change will further reduce rainfall intensity and seasonality in the tropics; this has a bigger impact on the livelihood of the people in the tropics including plant and animal species (FAO, 2006). Increase the concentrations of atmospheric CO_2 also affect plant metabolism directly through photo-synthesis and has altered the dynamics of tropical forests (Chidumayo *et al*., 2011). There are great opportunities in forestry sector for mitigating climate change increases in the atmospheric carbon pool (Negash, 2013). Forest ecosystems can be also sources and sinks of carbon (Watson *et al*., 2000).

Soil is the largest carbon reservoirs of the terrestrial carbon cycle 1500-1550 Gt of organic carbon and soil inorganic carbon approximately 750 Gt in to 1 m depth. About three times more carbon is contained in soils than in the world's vegetation 560 Gt and soils hold double the amount of carbon that is present in the atmosphere 720 Gt (Post *et al.*, 2001 and Lal, 2004b). Forest soil is part of any forest ecosystem and accumulates about 40 % of the total soil organic carbon of the global soils (Baker, 2007 and Rooney, 2013). Soils play a key role in the global carbon budget and greenhouse effect and it contains 3.5 % of the earth's carbon reserves, compared with 1.7 % in the atmosphere, 8.9 % in fossil fuels, 1.0 % in biota and 84.9 % in the oceans (Lal, 2004a). Carbon stocked in organic form in soils (SOC) is affected by environmental factors such as topography, parent material or soil depth (Fu *et al*., 2004 and Johnson *et al*., 2000). Forest soils are subjected to lower human disturbance than agricultural soils and having lower bulk density than others soils due to the presence of higher organic matter content (Lal, 2005).

The carbon pools in forest ecosystem are affected by altitude, slope, and land use types, (Diawei *et al.,* 2006 and Bhat *et al*., 2013), indicated that land use, land use change, soil erosion, and deforestation are the most important factors affecting the carbon stock density in the forest ecosystem. According to the Feyissa *et al.*, 2013, the forest carbon stock is affected by altitude and slope. Altitude has a significant effect on temperature or precipitation. This strongly affects the species composition, the diversity, the quantity, and the turnover of forest ecosystem (Sheikh and Bussman, 2009). According to Hamere *et al*., 2015 assessed the impact of the slope in above and belowground biomass, soil organic carbon, and total forest ecosystem carbon, in which east slope aspect showed the highest, whereas south slope showed the lowest total carbon stock. In the tropics, land use affects the global carbon cycle by increasing the rate of carbon emissions (silver *et al*., 2000). Conversion of forest to other land use or land cover into agricultural land use types reduced soil organic carbon stock density by 20 – 50 % (Solomon *et al*., 2002; Lemenih and Hama, 2004 and Lal, 2005).

A substantial proportion of the land area is situated in highlands of Ethiopia once covered by forests (Abate *et al*., 2005). Deforestation is mostly caused by the conversion of forested areas to agricultural land. The forest sector is the second biggest emitter (55 million t CO_2e), next to agricultural sector. If the current emission trend is unabated, the GHG emission of the country will reach 400 million t CO_2e in 2030, and the forest sector will continue to remain the second biggest emitter, reaching over 90 million tones CO_2e (CRGE, 2011). Climate change is mainly occurring due to anthropogenic activities. Scientists have reached a common agreement that the lower atmosphere and the earth's surface are definitely getting warmer (IPCC, 2006).

In Ethiopia there has been very limited forest carbon stock study by considering environmental factors and tree species that affect carbon stock. Therefore, this study was done to assess and differentiate the species variable with carbon content. And this gives basic information for the forest to mitigate climate change. Forests have the capacity to receive in high amount of atmospheric carbon dioxide for their photosynthesis and sinker carbon in their biomass. Fast growing plantation forest species such as *E. globulus* and *C. lusitanica* played a vital role in the climate change mitigation and adaptation endeavors through carbon sequestration and stock as a result of their fast growing nature. These fast growing tree species also played a vital role by reducing pressure on ruminant natural forest. This is one of the few studies addressed such research gaps. The study will also help to understand the two mainly carbon pools above and below ground of these fast growing tree species the targeted location. The information can be serve as a baseline data to apply for sustainable forest management for the targeted forest and hence, this study provided empirical evidences to consider these fast growing tree species as a source of carbon pools bio-based climate change mitigation strategies in the study region in particular Bule District and in the country in general.

1.2. Statement of the problem

Climate change is a global warming event that increases carbon dioxide concentration in the atmosphere. It is the most serious environmental challenge of the world today. It cannot be stopped. But it can be climate change mitigated. Tree plantation systems as land use can reduce the atmospheric concentration of the carbon dioxide. Carbon sequestration and store through forest plantations has a high potential in ameliorating global environmental problems such as atmospheric concentration of carbon dioxide and related climate change. Climate change which is attributed directly or indirectly by human activity alters the composition of the global atmosphere. In Ethiopia, *E. globulus* and *C. lusitanica* are exotic plantation species. These fast growing tree species helps to reduce more CO_2 from the atmosphere than they would release. This research work aimed to provide information on the carbon stocks of above ground and below ground biomass along with soil carbon stock in the *E. globulus* and *C. lusitanica* plantation species in the study site.

1.3. OBJECTIVES OF THE STUDY

1.3.1. General Objectives

The main purpose of this study is conducted to assess biomass and soil carbon stock of *E. globulus* and *C. lusitanica* tree species in community forest in Bule District SNNPRS of Ethiopia.

1.3.2. Specific Objectives

1. To estimate biomass carbon stock of *E. globulus* and C. *lusitanica* tree species plantation.

2. To estimate soil carbon stock density under studied tree.

3. To estimate total forest ecosystem carbon density for targeted tree species.

1.4. Research question

1. How much ACD, BCD, Litter carbon density and SOCD stored by the targeted tree species?

1.5. Significance of the study

Study on above ground biomass and carbon stock of *E. globulus* and *C. lusitanica* tree plantations gives basic information about the environment particularly land resources. Assessment of above ground biomass and carbon stock in any forest system is important because it gives economic and ecological benefits to the local people and environment. It was also important to growers, policy makers and development practitioners to have better knowledge as to where and how to focus on *E. globulus* and *C. lusitanica* tree plantation's potential to mitigation against global warming.

1.6. Organization of the Thesis

This study is presented in six headings. Heading one is an introduction part of the thesis to give a background to the research which is described and to the identified statement of the problem being researched and the objective of the study. Heading two presents a literature reviews that deal ideas related to the study that has been supported. In heading three, the methodology employed on the samples and the sampling techniques, data collection procedures, model development and data analysis strategies was discussed. Heading four is concerned with data presentations, analysis and interpretations. Heading five deals with discussion depending on the present results, whereas the last heading, heading six, presents conclusion and recommendations of the study

2. LITERATURE REVIEW

2.1. Definition of plantation forestry

The trend in Ethiopia today is to keep the remaining natural forests for their various social, economic and environmental values, and to meet increasing demand for fuel wood and wood products. Plantations are even-aged forest stands deliberately established by human's forest on non-forested land (Moges *et al*., 2010).

The size of plantations ranges from less than a hectare woodlots to several hundred thousands of hectares of land. Size of large-scale state or community plantations depends on whether the plantation is integrated with a processing industry and thus with its annual intake of wood, availability of market or the wood requirements of communities (Moges *et al*., 2010).

2.2. Plantation forest in the tropics and Ethiopia

Plantation forestry has intensified in current years and continues to do so, especially in the tropical countries. In these regions plantation forest shows faster growth and rotation age have high yields as compared to other regions (Paquette and Massier, 2010).

Plantation forest has increased over the past decade, representing 7 % of and the relative rate of annual expansion has been 2 % (Harver *et al*., 2010). Plantation forests in the tropics have been planted in the form of introducing a limited number of species which are exotic to most of the areas where they are cultivated (Plath *et al*., 2011). Plantation forest in Ethiopia is an old aged practice, which is wide spread in different forms in the diverse agro ecologies of the country. Mainly plantation forest types include industrial, farm, agro forestry and environmental plantations (Nanu *et al*., 2013). Most of the plantation forest dominated by

Eucalyptus species and known to provide more fuel wood, construction material and income generation for small scale land hold farmers (Teketay *et al*., 2000).

The composition of plantation species are *Eucalyptus* covering 58 % and *Cupressus lusitanica* 29 % of the total area followed by *Juniperus procera* 4 %, *Pinus potula* 2 %, and other species 7 % (Yitebtu Moges, 2010). *Eucalyptus* is fast growing and preferred species plantations; they are widely grown in Ethiopia and thus are of great commercial importance (Teketay, 2000).

2.3. *Eucalyptus globulus* (Labill), plantation in Ethiopia

According to Tesfaye Debela (2017), *E. globulus* tree species , usually grows to 45 m tall, sometimes reaching 70 m. Bark usually smooth, white to cream, yellow, bluish-grey or grey, peeling from the trunk throughout, but with accumulated grey-brown, not-peeling bark for up to one meter from the trunk base. Juvenile leaves numerous and prominent, opposite, sessile, cordate, base clasping the stem, ovate, grey-green to glucose, with strong difference in color between the two sides. In contrast, Eucalyptus generally has become well adapted to the Ethiopian environment. This is also perceived by farmers. During the socio-economic survey made by Haileab Zegeye, 2009 at Addis Zemen in South Gondar Zone, a farmer stated that "*Eucalyptus* is the king of trees though it has some adverse impacts on crops". *Eucalyptus* planting is mostly by farmers, but also by State and private sectors. Survival and growth rate is good. Local communities in different parts of the country have become increasingly dependent on *Eucalyptus* for fuel wood and construction material, among other uses. This has certainly contributed to the steady expansion of *Eucalyptus* in the country. Today *Eucalyptus* dominates rural and urban landscapes. However, in spite of the fact that this species has been planted widely throughout the highlands of Ethiopia, the availability of wood for fuel and construction materials is still problematic (Negash Mamo, 1995) and it helps to mitigated climate change.

2.4. *C. lusitanica* plantation in Ethiopia

Cupressus lusitanica (Mill) is an evergreen coniferous tree, 35 m height, with a dense, conical crown. Trunk short, 70 cm in diameter (Orwa *et al.,* 2009). The Latin name *'Cupresssus'* comes from the Greek 'kuparissos', which commemorates a youth of that name who was turned into a cypress tree by Apollo. The specific name is derived from Lusitania, Portugal, where the tree was introduced in the 17th century (Orwa *et al.,* 2009). Distribution of the species; Native to Belize, Costa Rica, Elsalvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, United States of America, and Exotic to Eritrea, Ethiopia, Kenya, Portugal, South Africa, Spain, Tanzania, Uganda (Orwa *et al*., 2009).

It originates from the moist forests of Mexico and Central America. After eucalyptus, it is one of the commonest plantation trees in Ethiopia. It grows best in dry, moist, and wet weyna dega and dega agro climatic zones. The tree is only moderately drought resistant and requires deep moist soils. It belongs to the *Cupressaceae* family. It is indigenous to Central America where it grows at altitudes ranges of 1200 – 3000 m.a.s.l (Azene Bekele, 2007).

C, lusitanica can be used for fuel wood, home furniture, construction, poles, posts, shade, ornamental purpose, windbreak, live fences. It is fast growing on good sites moderate on poorer sites. It can produce poles after 10 years and general purpose timber in as little as 20 years. From Ethiopia, Kenya, and south to Malawi *C. lusitanica* plantations have been badly affected by a cypress aphid and many thousands of trees have died in recent years (Azene Bekele, 2007) *C. lusitanica,* flourishes in deep, moist, well drained, fertile loams of neutral to slightly acidic reaction, (Orwa *et al*., 2009).

C. lusitanica Mill is the most widely planted conifer exotic tree species in Ethiopia. It was introduced in the country some 40 – 50 years ago Pukkala T and Pohjonen V. 1993.

The industrial purpose plantations were established in the 1950s around the first sawmills, 200 km south of Addis Ababa, in the Munessa forest, along the eastern escarpments of the Rift valley Pukkala T and Pohjonen V. 1993.

In the 1970s and 1980s *C. lusitanica* besides *E. globulus Labill*, was a widely planted tree exotic species in the soil conservation and community forestry programmed in the Ethiopian high lands which was supported by FAO, 1986.

2.5. Plantation forests for climate change mitigation

From the terrestrial sequestration, forests play an important role in the global carbon cycle (IPCC, 2001). Their temporal carbon dynamics are characterized by long periods of gradual build-up of biomass (a sink), alternated with short periods of massive biomass loss (Phillips *et al.*, 1998). Carbon dioxide (CO_2) is a major GHG and its absorption in the atmosphere is believed to be accelerated by human activities such as deforestation and forest degradation and burning of fossil fuel (Metz *et al*., 2007). To reduce CO_2 from the atmosphere, the two key activities are reduction of human emission of CO_2 and storing of the atmospheric carbon in the biosphere using land use systems such as afforestation / reforestation (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). Forest ecosystems accumulate carbon through the photosynthetic assimilation of atmospheric CO_2 and the subsequent storage in the form of biomass (trunks, branches, foliage, roots, etc) (Brown *et al*., 1996 and Malhi *et al*., 2002). plantation forests after 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, dead wood and litter and achieved through on expansion of forests either by planting currently unplanted land or by allowing the existing forests to accumulate higher biomass and other to utilized plantation forest directly as a source of energy which is considered as carbon neutral energy source (Kooten, 2000). According to Harvey *et al*., 2014, plantation forest is the important practice for climate change mitigation especially in the tropics, where the carbon sequestration capacity is high and successful implementation requires knowledge of the role of species identify and diversity on the carbon sequestration of plantations. However, there is a large variation in the carbon sequestration presence at different plantation species and there is varying estimation of the carbon sequestration taken of common plantation species (Sharma *et al.,* 2011).

Plantation forest can make a very significant contribution to a low cost of global climate change mitigation range that provides synergy with adaptation and sustainable development, including extending carbon retention in harvested wood products, produce substitution, and biomass production to meet society’s needs for timber, fiber, and fuel wood (Smith *et al*., 2007). Since plantation forests are a cost effective means of carbon sequestering and countries that have a large forests sector are interested in carbon credits related to reforestation and those with large tracts of agricultural land are interested in afforest ration as a means for achieving some of their agreed upon co_2 emission reduction (Sedjo *et al*., 1995). Plantation forest face of global climate change problem will continue to play a key role as carbon sinks, mitigating greenhouse gas emissions.

2.6. Carbon stock of plantation forests ecosystems.

Soil health and vegetation productivity are closely related to above- and below-ground carbon stocks (Aynekulu *et al*., 2011). Carbon stock is defined as total carbon stored 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). Different forest ecosystems have different biomass and carbon stock potentials (Nair *et al.*, 2009). This variability is mainly due to the species composition, growth rate, age, geographical location of the system (Jose, 2009), previous land use (Mutuo *et al*., 2005), climate, soil Chacterstics, crop tree mixture, site productivity and management systems (Montagini and Nair, 2004).

Tropical plantation forests have important role for carbon stock in a 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 always at individual tree and stand levels throughout time due to loss of carbon during deforestation caused by human activities and accumulation of carbon during growth of forests (Miyanoto *et al*., 2007). It is estimated that, the carbon stored globally in the forest biomass amounts to 240,439 Mega ton with an average carbon density of 71.5 ton ha^{-1} 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. Ethiopia proposes a Forest Reference Emission Level based on average annual emissions over the period 2000-2013 assessed by AD x EF of 19.5 Mt CO_2e/yr and a Forest Reference Level based on average annual removals over the period 2000-2013 assessed by AD x EF of -10.2

Mt CO_2e/yr (UNFCCC, 2016). According to information plantation forests have increased compared to the previous decades in 2005 (491,291 ha) to reach in 2015 (972,000 ha) (FRA, 2015). 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 *Eucalyptus* are used for energy in the form of charcoal, they have a positive net carbon balance (Marcolin *et al*., 2002).

The mean aboveground carbon stock of plantation forest is 123 t C ha^{-1}. 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 C ha^{-1} (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^{-1} (AGC=68.34 and BGC=23.92) (Metz *et al*., 2007). According to Fantu *et al*., 2007 study in Kofele districts, Ethiopia, the above ground biomass carbon stock of *E. 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^{-1}. According to (Yirdaw M, 2018) the total carbon content of *E. saligna* was 59.68 and *C. lusitanica* was 60.08 t ha^{-1}. *E. saligna* and *C. lusitanica* sequestered (38.74 and 39.05 t ha^{-1}) aboveground carbon respectively. According to George, 2014, whatever the importance of *Eucalyptu*s plantation in carbon sequestration and storage its potential is already accepted and well documented in many countries. However, there is no sufficient research done on carbon storage potential of many species in Ethiopia.

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 sustainability (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 of the species composition, stand age, origin of stand establishment (seed source and coppice), site quality, genetic variation, stand density, management regime, previous land use and environmental conditions such as elevation, slope and aspect of 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 of the selection system (Mckinely *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 wildfire. According to Mckinely *et al*., 2011, high severity fire can increase soil erosion and nutrient cycling and decrease post fire seedling recruitment, thus leading to long term loss.

2.8. Importance of carbon stock estimation in a forest ecosystem

Estimation of forest carbon stock is useful in assessing forest structure, condition, forest productivity and carbon stock based on sequential in biomass change, sequestration of carbon in biomass components and can be used as an indicator of site productivity (Chave *et al*., 2003). Estimation of carbon stock of a forest is crucial to quantify the environmental services provided by forests 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 in economic valuation of forests to explore possibilities of financial earns through mechanisms such as the united nations reducing emission from deforestation and forest degradation in developing countries program (UNREDD), organizations such as REDD+, CDM and other voluntary organization for carbon credits allocation based on carbon stocks performance that 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 scale land holder farmers of the region that are prone to climate change and variability by creating another important income source that would make the local livelihoods resilience to climate change (Gurney and Raymond, 2008). Measurement of carbon stock of forest species wise distribution in different geographical regions enable to identify region which are rich or no in carbon stocks while providing information on specific tree species and which species are greater carbon sequestration ability under their respective climatic and soil conditions (Pearson *et al*., 2007). Furthermore, comparative carbon stock estimates provide indications of the condition of forest resources in a given climate zone and an indirect estimate of site quality (Houghton and Goodale, 2004). According to Houghton and Goodale, 2004, there is variation between carbon storage potential of species and extrapolation of biomass stocks to ecosystem and allow reliable emission estimates from land use and land cover change scenarios.

2.9. Type of Carbon pools and biomass

(UNFCCC, 2015) classify carbon stored in the forest ecosystems into five pools such as above ground woody and non woody, below ground (roots), and standing or down dead wood, litter and carbon in soil organic matter. To estimate carbon stock in above ground tree biomass per unit area is estimated depending on field measurements in fixed area sample plots or temporary sample points that are selected systematically. The below ground tree biomass to above ground biomass (usually a root-to-shoot ratio) has a range of relationship. For tropical rain forest or humid forest, below ground biomass is estimated to be about 27 % of the above ground biomass (woody and non woody) estimates (IPCC, 2006 and Pearson *et al*., 2007).

In estimating aboveground biomass through using allometric equation woody basic density, height, DBH (Diameter at Breast Height) were widely used variables. These traits were varying among species, forest types, age, and soil fertility (Chave *et al*., 2005). The level of aboveground biomass carbon stock on the species type, ages of land use, site, allometeric equation used, and agro ecology (Henry *et al*., 2009 and Chave *et al*., 2005)

Allometric equations of individual trees measurements are usually used for biomass and carbon stock determination by non- destructive method. It has been demonstrated that choosing suitable allometric equations for each forest type is of great importance, because biomass and related carbon estimates are highly sensitive to the choice of allometric equation (Chave *et al*., 2004; Pearson *et al*., 2005 and Jepsen, 2006). To quantify carbon sources and sinks, it is essential to estimate the above ground and below ground biomass in forests. Thus, the aim of this study will be to estimate and compare the biomass (above and below ground biomass) and soil carbon stock between plantation forests of *E. globulus* and *C. lusitanica* stand in Bule districts at south West Gedeo Zone of SNNPs.

2.9. 1. Biomass carbon stock estimation methods

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 sample area level (Gibbs *et al.*, 2007), Non- destructive biomass estimation method without harvesting of trees and it can be done using existing biomass equations to extrapolate biomass to a given unit area (Pearson *et al.*, 2007). Non- destructive methods use readily measurable variable, such as diameter at breast height (dbh), tree height, or other vegetation indices that can be converted to biomass based statistical relationships developed by destructive sampling methods (Massada *et al*., 2006).

To estimate the aboveground tree biomass used equation are different depending on the type species, geographical location, and type of forest, climate and other factors, that using Species specific allometric equations are used to predict tree and stand biomass, based on easily measured tree variables such as diameters and total height of tree. Such equations are specific to species, sites, tree age and management (Kairo *et al*., 2009). It is necessary to achieve higher levels of accuracy for biomass estimation and quantifying carbon. Studies in temperate and tropical regions have shown the advantages of species-specific biomass and volume Allometry (Basuki *et al*., 2009). Species-specific allometric equations are preferred, because tree species may differ greatly in tree architecture and wood gravity (Ketterings *et al*., 2001).

There are different types of generic allometric equations which are developed to estimate the aboveground tree biomass, tropical, temperate and boreal natural forests as general (Solomon *et al*., 2007). But, there no well-defined and organized plantation forest species specific equation except a few species (Solomon *et al*., 2007). Due to this case, most of the researchers are using generic allometric equation developed for natural forests to estimate the above ground tree biomass of plantation forest (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 forest inventory and absence of site and species specific allometric equations. Due to 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 mainly carbon pools such as living above and below ground biomass, dead wood and litter and soil organic carbon. But most of the total carbon in plantation forests is stored in aboveground biomass of truck, branches and foliage (Sharma *et al*., 2011).

Below ground biomass carbon stock consist of all living biomass of root of trees, and the biomass in tree stem below 1% height stump (Nadelboffer and Raich, 1992). Estimation of below ground biomass is relatively tidies and expensive as compared to above ground biomass estimation due to wide variability in the way that roots are distributed in the soil (Pearson *et al*., 2007). The belowground biomass will be estimated by multiplying the aboveground biomass by 24 % ratio factor (IPCC, 2006). 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 different regression models with less data that are existing for estimation of below ground biomass as a function of above ground biomass for different region (Pearson *et al*., 2007). However, according to MacDicken, 1997, for cases in which more accurate estimates of below ground biomass are economically affordable using locally established methods is important.

Forest litter layer is defined as all organic surface material that includes dead leaves, twigs, foliages, 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 contents in the litter biomass is estimated by decomposition of dead biomass in the warm, humid climatic conditions which leads to carbon and nutrient leaching (Trumper *et al*., 2009). The type of tree species found system also plays an indirect role on the SOC accumulation through their productivity allocation of AGB & BGB (Lemenih *et al*., 2004). However the carbon of the litter to SOM will depend on the quality of the litter. Litter rich in phenolic and will have higher C/N values and contribute to the slower decomposition rates leading to have SOM found in short term (Jandl *et al*., 2007).

2.9.2. Above and below ground biomass carbon stock

Biomass is defined as organic material both above and belowground, and both living and non-living, e.g., trees, crops, grasses, litter, roots etc. aboveground biomass consists of all living biomass above the ground including stem, branches, bark, seeds, and foliage. Belowground biomass consists of all living roots excluding fine roots (< 2 mm in diameter). In forest tree biomass studies, two biomass units are used, fresh weight (Araujo *et al*., 1999), and dry weight (Aboal and Saint-Andre *et al*., 2005). Vegetation biomass is the living organic matter that is produced by photosynthesis (Brown, 1997). Forests are the largest terrestrial reservoir for atmospheric carbon because they remove CO_2 from the atmosphere and store in it biomass, litter, soil and other organic matter. The recent carbon store in tree biomass comprises half of the atmospheric storage and is continuing to grow despite deforestation, the rate of which is decreasing but still high (Mwakisunga, 2012). Different studies show that forests ecosystem store different amount of carbon in defined pools including aboveground biomass carbon (AGBC), belowground biomass carbon (BGBC), leaf litter (fine necromas), dead woody (coarse woody necromas) and soil organic carbon matter (Mwakisunga, 2012). It is clearly known that the changes in forest land affect the carbon density (Rowell, 1994).

Estimated at global level, 19 % of the carbon in the earth's biosphere is stored in the plant biomass and 81 % in the soil (IPCC, 2000). In all forest, tropical, temperate and boreal together, approximately 31.3 % of the carbon is stored in the biomass and 69 % in the soil. In the tropical forest, approximately 50 % of the carbon is stored as biomass and 50 % in the soil. Recently, biomass measurements have become crucial for determination of carbon sequestration in vegetation and for understanding the impact of land use land cover changes (LULCC) on carbon fluxes (Cole and Ewel, 2006 and Heryati *et al*., 2011).

The most precise method for determining carbon biomass is to destructively harvest all plants, partition each by mass into various constituent components (e,g, stem, branches, leaves, flowers, fruits and roots) and subsequently determine the carbon content of the various components analytically. However, uprooting vegetation, especially trees, is time consuming, costly, and sometimes illegal. With respect to the latter, cutting forest trees often goes against the goal of conserving forests (Basuki *et al*., 2009; Djomo *et al*., 2010 and Jachowski *et al*., 2013). Although direct measurements of forest biomass provide higher estimation accuracy than other methods, it is impractical for larger areas. As alternative approach is to use established allometric equations to estimate biomass and then calculate biomass as a fraction of this value. Allometry in the context of tree biomass estimation refers to mathematical equations relating biomass of an entire tree or individual tree components such as stems, branches, leaves, or roots to one or two easily measured biophysical factors, i, e tree diameter at breast height, tree height, or wood density (Banaticla *et al*., 2007; Basuki *et al*., 2009 and Kuyah *et al*., 2012). Allometric models have been developed from non destructive surrogate measurements, such as tree bole diameter at breast height (DBH), non destructive or indirect method attempts to estimate tree biomass by measuring variables that are more accessible and less time consuming to assess, wood volume and density (Peliter *et al*., 2007). By constructing a functional relationship between tree biomass and other tree's dimension, such as stem diameter, height and wood density, by means of regression analysis rather than performing the "destructive sampling" in the field. Additional, these equations can help in predicting the biomass components, based on some easily measurable estimator variables such as stem diameter or circumference, crown diameter or height which can be measured non destructively (Whitaker and Wood well, 1968). Moreover, allometric relationships through regression analysis have advantages I. e, once equations are developed and validated; they can be used for similar forest types on a wide range of sites in a particular geographic region. Such estimates are clearly most precise, when they are calibrated with samples from the species of interest and this kind of measurement is environmental friendly and applicable at species level.

2.9.3. Litter biomass carbon stock

Forest litter is the dead organic matter produced by aboveground plants in forest ecosystems, (Wang *et al*., 1989). It is one of the most important components of carbon pool and nutrient cycling and regulates soil microclimate by forming a buffering interface between the soil surface and the atmosphere (Sayer, 2006; Zhou *et al*., 2008), reported that the carbon storage in forest litter should not be neglected as it is the third largest carbon pool in forest ecosystem. Generally the annual nutrients released from litter decomposition could meet 69-87 % of total nutrients required for forest growth (Waring and Schlesinger, 1985). The amount of litter on the forest floor also affects soil nutrient status, soil water content, soil temperature, and soil PH (Sayer, 2006). The forest litter (fallen leaves, twig, flower and fruit) forms a specific carbon pool, playing an important role between soil organic carbon and biomass carbon. It is influenced by forest types, site conditions and forest management operations (Jiang, 2014). Although litter decomposition is one of the major sources of SOC and quality of litter is very important in this regard (Mafongoya *et al*., 1998; Issac and Nair. 2006 and Lemma *et al*., 2007). In systems with high plant diversity, it is likely that they would have litters with different degrees of chemical resistance, creating the possibility of longer resistance of carbon through slower decomposition of litters from some species. Lignin in litter is highly resistance to decomposition and therefore, litter with high lignin content would have slower decomposition rate (Mafongoya *et al*., 1998). In contrast, litter with low lignin, phenols, and high N content would have faster rate of decomposition.

In contrast, litter with low, phenols, and this pool comprises biomass in various states of decomposition prior to complete fragmentation and decomposition where it is transformed to SOM. Local estimation of the DOM litter pool again relies on the establishment of the wet-to-dry mass ratio. Where this is not possible default values are available by forest type and climate regime from IPCC ranging from 2.1 tons of carbon per hectare in tropical forests to 39 tons of carbon per hectare in moist boreal broadleaf forest (IPCC, 2006).

2.9.4. Soil carbon pool estimation method

Soil organic carbon is thought to the largest component of the global carbon cycle, holding more than the atmosphere and vegetation combined (Lal, 2004). Soil carbon is found in mineral and organic soils to a specified depth chosen (FAO, 2010). Soil carbon content is the result of the net balance between carbon inputs and outputs (Vashun and Jayakumar, 20120). These biological activities depend on primary production and organic matter decomposition. Soil carbon sequestration increases SOC stocks through judicious land use and recommended management practices. The potential soil carbon sink capacity of managed ecosystems approximately equals the cumulative historic carbon loss estimated. The attainable soil carbon sink capacity is only 50 to 66 % of the potential capacity. The strategy of soil carbon sequestration is cost effective and environmentally friendly (Lal, 2004).

The amount of carbon present in soil depends on the rate of decomposition by micro organisms, the rate of organic matter input from plant residues, soil properties and climate region (Grandy and Robertson, 2007 and Harris *et al*., 2015). Soil carbon is an important attribute of soil quality and its productivity (Sarika *et al*., 2014). Soil quality defined as the capacity of a soil to function. Within ecosystems boundaries, to sustain biological productivity, improve environmental quality and support human and plant health's (Doran and Parkin, 1994). Soli are the largest carbon reservoirs of the terrestrial carbon cycle, 1500-1550 Gt, of organic soil carbon and soil inorganic carbon approximately 750 Gt both to 1 m depth. About three times more carbon is contained in soils than in the global vegetation (560 Gt) (Post *et al*., 2001 and Lal, 2004). Soils play a key role in the global carbon budget and greenhouse gas effect. Soils contain 3.5 % of the earth's carbon reserves, compared with 1, 7 % in the atmosphere, 8.9 % in fossil fuels, 1 % in biota and 84.9 % in the oceans (Lal, 2004), or according to Jastrow, 2002 and Baker, 2007 about 75.5 in the terrestrial carbon is stored in the global soils. Thus, they provide potential way to reduce atmospheric concentration of CO_2 (Sarika *et al*., 2014). Soils store two/ three times more carbon than that exists in the atmosphere as CO_2 (Davidson *et al*., 2000), and 2.5 to 3 times as much as that stored in plants (Post, Mann and Houghton, 1990) carbon storage in soils is the balance between the input of dead plant material (leaf and root litter) and losses from decomposition and mineralization processes (heterotrophic respiration) soil organic carbon is this extremely valuable natural resource (Sarika *et al*., 2014). Irrespective of the climate debate, the SOC stock must be restored, enhanced and improved.

Globally, soils store more carbon than the atmosphere and biosphere combined, acting both as a source and sink of atmospheric CO_2 (IPCC, 2013). However, cultivation loss of SOC ranges from 50 to 70 % (Lal and Bruce, 1999). On the other hand, conversion from cultivation to native grasslands, such as through enrollment in the conservation reserve program resulted in increased soil carbons (Teixeira and Pineiro *et al*., 2009). Therefore, it is critical to evaluate the impact of agricultural land use and management on regional carbon budgets (Drewniak *et al*., 2015). The influence of agriculture on the carbon cycle is complex; carbon capture and storage in crop lands are dependent on management practices, including tillage, fertilizer applications, residue management, and crop sequence (Huggins; Khan *et al*., 2007 and Kim *et al.*, 2009). SOC stocks and fluxes at a particular location are soil and site specific and reflect the long term balance between organic matter inputs from vegetation and losses due to decomposition, erosion, and leaching (Drewniak *et al*., 2015). Some studies have attempted to quantify carbon sequestration from mitigation strategies such as no- till or conservation tillage practices, residue management, use of cover crops, and restoration and reserve actions (Conant *et al*., 2001; West and Post, 2002).

The bulk density of a soil varies with texture, depth, management as well as with inherent soil quality (Zhou *et al*., 2010). Increase in bulk density usually indicates a poorer environment for root growth, reduced aeration, and undesirable changes in hydrologic function, such as reduced water infiltration (Brady and Weil, 2010). Bulk density can be changed by management practices that affect soil cover, organic matter, soil structure, compaction, and porosity. Excessive tillage destroys soil organic matter and weakens the natural stability of soil aggregates making them susceptible to erosion caused by water and wind. When eroded soil particles fill pore space, porosity is reduced and bulk density increases. Tillage and equipment travel results in compacted soil layers with increased bulk density, most notably a “plow pan”. Tillage prior to planting temporarily decreases bulk density on the surface but increases at the depth of tillage. Subsequent trips across the field by farm equipment, rainfall events, animals, and other disturbance activities will be compact soil. Long-term solutions to soil compaction center on decreasing soil disturbance and increasing soil organic matter (Greg and Robert, 2009).

3. MATERIAL AND METHODS

3.1. Description of the study area

3.1.1. Location of the study site

The study area was conducted in Bule District, which is one of the ten woredas found in Gedeo zone (6^0 30’19” N latitude and 38^0 40’87” E longitudes). The study area is located at 122 km distance from Hawassa town and 387 Km south to Addis Ababa, the capital city of Ethiopia. Bule is bordered on the south by Gedeb woreda, on the south west by Yirgachefe, on the west by Wonago, on the North West by Dilla zuria, on the north by the Sidama zone and on the east by the Oromia region. Elevation 1,700 m.a.s.l to 3,064 m.a.s.l. Bule woreda is characterized by two agro ecological zones or altitude ranges between 34.3 % and 65.7 % (Weyina-dega and Dega respectively), Herede kebele is found 10 km from Bule town. The forest is part of the Herede farmer association specifically Buna koba community plantation forest. The district has 34 kebeles with administrative town of Bule, comprising 30 rural and 4 urban kebeles.

Map of study area

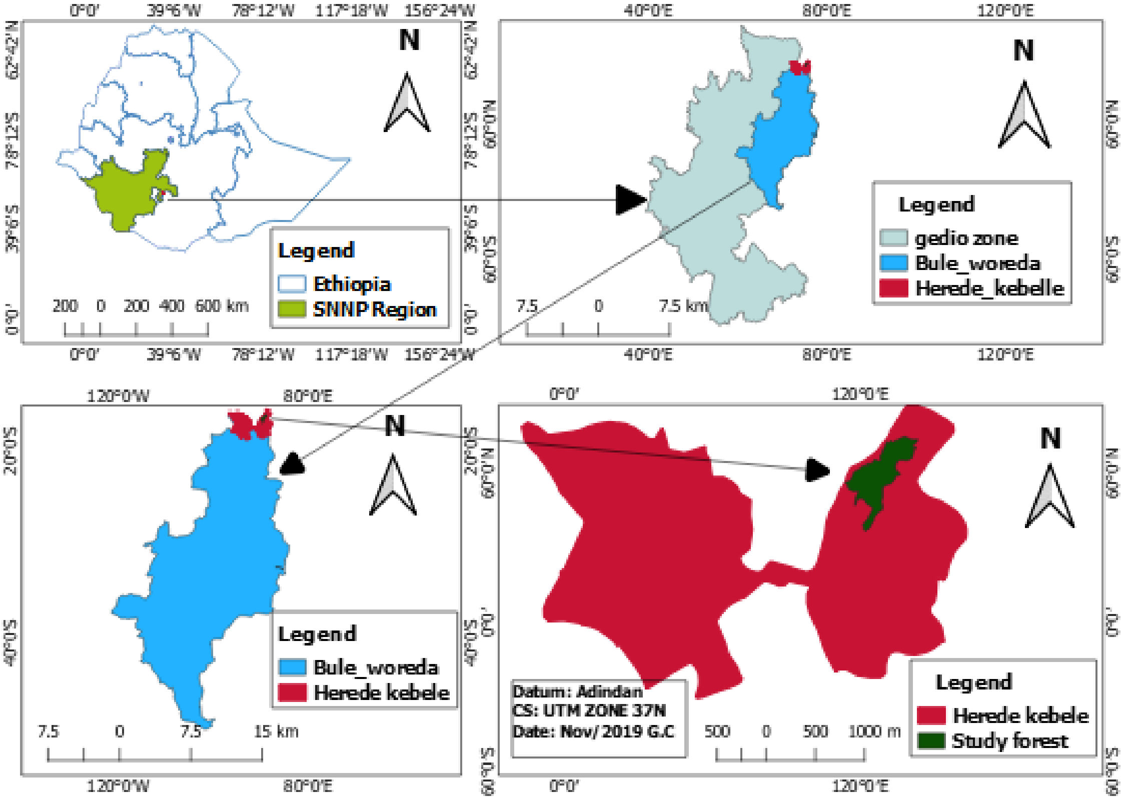


Figure 1: Map showing Gedeo zone Bule district and Buna koba community forest in Herede farmer association in southern, Ethiopia

3.1.2. Population

The population of Bule woreda is estimated at 77,449 and 75,882 as males and females, respectively with a total population of 153,331. From the total population 87.17 % live in rural areas while 12.83 % residents are urban dwellers (Bule woreda finance and economy office, 2010). The district is the home of Gedeo, Oromo, Sidama, Amhara and others.

3.1.3. Climate

The climatic condition of Bule District has a bimodal annual rain fall distribution. Most rain falls between May and September, although occasional rainfall occurs throughout the year and the dry months in the study area are December to February. The mean annual precipitations vary from 1200 mm to 1800 mm and mean annual temperature ranges from12.6 to 22.5 ^{O}C (Data source, woreda finance and economy office, 2010).

3.1. 4. Vegetation

The study area has diversified green vegetation cover and the species found in the area both indigenous and exotics. Some of the tree species are *Cordia africana*, *Vernonia amygadalina*, *Persea americana*, *Mellitia feruginea*, Fruits-trees, *Podo carpus falcatus, Albizia qummifera*, *Hagenia abyssinica*, high land Bamboo forest (*Arundinaria alpina*), *Olea capensis, Croton macrostachyus*, *Ficus sur*, *Enset*, and *Coffee, Eucalyptus*, and *Cupressus lusitanica*. Moreover, tree species like *Aningeria adolfi- friedericii*, *Erythrina abyssnica* and *Eucalyptus globulus* are dominantly grown in the area. The land use/cover vegetations are useful for water stream percolation, organic matter accommodation, soil fertility, soil and water conservation, biodiversities conservation and environmental goods and services.

3.1.5. Soil types and major land uses

The dominant soil type of the study area is Nitisols (Haile Ketema *et al*., 2015). Its surface horizon is characterized by a granular to crumb structure, porous and well aerated with good internal drainage potentials that can be suitable for a wide range of agricultural uses. The land use system of the study area is a mixed farming of crop, animals raring and agro forestry system. Cereal crops such as Barley and Wheat are the cultivated crops in the area. In addition, Beans, Peas and Haricot beans are grown. Growing Vegetables such as Cabbage, Onion and Garlic are cultivating known unlimited season summery to winter. Enset based agro forestry practices also used commonly by the local people.

3.1.6. Characteristics of the forest plantation

The study was conducted in pure stands of the *C. lusitanica* and *E. globulus* each of area covered was 17.3 ha and 22.83 ha respectively. It was established by local community, by helps of agricultural office in 1979 and 1986 *C. lusitanica* and *E. globulus* respectably, for forest production on the open grazing land. The plantations were established with 3 m spacing along the rows and 2.5 m spacing between plants. The plantations were surrounded by the agricultural land. In general, *E. globulus* have broad leaves, whereas *C. lusitanica* is a coniferous species, having needle shaped leaves. *E. globulus* has open crowns and longer straight boles, whereas the *C. lusitanica* had a dense and deep crown.

3.2. METHODOLOGY

3.2.1. Study site selection

Reconnaissance field survey was conducted through a field visit observation across the forest, using informants. The site was selected based on presence of both plantations' species to estimate biomass and soil carbon stocks in targeted forest ecosystem. The study site was purposively selected based on define plantation forest boundary and interest to compare biomass and soil carbon stocks between species and equal number of sample plots with the trees sizes ≥ 5 cm in diameter, DBH and representative of the current study the species occurring in the study area.

The spatial boundaries of the study area were clearly defined and properly recognized to facilitate correct measuring, accounting and verification. GPS tracking were used for boundary delineation. Then systematic sampling method was done to obtain the same units, this increase the precision of measuring and estimating carbon stock without increasing the cost improperly.

3.2.2. Forest inventory and Sampling design

In this study, a systematic sampling method was used to conduct tree inventory in Herede community plantation forests. A forest inventory was taken to compile information about tree stand depending on the diameter at breast height (DBH) and total height of trees. Sampling of the forest was conducted by the line transects at an interval bottom, middle and top part the forest area. A total of 30 sample plots with 10 m x 20 m (200 m^2) size were laid out in each forest plantation. The distance between transect line was 100 m and between plot was 75 m determined using measuring tape. Five smaller sub plot of 1m^2 in size were established at the four corners of each square plot for sampling fallen litter and soil samples (Fig. 2).

Therefore, the reduction in the distance between sample plots in both stands was to have enough sample plots for determining above ground biomass. Hence, the number of sample plots laid in the study area was determined after measuring all transect lines based on their distance between each sample plots. Therefore, for one stand site 6 transects and 30 sample plots for each stands were established. In general, 60 main plots were established.

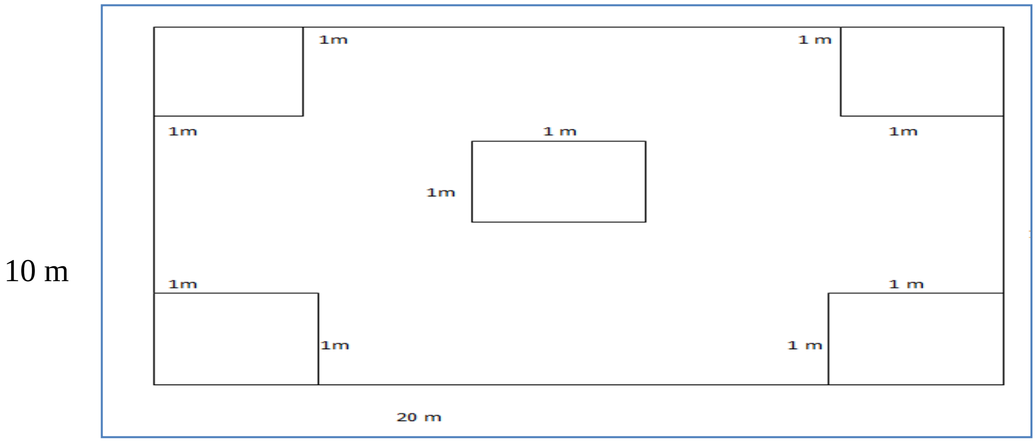


Figure 2: example plot and quadrant lay out

3.3. Data collection method

3.3.1. Data type

The primary and secondary data were used to meet the objectives of current study. The primary data were obtained from field measurements. The secondary data were collected from published and unpublished documents.

3.3.2. Tree biomass

The data collection methods and procedures used to estimate the biomass and carbon stocks for this study were based on the standard carbon inventory principles and techniques. Data for estimation of AGB in this study was collected by using both destructive and non-destructive sampling: for the litter, non-woody, soil organic matter and trees.

For tree biomass and carbon stock estimation, first the boundary of the both targeted tree species plantation sites was determined. The above ground biomass was determined depending on the two variables such as diameter at breast height (dbh) and total height (h) of the trees. These variables are considered to be the most efficient input variables for tree level biomass and volume prediction (Brown, 1997; IPCC, 2003 and Chave *et al*., 2014).

DBH is simply the average stem diameter outside bark at 1.3 m above ground. Total height of the tree is straight line distance from the tip of the leading shoot to the ground level. Height of each tree species was measured by using suunto hypsometer in the position where possible to observe the tip of the woody plant (Pearson *et al*., 2005). The DBH and height of every tree species having diameter ≥ 5cm in the area of study was measured using measuring tape.

Finally, the biomass carbon pool was estimated based on the stand living above and below ground woody biomass.

3.3.3. Aboveground tree parameter measurements

Each tree was recorded individually, together with its name and code targeted stand. All tree species with DBH ≥5 cm were measured in each plot. To estimate above ground biomass and carbon stock individual tree parameter directly measured in the field such as diameter at breast height (1.3 m) and height of trees were measured within sample plots using Tape meter and Hypsometer respectively (Brown, 2002 and Pearson *et al*., 2007). Individual tree biomass was estimated using allometic equation model. The DBH and height of each trees ≥ 5cm DBH was measured in each site's rectangular sample plot of 10 m x 20 m (200 m^2) using, diameter tape starting from the edge and working inwards, and marking each tree to avoid double counting. According to Karky and Banskota, 2007 and MacDicken, 1997 trees on the border must be included if > 50 % of their basal area falls within the plot and excluded if < 50 % of their basal area falls outside the plot. In addition, trees over hanging into the plot are needs to be excluded, but trees with their trunks inside the sampling plot and branches outside will be included. To convert field measurement in to above ground biomass estimates the allometric equation developed by (Leakemariam Berhe. and Genene Assefa, 2013) for *C. lusitanica* and (Tesfaye Debela, 2017) for *E. globulus* specific tree species model were used (eq.1 and 2).

3.3.4. Litter sampling

The litter samples were collected from sub-plot of 1 m × 1 m in each plot. Five 1 m^2 sub-quadrant of in size were established at each corner and center of main plot. Whole litter samples in the sub-quadrats were collected by manual from each sub-quadrat. The fallen litter within the 1m^2 sub-quadrats were collected and weighted. A 100 gm composite sample was measured in the field to determine fresh weight. After the fresh weight determination, the sample was taken for laboratory analysis. To determined moisture contents maintained a constant weight (Jina *et al.*, 2008), which total dry mass and organic matter can then be calculated. Finally, carbon in litter t ha^{-1} for each sample was determined. Dead wood was not considered in this current study due to the unavailability of the material in study sites.

3.3.5. Soil data collection

The soil samples were collected for soil organic carbon and bulk density analysis from each sample plot. The samples were taken from quadrants 1 m^2 allocated in the four corners of the sample plots and from the one center of within (10 m x 20 m). Soil samples for the determination of soil organic carbon density were collected from 60 cm in three depth class from 0-20 cm; 20-40 cm and 40-60 cm after remove fallen litter. A total of 168 soil sample were collected from both current study targeted forest plantations: (28) samples were from 0 – 20 cm depth, (28) were from 20 – 40 cm depth and (28) were from 40 – 60 cm depths in each stand. Soil samples were taken by using ring auger and core sampler for SOC and bulk density respectively.

From the four corners soil samples were mixed homogenously and 200 gm samples were taken from each sample quadrat for the determination of soil organic carbon in the laboratory using Walkley anal Black method, 1934. In addition, at the same time from the center same quadrants undistributed soil samples for bulk density determination were collected from the surface soil using core sampler carefully driven into the soil to avoid compaction (Roshetko *et al.*, 2002).

3.4. Data analysis

After the data collection was completed, data analysis at vary carbon pools measured in the yet another major task to be accomplished. Analysis of the different carbon pools in this current study was explained the below.

3.4.1. Field data analysis

3.4.1.1. Above and belowground biomass carbon density

Above ground biomass estimates the allometric equation developed by (Leakemariam Berhe, 2013) for *C. lusitanica* and (Tesfaye Debela, 2017) for *E. globulus* specific tree species allometric equation was used (eq.1and 2).

Aboveground biomass was calculated using the following equation:

For *Cupressus lusitanica* (DBH range from 2.5 to 48.8 cm)

$AGB = 0.0319 * d^{1.8903} * h^{0.9194}$ --- (eq. 1)

For *Eucalyptus globulus* (DBH range from 7 to 105 cm)

$AGB = 0.479 * (DBH)^{2.2578} * (H)^{-0.374}$ -- (eq. 2)

Where AGB = above ground biomass, d = DBH (in cm), DBH = diameter at breast height, H (in m) = height

Moreover, suitable allometric equation models are essential tools that used to convert field data (species, DBH and height) into the oven- dried weight of biomass and carbon estimates (Brown *et al*., 2004).

The biomass stock densities were converted to carbon stock densities using the IPCC (2006) default value of 0.47, while multiplication factor 44/12 or 3.67 needs to be used to estimate CO_2 equivalent (Pearson *et al*., 2007).

$AGBC = AGB \times CF$ -- (eq. 3)

Where, AGBC = above ground biomass carbon stock (t ha^{-1}) and CF = carbon fraction (47 %)

The Below Ground Biomass (BGB) of *Cupressus lusitanica* and *Eucalyptus globulus* stand trees was estimated depending on the above ground biomass of each stand by multiplying 0.24 roots to shoot ratio default value (IPCC. 2006). Belowground biomass (t ha^{-1}) = 0.27 × above-ground biomass (t ha^{-1}) is estimate by following equation (eq.3).

$BGB = 0.27 * AGB$-- (eq.4)

Where, BGB = below ground biomass, AGB = above ground biomass, 0.27 is conversion factor of AGB.

Conversion of BGB to carbon stock was done using 0.47 carbon fraction default value of IPCC (2006).

$BGBC = BGB \times CF$ -- (eq. 5)

Where, BGBC = below ground biomass carbon stock (t ha^{-1}) and CF= carbon fraction (47 %)

3.4.2. Laboratory analysis

3.4.2.1. Litter biomass carbon

All the litter samples collected from 1 m^2 sub plots within sample plot were oven dried at 65 ^{O}C for 24 hours to maintain constant weight (Jina *et al*., 2008). The amount of dry biomass in the fallen litter per unit area was estimated according to Pearson *et al*., 2005 were used:

$$LB = \frac{w\ field}{A} \times \frac{w\ sub\text{-}\ sample\ (dry)}{w\ sub\text{-}\ sample\ (fresh)} \times \frac{1}{10,000} \text{ --- (eq. 6)}$$

Where: LB = Litter biomass (of litter t ha^{-1}); W field = weight of fresh field sample of litter within an area of size (g); A = size of the area in which litter were collected (ha); W sub-sample, dry = weight of the oven-dry sub-sample, and W sub-sample, before dry = weight of the fresh subsample of litter taken to the laboratory to determine moisture content (g).

The carbon content of litter biomass was calculated by 0.37 of the dry weight of litter biomass per unit area (IPCC. 2006) and was estimated using the following formula.

$CL = LB \times 37\ \%$ -- (equ.7)

Where, CL is total carbon stocks in the fallen litter in t ha^{-1}, LB is litter biomass, and 37 % is carbon fraction determined in the dry mass.

3.4.2.2. Soil organic carbon

The collected soil samples for soil carbon analysis were air-dried, well mixed and sieved through a 2 mm mesh size sieve. Therefore, SOC content was determined following the Walkley and Black wet oxidation method (yimer *et al*., 2007) at Wondo Genet College of Forestry and Natural Resource soil laboratory. Accordingly, one gram of soil, previously ground to pass a 0.5 mm sieve was reacted with a mixture of 10 ml of 0.17M $K_2Cr_2O_7$ 20 ml of 96 % Sulphuric acid. The excess dichromate solution was titrated against 1 ml ferrous sulphate after addition of about 150 ml distilled water, 10 ml of 85 % of phosphoric acid and 1 ml indicator solution (0.16 % Barium diphenylamine sulphate).

Soil bulk density was determined in the three soil depths from undisturbed soil samples, similar in W/Genet soil laboratory, after drying the core samples of soil at 105 ^{O}C and the volume of the core sampler divided the weight of the soil. The weight of the gravel above 2 mm diameter was subtracted to determine the bulk density of the soil samples. The soil organic carbon stocks were calculated using the formula (Aynekulu *et al*., 2011)

$$BD = \frac{W_{av,\ dry}}{V} \text{ --- (eq. 8)}$$

Where, BD is Bulk density soil core sampler (in g cm^{-3}), Wav, dry is average air dry weight of soil sampler (in g) and V is volume of modified to collect soil sample core sampler volume is 565.2 cm^3 were used for determining the bulk density of the soil samples of each soil layer. Collected soil samples were analyzed in soil laboratory and Soil organic carbon percent was calculated (Pearson *et al.*, 2005). The SOC stock density in mineral soil was calculated based on fixed depth method using carbon concentration, thickness of each layer, soil bulk density, and coarse fragmented matter at each depth (Aynekulu *et al*., 2011). Soil organic carbon for a given soil layer was calculated by multiplying the carbon concentration in soil fines with bulk density and soil depth. SOC was determined on the fine soil fraction (< 2 mm) and the bulk density should be corrected for the proportion of the soil volume occupied by coarse fragments (> 2 mm) extracted by washing soil bulk density sample (Aynekulu *et al*., 2011).

$$SOC = \frac{C}{100} * Bd * D * (1- frag) * 100 \text{ --- (eq. 9)}$$

Where, SOC = soil organic carbon stock (t c ha^{-1}), C = soil organic carbon concentration of soil fines (fraction < 2 mm) determined in the laboratory (%), Bd = soil bulk density (g cm^{-3}), frag = % volume of coarse fragments / 100, D = depth of soil sampled soil layer (60 cm) and 100 is used to convert the unit to t C ha^{-1}.

3.4.3. Total ecosystem carbon density

The total amount of the carbon sequestered in the forest stands of different carbon pools in two stands such as *E. globulus* and *C. lusitanica* plantations in the Bule district SNNPs southern Ethiopia was calculated. The total carbon stock of both stands was calculated by summing the carbon stock of individual carbon pools plantation forest stands separately following the (Pearson *et al.,* 2005) approach.

The total Carbon stock density of the sampling area was estimated as:

C density = AGC + BGC + LC + SOC -- (eq. 11)

Where: C density = the sum of all carbon pools (t ha^{-1}), AGC = aboveground carbon (t C ha^{-1}), BGC = belowground carbon (t C ha^{-1}), LC = litter carbon (t C ha^{-1}) and SOC = Soil organic carbon (t C ha^{-1})

The total carbon stock is then converted to tons of CO_2 equivalent by multiplying it by 44/12 or 3.67 (Pearson *et al.*, 2007).

3.5. Statistical analysis

The data obtained from the field measurements was collected, organized and recorded into the excel version 2007 spread sheet and different comparison graphs and tables were prepared. Field data was DBH and total height of tree, fresh weight and dry weight of litter and soil were statistically analyzed by using Minitab version 17.1 software. A one-way analysis of variance (ANOVA) was carried out to check for significance differences of carbon stock between both targeted tree species of forest biomass and soil organic carbon across the three depth classes. When the analysis of variance (ANOVA) showing a significant difference among the different treatment taken into consideration at ($P \leq 0.05$), a mean separation for each treatments were made by Tukey least significant different comparison method.

4. Results

4.1. Stand Characteristics for the studied species

The mean height of *E. globulus* stand was larger ($p < 0.000$) than *C. lusitanica* stand. The mean DBH of C. *lusitanica* stand was higher than the *E. globulus* stand (Table 1). The BA m^2ha^{-1} of *C. lusitanica* stand was greater ($P < 0.000$) that of *E. globulus* stand (Table 1).

Table 1: stand characteristics for the studied species (mean ± SD).

Characteristics of Stand	*C.lusitanica* (n=30)	*E. globulus* (n=30)	p- value
Age	32yr	25yr	<0.01
DBH (cm)	21.45± 5.6	18.4± 6.0	< 0.01
H (m)	16.24± 3.94	17.7± 5.4	< 0.01
BA (m^2ha^{-1})	48.24 ± 8.74	41.4± 5.76	< 0.01
Stem ha^{-1}	1256.7± 259.9	1300 ± 311.6	> 0.05

n= number of sample plots

4.2. AGB, BGB and Litter biomass for the studied species

The mean biomasses of both stands is presented in the given below (Table 2). This result revealed that the total mean biomass carbon of the current study was significantly varied among the species ($p \leq 0.000$) (Table 2), the mean, aboveground biomass carbon stock in the current study site was 96.04 t C ha^{-1} and 83.46 t C ha^{-1}, while the mean belowground biomass carbon stock study site was 25.93 t C ha^{-1} and 22.53 t C ha^{-1} and the mean, total biomass carbon stock without including litter biomass in the study site was 121.97 t C ha^{-1} and 106 t C ha^{-1} of *C. lusitanica* and *E. globulus* stand, respectively (Table 2).

The analysis of variance revealed that the litter carbon density insignificantly affected by the species type; fuel wood collection and production of inputs organic matter ($p > 0.05$) (Table 2). The mean total carbon stock in litter biomass of the study site was 0.068 t C ha^{-1} and 0.065 t C ha^{-1} for *C. lusitanica* and *E. globulus* stands respectively. The litter carbon density of *C. lusitanica* was higher species *E. globulus* (Table 2). There was insignificance difference among species and within the same environmental condition.

Table 2: (Mean±SD) AGC, BGC and Litter biomass for the targeted tree species results of one way ANOVAs ($P < 0.05$)

Stand	AGBC (t ha^{-1})	BGBC (t ha^{-1})	LC (t ha^{-1})	TBC (t ha^{-1})	P – value
C. lusitanica	96.04±20.72	25.93±5.4	0.068±0.03	122.38±26.14	< 0.01
E. globulus	83.46±11.87	22.53±3.09	0.065±0.03	106.06±15	< 0.01

n= 30 for each stands

4.3. Soil organic carbon.

The one way ANOVA results revealed that soil organic carbon stock density (SOCSD), varied significantly among soil depths and trees on (Table 3). However, The SOCD up to 60 cm depth was higher at (159.32 ± 17.52 t C ha^{-1}) under *E. globulus* than *C. lusitanica* (138.19 ± 28.3 t C ha^{-1}) (Table 3). SOC density significant, among soil depth within the species at 40 – 60 cm depth was non-significant (Table 3). The total mean soil organic carbon stock density was significantly higher ($P < 0.01$) in *E. globulus* than the *C. lusitanica* stand (Table 3), Moreover mean soil organic carbon was stored in the top layer (35.56 %), of in *E. globulus* and (33.33 %) than *C. lusitanica* stand. While, in the bottom layer (40 - 60 cm) accounted

(31.10 %) among of the total soil organic carbon stocks in *C. lusitanica* and in the *E. globulus* stand. In general, soil organic carbon concentration significantly decreased with depth in under the targeted tree species (Table 3).

Result revealed that mean soil bulk density significantly differenced with soil depth. Bulk density showed an increasing trend with soil depth in both species. The lowest bulk density as lower (0.41 g cm $^{-3}$) under *C. lusitanica* in the top soil (0 – 20 cm soil depth), whereas, the highest bulk density (0.78 g cm $^{-3}$) was found in *E. globulus* stand (40 – 60 cm soil depth). Soil organic carbon was inversely and significant relationship with bulk density.

Table 3: (Means± SD) of soil organic carbon.

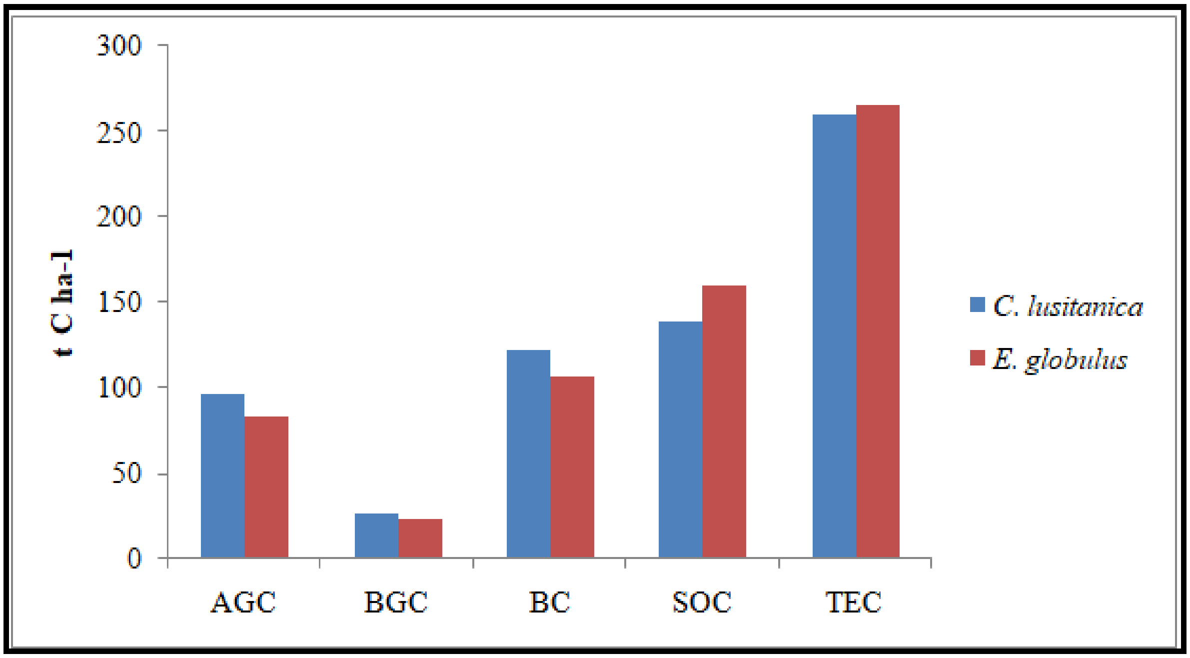
Variable	Soil depth (cm)	*C. lusitanica* (n=14)	*E. globulus* (n=14)	p- value
SOC (t ha^{-1})	0 – 20	48.83± 9.89	56.97±10.79	<0.01
	20 – 40	46.19±9.15	52.96±4.50	<0.01
	40 – 60	43.16±11.33	49.39±6.52	>0.05
	0 – 60	138.19±28.30	159.32±17.52	<0.01

n= number of sample plots

4.4. Total ecosystem carbon density.

The TECD was significantly varied among the species (P <0.01) higher than the total carbon stock density *C. lusitanica* was 1.02 times larger than that of *E. globulus*. The total mean SOC current study was 1.3 times higher than the total mean BCS density of site (Figure 3). Contribution of the biomass carbon stock from the total carbon stock in *C. lusitanica* was 46.9 % and 40 % for *E. globulus*. Soil organic carbon stock accounted 53.1 % of the total carbon stock in *C. lusitanica* and 60 % in *E. globulus* stand.

Figure 3: (Means± SD) of total ecosystem carbon density.



Results of one way ANOVAs (P <0.05); n is number of samples

5. Discussion

5.1. Stand Characteristics of targeted species.

In this study, the total mean height of C. *lusitanica* was lower than and *E. globulus* (Table 1). The mean diameter at breast height of *C. lusitanica* was also higher than of *E. globulus*. Though, the two stands were established at the different time. This difference might be, due to the variation of the species characteristics while they are planted in different year and due to difference edaphic factors within the same agro-ecological zone. According to (Bekele Tesema, 2007) In Ethiopia, *Eucalyptus* grows in height 40-55 m and to a diameter of 2 m, while *C, lusitanica* tree grows up to 35 m at suitable environmental condition (Orwa *et al.,* 2009).

5.2. Biomass carbon stocks of *E. globulus* and *C. lusitanica* stands

The present carbon stock study is estimating carbon storage at two stands of tree species is essential for assessing the role of forests ecosystems in regional and global carbon management. These results indicate that, *C. lusitanica* was stored large amount of biomass carbon stock both in the above and belowground than *E. globulus*. This difference might be, due to species type, age of forest and difference in species specific allometric equation. This study indicated that, there is statistically high significant difference between biomass carbon stocks of *C. lusitanica* and *E. globulus* (P <0.01) (Table 2). In this current study mean biomass carbon stock of species plantation at two stands was (121.97 t C ha^{-1} and 106 t C ha^{-1}) respectively.

The current study mean biomass carbon stock of *C. lusitanica* and *E. globulus* trees was significantly very lower as compared to mean total aboveground biomass carbon stock baseline study (197 t C ha^{-1} and 292 t C ha^{-1}) of *C. lusitanica* and *Eucalyptus* plantation in Kenya (Omoro *et al*., 2013). In this case difference might be, due to the difference of stand age. i.e., currently studied 32 and 25 years was *C. lusitanica* and *E. globulus* respectively, which is lower by 38 yrs (Omoro *et al*., 2013). 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 grown. As stated by (Yitebitu Moges *et al*., 2011) the different types of the models used for biomass estimation have impact on the value of carbon estimated in a given forest.

This study indicated that, there is insignificance difference between litter biomass carbon stocks of *C. lusitanica* and *E. globulus* 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 is might be, due to the fall of litter inputs organic matter un-decomposed rate. The mean litter biomass carbon stock in *C. lusitanica* was slightly higher than as compared to *E. globulus*. This current study difference among species might be, due to the *E. globulus* leaf fall for fuel wood collected by local community and grazing observed in site.

5.3. Soil organic carbon stocks in the study site.

Soil organic carbon is affected by soil properties, forest management practices, litter inputs, decomposition rate and root turnover (Jandl R. *et al*., 2007). The soil organic carbon stock of both stands was significant ($P < 0.01$) affected by the soil depth ranges. In both plantation stands, soil organic carbon stock was statistically significance higher in the middle layer than in the lower layer. This difference might be, due to the land use history of the stands where they are grow and difference might be, decomposition rate of litter. Additionally, reason might be, due to the different species type. The decomposition of litter from broadleaved species tends to be faster than that of coniferous species (Prescott *et al.*, 2000), which often results in the accumulation of a litter layer in coniferous forests and slowly decomposed. Lignin in litter was highly resistance to decomposition and therefore, litter with high lignin content would have slower decomposition rate (Mafongoya *et al.*, 1998). Contrast, within low litter lignin, phenols and high nitrogen content would have faster rate of decomposition. In the current study, the mean SOC stock (109.93 t ha^{-1}) of *E. globulus* and (95.02 t C ha^{-1}) of *C. lusitanica* at soil depth up to (0-40 cm) where within the range of soil organic carbon stock (0-40 cm) depth which is reported for the *C. lusitanica* (86.1 kg ha^{-1}), and *E. globulus* (87 kg ha^{-1}) in Ethiopia, (Abate. 2004). Variability in this case might be, due to difference in ecosystem type plantation forest, rate at mineralization by soil micro – organisms, climate and soil type (Lal, 2004).

5.4. Total forest ecosystem carbon stocks

The current study result indicated that the soil carbon pool constituted higher carbon stock than biomass carbon stock in both exotic species. This is in baseline with the report (Omoro *et al.*, 2013) in Kenya, who stated that is the largest pool of soil organic carbon in the *C. lusitanica* forest ecosystem. However, this result contradicts with the finding of (Abate, 2004), who found that high carbon in the standing tree biomass and small amount of organic carbon in the soil. This small value is might be, due to the differences of the soil depth in which the data was taken (0 – 30 cm). In agreement with this study, Hiederer, 2009 explained the relationship between soil organic carbons with soil depth; as depth increases, soil organic carbon decreases in the soil profile.

The plantation forest ecosystem carbon estimated in the present study indicated that higher than the average value for carbon storage of *C. lusitanica* plantation (128.36 t C ha^{-1}) at W/Genet Genene, 2009. This variation is might be, due to differences in soil depth and age of tree species between the two studied sites.

Based on current results, lower biomass carbon stock was found in *E. globulus* (above and belowground and litter) and lower soil organic carbon pool was estimated in *C. lusitanica*, while the highest biomass carbon pool was in *C. lusitanica* biomass and *E. globulus* in soil pool at the current study sites. However, it showed among difference in exotic species, which may be, due to the carbon content for aboveground, belowground, litter and soil carbon stacks difference was in species type and difference in species specific biomass allometric equation. When compared to *C. lusitanica* with *E. globulus* even through the carbon stock in aboveground pool was better at *C. lusitanica* (Table 2). This study exhibited substantial amount of the mean total carbon stock (260.23 t C ha^{-1}) *C. lusitanica* lower as compare to *E. globulus* stand (265.37 t C ha^{-1}). But higher amount at biomass carbon stock (121.97 t C ha^{-1}) was stored in *C. lusitanica* stand than in *E. globulus* (106 t C ha^{-1}). In this case variability might be, due to difference in allometric equation and forest species type.

6. Conclusion and Recommendations

6.1. Conclusion

Biomass and soil organic carbon in this study of two targeted tree species of Bule District community plantation forest in Southern Ethiopia are using DBH and total height of tree as independent variables to estimate biomass for above ground. In the current study result shows that among targeted tree species, which one is more sequestered. Accordingly, the total carbon content of *C. lusitanica* was (260.23 t C ha^{-1}) and *E. globulus* was (265.38 t C ha^{-1}). This study result indicates that, *C. lusitanica* and *E. globulus* are important in storing carbon stock in their biomass and soil. Finally, it could be concluded that *E. globulus* has stored more carbon than *C. lusitanica*. Hence it has a considerable role in mitigating the climate change by sequestrating carbon dioxide and to earn income from the current carbon marketing system in addition to its direct economic benefit plantation forests.

6.2. Recommendation

Based on the finding of the current study the following recommendations are forwarded. Large amount of biomass and soil carbon of exotic species are *E. globulus* and *C. lusitanica* stands should be seen as an opportunity and need to be integrated to reduce emission from deforestation and degradation (REDD+) and other carbon related incentive mechanisms such as clean development mechanism (CDM) and thereby, benefits small-scale farmers in their efforts to expand plantation of these species.

Therefore, it is recommended that a forest carbon related awareness creation for local community and promotion of the indigenous knowledge can be regarded as a possible option for conservation forest; enhance carbon by A/R and sustainable forest management.

Further study is important to assure the biomass carbon stock, both species; particularly *E. globulus* grows fast than helps to reduce more CO_2 from the atmosphere than they would release due to its higher contribution for the above ground biomass and carbon stock. I recommend an approach that focuses on use of tree species specific study for assessing biomass and carbon stock of local levels. This approach helps to which species has a potential to store and sequester more carbon by providing to climate change mitigation.

7. REFERENCE

Abate, A. 2004. Biomass and nutrient studies of selected tree species of natural and plantation forests: Implications for a sustainable management of the Munessa-Shashemene Forest, Ethiopia (Doctoral dissertation).

Ackerman, K.V. and Sundquist *et al*., 2008. Comparison of two US power-plant carbon dioxide emissions data sets. Environmental science & technology, *42*(15), pp.5688-5693.

Alley, R. 2007. Climate Change 2007, the Physical Science Basis: Summary for Policymakers: Contribution of Working Group I to the Intergovernmental Panel on Climate Change.

Aynekulu, E., Vagen, T.G., Shepherd, K.D. and Winowiecki, L.A. 2011. A protocol for measurement and monitoring soil carbon stocks in agricultural landscapes.

Baker, J.M., Ochsner, T.E., Venterea, R.T. and Griffis, T.J. 2007. Tillage and soil carbon sequestration-what do we really know? Agri, ecosystems environment, 118(1-4), pp.1-5.

Bekele, M., Tesfaye, Y., Mohammed, Z., Zewdie, S., Tebikew, Y., Brockhaus, M. and Kassa, H., 2015. The context of REDD+ in Ethiopia*:* Drivers, agents and institutions (Vol. 127).

Bekele Tesemma, A. and Tengnäs, B. 2007. Useful trees and shrubs of Ethiopia: identification, propagation, and management for 17 agro climatic zones.

Black, C.A. Evans, D.D. White, J.L. Ensminger, L.E. and Cark, F.E. 1965. Methods of soil analysis. Part I. Physical and mineralogical properties, including statistics of measurement and sampling. American Society of Agronomy Ins. Madison, Winconsin.

Berhe, L., Assefa, G., and Teklay, T. 2013. Models for estimation of carbon sequestered by *C.*

lusitanica plantation stands at Wondo Genet, Ethiopia. Southern Forests: a Journal of Forest Science, 75 (3), 113-122.

Bravo, F. Del Río, M., Bravo-Oviedo, A., Del Peso, C. and Montero, G. 2008. Forest management strategies and carbon sequestration. In Managing forest ecosystems: the challenge of climate change (pp. 179-194).

Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a primer (Vol. 134). Food and Agriculture Org.

Brown, K. 2002. Innovations for conservation and development. Geographical Journal, 168(1), pp.6-1

Castles, I. and Henderson, D. 2003. Economics, emissions scenarios and the work of the IPCC. Energy and environment, 14 (4), pp.415-435.

Chakra borty, S., Tiedemann, A.V. and Teng, P.S. 2000. Climate change: potential impact on plant diseases. Environmental pollution, 108 (3), pp.317-326.

Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T. and Lescure, J.P. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Ecological, 145 (1), pp.87-99.

Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B. and Henry, M. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. Global change biology, 20 (10), 3177-3190.

Chidumayo, E. 2011. Climate change and the woodlands of Africa. Climate change and African forest and wildlife resources, pp.85-101.

Clark, D.A., Brown, S., Kick lighter, D.W., Chambers, J.Q., Tomlinson, J.R. and Ni, J. 2001. Measuring net primary production in forests: concepts and field methods. Ecological applications, 11(2), pp.356-370.

Clark, D. B. and Kellner, J. R. 2012. Tropical forest biomass estimation and the fallacy of misplaced concreteness. Journal of Vegetation Science, 23 (6), 1191-1196

Creamer, C. A., Filley, T. R., Boutton, T. W., Oleynik, S. and Kantola, I. B. 2011. Controls on soil carbon accumulation during woody plant encroachment: Evidence from physical fractionation, soil respiration, and δ13C of respired CO_2. Soil Biology and Biochemistry, 43 (8), 1678-1687.

Dagne, E. 2011. Natural data base for Africa (NDA) on CD-ROM version 2.0. Addis Ababa, Ethiopia.

Daly, C., Taylor, G.H., Gibson, W.P., Parzybok, T.W., Johnson, G.L. and Pasteris, P.A. 2000. High-quality spatial climate data sets for the United States and beyond

Data source, woreda finance and economy office. 2010, dimorphic and climate.

Durst, P.B., McKenzie, P.J., Brown, C.L. and Appanah, S. 2006. Challenges facing certification and eco-labeling of forest products in developing countries. International Forestry Review, 8 (2), pp.193-200.

FAO. 2001a. Global Forest Resources Assessment 2000 (FRA 2000). Forestry Paper139, Rome, Italy.

FAO, (2006) Choosing a forest definition for the Clean Development Mechanism: Forest and

Climate Change Working Paper 4, Rome, Italy (http//: www. fao.org/forestry/11280-1-0.pdf, accessed date October 7 -2010)

Feyissa, A., Soromessa, T. and Argaw, M. 2013. Forest carbon stocks and variations along altitudinal gradients in Egdu forest: implications of managing forests for climate change mitigation. Science, Technology and Arts Research Journal, *2* (4), pp.40-46.

Fraterrigo, J.M. 2005. Influence of land-use change on the long-term persistence of forest understory herbs in the southern Appalachian Highlands. The University of Wisconsin-Madison.

Gedefaw, M., Soromessa, T. and Belliethathan, S. 2014. Forest carbon stocks in woody plants of Tara Gedam forest: Implication for climate change mitigation. Science, Technology and Arts Research Journal, 3 (1), 101-107.

Gibbs HK, S Brown, JO Niles and JA Foley. 2007. Monitoring and estimating forest carbon Stocks: Making REDD a reality. Environmental Resource Letters 2: 1-13.

Gibbs H K and Brown S. 2007a. Geographical distribution of woody biomass carbon stocks in tropical Africa: an updated database for 2000. Available a

Gillman, G. P., Sinclair, D. F. and Beech, T. A. 1986. Recovery of organic carbon by the Walkley and Black procedure in highly weathered soils. Communications in Soil Science and Plant Analysis, 17 (8), 885-892.

Hairiah, K., Sitompul, S. M., van Noordwijk, M. and Palm, C. (2001). Methods for sampling carbon stocks above and below ground (pp. 1-23). Bogoi: ICRAF.

Hansen, M.C., Stehman, S.V. and Potapov, P.V. 2010. Quantification of global gross forest covers loss. Proceedings of the National Academy of Sciences, 107 (19), pp.8650-8655.

Held, I.M., Winton, M., Takahashi, K., Delworth, T., Zeng, F. and Vallis, G.K. 2010. Probing the fast and slow components of global warming by returning abruptly to preindustrial forcing. Journal of Climate, 23 (9), pp.2418-2427.

Houghton R A. 1999. The annual net flux of carbon to the atmosphere from changes in land use 1850 -1990 Tellus B 51 298-13

Humlum, O., Stordahl, K. and Solheim, J.E. 2013. The phase relation between atmospheric carbon dioxide and global temperature. Global and Planetary Change, 100, pp.51-69.

IBC. 2005. National Biodiversity strategy and action plan. Institute of Biodiversity Conservation, Addis Ababa.

IPCC. 2006. Guidelines for national greenhouse gas inventories. Institute for Global.

IPCC, Climate change. 2007. Mitigation of climate change. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, editors. Contribution of working group III to the 4th assessment report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press; 2007. p. 851

Jandl, R., Neumann, M. and Eckmullner, O. 2007. Productivity increase in Northern Austria Norway spruce forests due to changes in nitrogen cycling and climate. Journal of Plant Nutrition 170, 157-165.

Joint FAO/WHO Expert Committee on Food Additives. Meeting and World Health Organization. 2010. Evaluation of Certain Food Additives: Seventy-first Report.

Juntheikki, J. 2014. Estimation of *Eucalyptus* forest plantations carbon sequestration potential in Uruguay with the CO2fix model (Doctoral dissertation, Helsingborg University).

Karekezi, S., Lata, K. and Coelho, S.T. 2006. Traditional biomass energy: Improving its use and moving to modern energy use. Renewable Energy-A Global Review of Technologies, Policies and Markets, 1, pp.231-261.

Karky, B. S. and Banskota, K. 2007. The Kyoto Protocol and community-managed forests. Reducing carbon emissions through community-managed forests in the Himalayas, 23-37.

Kassa AG. 2015. Forest carbon stock and variations along environmental gradients in Yeka forest and its implication for climate change mitigation. MSC Thesis, AAU, Graduate progarmme

Kelbessa, E. and Demissew, S. 2014. Diversity of vascular plant taxa of the flora of Ethiopia and Eritrea. Ethiopian Journal of Biological Sciences, 13 (Supp.), pp.37-45.

Kent, M. and Coker, P. 2001. Vegetation description and analysis. Boca Raton, CRC.

Kuplich, Tatiana Mora. "Temporal, spatial, spectral and polarization characteristics of the SAR backscatter from regenerating tropical forests." PhD diss., University of Southampton. 2001.

Lal, R. 2001. Potential of desertification control to sequester carbon and mitigate the greenhouse effect. Climatic change, 51 (1), pp.35-72.

Lal, R. 2004a. Soil carbon sequestration to mitigate climate change. *Geoderma*, 123 (1-2), pp.1-22.

Lal, R. 2004b. Carbon emission from farm operations. Environment international, 30 (7), pp.981-990.

Lamboll, R., Nelson, V. and Nathaniels, N. 2011. Emerging approaches for responding to climate change in African agricultural advisory services: Challenges, opportunities and recommendations for an AFAAS climate change response strategy.

LeComte, D. 2014. International weather highlights 2013: super typhoon Haiyan, super heat in Australia and China, a long winter in Europe. *Weatherwise*, 67 (3), pp.20-27.

Lemenih, M. 2004. Effects of land use change on soil quality and native flora degradation and restoration in the highlands of Ethiopia. PhD dissertation. ISSN 1401-6230, ISBN 91-576-6540-0, Swedish University of Agricultural Sciences, Department of Forest Soils, Uppsala1 64.

Lemenih, M., Gidyelew, T. and Teketay, D. 2004. Effect of canopy cover and under storey environment of tree plantations on richness, density, and size of colonizing woody species in southern Ethiopia. Forest Ecology and Management 194, 1-10.

Lemma, B. 2006. Impact of exotic tree plantations on carbon and nutrient dynamics in abandoned farmland soils of southwestern Ethiopia. PhD dissertation. Swedish University of Agricultural Sciences, Faculty of Natural Resources and Agricultural Sciences, ISSN 1652-6880, ISBN 91-576-7257-1, Uppsala. 1-42

Lemma, B., Kleja, D.B., Olsson, M. and Nilsson, I. 2007. Factors controlling soil organic carbon sequestration under exotic tree plantations: A case study using the CO_2Fix model in southwestern Ethiopia. Forest Ecology and Management, 252 (1-3), pp.124-131.

Lemma, B., Nilsson, I., Kleja, D.B., Olsson, M. and Knicker, H. 2007. Decomposition and substrate quality of leaf litters and fine roots from three exotic plantations and a native forest in the southwestern highlands of Ethiopia. Soil Biology and Biochemistry, 39 (9), pp.2317-2328.

Lemieux, C.J. and Scott, D.J. 2005. Climate change, biodiversity conservation and protected area planning in Canada. Canadian Geographer/Le Géographecanadien, 49 (4), pp.384-397.

Le Toan, T., Quegan, S., Davidson, M.W.J., Balzter, H., Paillou, P., Papathanassiou, K., Plummer, S., Rocca, F., Saatchi, S., Shugart, H. and Ulander, L. 2011. The BIOMASS mission: Mapping global forest biomass to better understand the terrestrial carbon cycle. Remote sensing of environment, 115 (11), pp.2850-2860.

Lindner, M. and Karjalainen, T. 2007. Carbon inventory methods and carbon mitigation potentials of forests in Europe: a short review of recent progress. *European Journal of Forest Research*, 126 (2), pp.149-156

MacDicken, K.G. 1997. A guide to monitoring carbon storage in forestry and agro forestry projects.

Meersmans, J., Van Wesemael, B. and Van Molle, M. 2009. Determining soil organic carbon for agricultural soils: a comparison between the Walkley & Black & the dry combustion methods (north Belgium). Soil Use and Management, 25 (4), pp.346-353.

Mesele N and Mike S. 2015. Biomass and soil carbon stocks of indigenous agro forestry systems on the south-eastern Rift Valley escarpment, Ethiopia. Plant and soil.

Metz, B., Davidson, O., Swart, R. and Pan, J. eds. 2001. Climate change 2001: mitigation: contribution of Working Group III to the third assessment report of the Intergovernmental Panel on Climate Change (Vol. 3). Cambridge University Press.

Moges, Y., Eshetu, Z. and Nune, S. 2010. Ethiopian forest resources: current status and future management options in view of access to carbon finances. A report prepared for the Ethiopian Climate Research and Networking and the United Nations Development Programme (UNDP).

Montagnini, F. and Nair, P.K.R. 2004. Carbon sequestration: an underexploited environmental benefit of agro forestry systems. In New vistas in agro forestry (pp. 281-295).

NCDC, N. 2013. National Climate Data Center, (2013) Climate at a Glance.

Negash, M., Starr, M., Kanninen, M. and Berhe, L. 2013. Allometric equations for estimating aboveground biomass of Coffee arabica L. grown in the Rift Valley escarpment of Ethiopia. Agro forestry systems, 87 (4), pp.953-966.

Newman, T.P. 2017. Tracking the release of IPCC AR5 on Twitter: Users, comments, and sources following the release of the Working Group I Summary for Policymakers. Public Understanding of Science, 26 (7), pp.815-825.

Okali, D., Kowero, G. and Larwanou, M. 2011. Climate change and African forest and wildlife resources. Nairobi: African Forest Forum.

Ozturk, I. 2015. Measuring the impact of energy consumption and air quality indicators on climate change: evidence from the panel of UNFCC classified countries. Environmental Science and Pollution Research, 22 (20), 15459-15468.

Pearson, A. 2005. Carbon dioxide-new uses for an old refrigerant. International Journal of Refrigeration, 28 (8), pp.1140-1148.

Pearson, R.G., Raxworthy, C.J., Nakamura, M. and Townsend Peterson, A. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of biogeography*, 34 (1), pp.102-117.

Pittock, B., Arthington, A., Booth, T., Cowell, P., Hennessy, K., Howden, M., Hughes, L., Jones, R., Lake, S., Lyne, V. and McMichael, T. 2003. *Climate change: an Australian guide to the science and potential impacts*. Australian Greenhouse Office.

Roshetko, J.M., Delaney, M., Hairiah, K. and Purnomosidhi, P. 2002. Carbon stocks in Indonesian home garden systems: Can smallholder systems be targeted for increased carbon storage? *American Journal of Alternative Agriculture*, 17 (3), pp.138-148.

Saatchi, S.S., Harris, N.L., Brown, S., Lefsky, M., Mitchard, E.T., Salas, W., Zutta, B.R., Buermann, W., Lewis, S.L., Hagen, S. and Petrova, S. 2011. Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the national academy of sciences*, 108 (24), pp.9899-9904.

Sheikh, Mehraj A., Munesh Kumar, and Rainer W. Bussmann. 2009. "Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya." Carbon balance and management 4, no. 1 (2009): 6.

Silver, W.L., Ostertag, R. and Lugo, A.E. 2000. The potential for carbon sequestration through reforestation of abandoned tropical agricultural and pasture lands. *Restoration ecology*, 8 (4), pp.394-407.

Simms, A. and Murphy, M. 2005. Africa Up in Smoke: The second report from the working group on climate change and development. Oxfam Policy and Practice: Climate Change & Resilience, 1(1), pp.58-101.

Smith, P. 2004. Soils as carbon sinks: the global context. Soil use and management, 20 (2), pp.212-218.

Takimoto, Asako, PK Ramachandran Nair, and Vimala D. Nair. 2008. "Carbon stock and sequestration potential of traditional and improved agro forestry systems in the West African Sahel." Agriculture, Ecosystems & Environment 125, no. 1-4 (2008): 159-166.

Tesfaye, M.A., Gardi, O., Bekele, T. and Blaser, J. 2019. Temporal variation of ecosystem carbon pools along altitudinal gradient and slope: the case of Chilimo dry afromontane natural forest, Central Highlands of Ethiopia. *Journal of Ecology and Environment*, 43 (1), p.17.

Thompson, D.W. and Solomon, S. 2002. Interpretation of recent Southern Hemisphere climate change. Science, 296 (5569), pp.895-899.

UNFCCC, V. 2015. Adoption of the Paris agreement. United Nations Office at Geneva, Geneva

Van Breugel, M., Ransijn, J., Craven, D., Bongers, F. and Hall, J.S. 2011. Estimating carbon stock in secondary forests: decisions and uncertainties associated with allometric biomass models. Forest ecology and management, 262 (8), pp.1648-1657.

Vashum, K. T. and Jayakumar, S. 2012. Methods to estimate above-ground biomass and carbon stock in natural forests-A review. *J*. Ecosyst. Ecogr, 2 (4), 1-7.

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, 37 (1), pp.29-38.

Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J. and Dokken, D.J. 2000. Land use, land-use change and forestry: a special report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Wild, M. 2013, May. Relevance of decadal variations in surface radioactive fluxes for climate change. In AIP Conference Proceedings (Vol. 1531, No. 1, pp. 728-731).

WMO, U. 2013. Establishing a WMO sand and dust storm warning advisory and assessment system regional node for West Asia: current capabilities and needs. WMO Technical Report, 1121.

Yirdaw, M. 2018. Carbon Stock Sequestered by Selected Tree Species Plantations in Wondo Genet

College, Ethiopia. J Earth SciClim Change, 9 (472), p.2.

Yohannes, Hamere, Teshome Soromessa, and MekuriaArgaw. 2015. "Carbon stock analysis along slope and slope aspect gradient in Gedo Forest: implications for climate change mitigation." J. Earth Sci. Clim. Change 6, no. 9 (2015).

Yohannes, H., Soromessa, T. and Argaw, M. 2015. Carbon Stock Analysis along Forest Disturbance Gradient in Gedo Forest: Implications of Managing Forest for Climate Change Mitigation. J Ecosystem Ecograph, 5 (170), p.2.

8. Appendixes

Appendix 1: Tree biomass carbon stock of *C, lusitanica* stand

Plot No	Above ground biomass (n= 30)				BGB	
	Biomass (kg plot^{-1})	Biomass (kg ha^{-1})	Biomass (t ha^{-1})	BC (t ha^{-1})	BGBC (t h^{a-1})	co2e (t ha^{-1})
1	3576.25	178812.5	178.81	89.41	23.25	85.31
2	4656.4	232820	232.82	116.41	30.27	111.08
3	3199.02	159951	159.95	79.98	20.79	76.31
4	5635.57	281778.5	281.78	140.89	36.63	134.44
5	4889.22	244461	244.46	122.23	31.78	116.63
6	4473.78	223689	223.69	111.84	29.08	106.72
7	5760.11	288005.5	288.01	144.00	37.44	137.41
8	4168.94	208447	208.45	104.22	27.10	99.45
9	4614.01	230700.5	230.70	115.35	29.99	110.07
10	4504.92	225246	225.25	112.62	29.28	107.46
11	3176.24	158812	158.81	79.41	20.65	75.77
12	2839.36	141968	141.97	70.98	18.46	67.73
13	2845.35	142267.5	142.27	71.13	18.49	67.88
14	3320.85	166042.5	166.04	83.02	21.59	79.22
15	4268.16	213408	213.41	106.70	27.74	101.82
16	3015.95	150797.5	150.80	75.40	19.60	71.95
17	3481.4	174070	174.07	87.04	22.63	83.05
18	3732.67	186633.5	186.63	93.32	24.26	89.04
19	4117.49	205874.5	205.87	102.94	26.76	98.22
20	2193.42	109671	109.67	54.84	14.26	52.32
21	3159.86	157993	157.99	79.00	20.54	75.38
22	3037.27	151863.5	151.86	75.93	19.74	72.45
23	3331.94	166597	166.60	83.30	21.66	79.48
24	4454.72	222736	222.74	111.37	28.96	106.27
25	3937.62	196881	196.88	98.44	25.59	93.93
26	3649.51	182475.5	182.48	91.24	23.72	87.06
27	3943.22	197161	197.16	98.58	25.63	94.07
28	4250.38	212519	212.52	106.26	27.63	101.39
29	2995.41	149770.5	149.77	74.89	19.47	71.46
30	4020.13	201006.5	201.01	100.50	26.13	95.90
mean	384.2	192082	192.08	96.04	23.05	91.64

Appendix 2: Tree biomass carbon stock of *E, globulus* stand

Above ground biomass (n= 30)					BGB	
plot no,	biomass (kg plot^{-1})	biomass (kg ha^{-1})	Biomass (t ha^{-1})	AGBC (t ha^{-1})	BGBC (t ha^{-1})	co2e (t ha^{-1})
1	3605.24	180262	180.262	90.13	21.63	79.39
2	4000.37	200018.5	200.0185	100.01	24.00	88.09
3	4100.33	205016.5	205.0165	102.5	24.60	90.28
4	2601.1	130055	130.055	65.03	15.61	57.28
5	2521.44	126072	126.072	63.03	15.13	55.52
6	3620.9	181045	181.045	90.5	21.72	79.71
7	3844.77	192238.5	192.2385	96.12	23.07	84.66
8	3651.25	182562.5	182.5625	91.3	21.91	80.42
9	3566.26	178313	178.313	89.15	21.40	78.52
10	3598.18	179909	179.909	89.95	21.59	79.23
11	2466.15	123307.5	123.3075	61.65	14.80	54.30
12	2789.43	139471.5	139.4715	69.73	16.74	61.42
13	3399.37	169968.5	169.9685	85	20.40	74.87
14	3975.11	198755.5	198.7555	99.4	23.86	87.55
15	3503.54	175177	175.177	87.6	21.02	77.16
16	3714.32	185716	185.716	92.86	22.29	81.79
17	3401.71	170085.5	170.0855	85.04	20.41	74.90
18	2327.31	116365.5	116.3655	58.18	13.96	51.24
19	2807.66	140383	140.383	70.2	16.85	61.83
20	3249.59	162479.5	162.4795	81.2	19.49	71.52
21	2828.1	141405	141.405	70.7	16.97	62.27
22	3972.06	198603	198.603	99.3	23.83	87.46
23	2402.38	170119	170.119	85.06	20.41	74.92
24	3823.14	191157	191.157	95.6	22.94	84.20
25	3127.07	156353.5	156.3535	78.2	18.77	68.88
26	3204.73	160236.5	160.2365	80.1	19.22	70.55
27	2941.31	147065.5	147.0655	73.5	17.64	64.74
28	3535.75	176787.5	176.7875	88.4	21.22	77.86
29	3396.8	169840	169.84	84.92	20.38	74.80
30	3175.32	158816	158.816	79.41	19.06	69.94
mean	3305.023	166919.5	166.92	83.46	20.03	73.51

Appendix 3: Litter biomass carbon stock of *C, Lusitanica* and *E. globulus* stand

Plot no.	Fresh mmass (g)	Sample mass (g)	Oven dry mass (g)	LB (t ha^{-1})	LBC (t ha^{-1})	CO2e (t ha^{-1})
1	2953.6	100	92.3	0.273	0.136	0.500
2	2546.1	100	94.3	0.240	0.120	0.441
3	1970.05	100	96.1	0.189	0.095	0.347
4	1711.5	100	97.8	0.167	0.084	0.307
5	1296.3	100	89.4	0.116	0.058	0.213
6	959.7	100	91.4	0.088	0.044	0.161
7	618.8	100	72.8	0.045	0.023	0.083
8	3170.55	100	91.9	0.291	0.146	0.535
9	1742.325	100	89.35	0.156	0.078	0.286
10	1598.85	100	94.05	0.150	0.075	0.276
11	4105	100	82.1	0.337	0.169	0.618
12	1971.075	100	96.15	0.190	0.095	0.348
13	1596.6	100	88.7	0.142	0.071	0.260
14	1867.275	100	86.85	0.162	0.081	0.298
mean	2008		90.23	0.18	0.068	0.33
	Eculyptus					
1	1759	100	87.95	0.155	0.077	0.284
2	3472.5	100	92.6	0.322	0.161	0.590
3	3227.4	100	97.8	0.316	0.158	0.579
4	770	100	96.25	0.074	0.037	0.136
5	1373.3	100	88.6	0.122	0.061	0.223
6	2291.95	100	99.65	0.228	0.114	0.419
7	2681.05	100	92.45	0.248	0.124	0.455
8	2206.8	100	91.95	0.203	0.101	0.372
9	714	100	89.25	0.064	0.032	0.117
10	1246.05	100	92.3	0.115	0.058	0.211
11	2223.75	100	88.95	0.198	0.099	0.363
12	919	100	91.9	0.084	0.042	0.155
13	2104.425	100	89.55	0.188	0.094	0.346
14	1576	100	98.5	0.155	0.078	0.285
mean	1898		92.69	0.177	0.065	0.32

Appendix 5: Soil organic carbon stock of *C, lusitanica* and *E. globulus* stand

Plot no,	Soil depth (cm)	Volume (cm)	BD (g cm^{3})	Oven dry mass (g)	% SOC (t ha^{-1})	SOC (t ha^{-1})	CO2e(t ha^{-1})
1	20	565.2	0.63	358.37	3.7	46.62	171.10
2	20	565.2	0.62	349.43	3.3	40.92	150.18
3	20	565.2	0.75	425.8	4.11	61.65	226.26
4	20	565.2	0.6	338.63	2.9	34.8	127.72
5	20	565.2	0.59	334.50	3.9	46.02	168.89
6	20	565.2	0.64	361.93	5.4	69.12	253.67
7	20	565.2	0.54	304.67	5.1	55.08	202.14
8	20	565.2	0.6	336.67	3.8	45.6	167.35
9	20	565.2	0.54	304.47	3.5	37.8	138.73
10	20	565.2	0.64	360.00	4.3	55.04	202.00
11	20	565.2	0.56	315.83	4.5	50.4	184.97
12	20	565.2	0.61	342.03	2.9	35.38	129.84
13	20	565.2	0.66	373.30	3.4	44.88	164.71
14	20	565.2	0.42	238.17	4.7	39.48	144.89
Mean						138.81	509.42
1	20	565.2	0.61	346.3	4.26	51.97	190.74
2	20	565.2	0.62	350.37	4.85	60.14	220.71
3	20	565.2	0.75	425.8	4.11	61.65	226.26
4	20	565.2	0.56	318.9	4.43	49.62	182.09
5	20	565.2		384.33	4.62		230.59
6	20	565.2	0.68	381.93	3.95	53.72	197.15
7	20	565.2	0.56	318.7	4.05	45.36	166.47
8	20	565.2	0.59	334.37	4.61	54.40	199.64
9	20	565.2	0.56	317.73	4.79	53.65	196.89
10	20	565.2	0.63	357.37	4.73	59.60	218.72
11	20	565.2	0.55	312.07	4.32	47.52	174.40
12	20	565.2	0.57	323.33	4.11	46.85	171.95
13	20	565.2	0.67	379.1	3.83	51.32	188.35
14	20	565.2	0.58	330.27	4.22	48.95	179.65
Mean						**160.20**	**587.92**

Appendix 7: Summary of carbon stock of *C, lusitanica* forest plantation

Plot no	AGB (kg ha^{-1})	AGBC (t ha^{-1})	BGB (kg ha^{-1})	BGBC (t ha^{-1})	BL (t ha^{-1})	LC (t ha^{-1})	SOC (t ha^{-1})	SOC(t ha-^{1})2
1	178812.5	89.41	46491.25	23.25	0.27	0.10	46.62	139.86
2	232820	116.41	60533.2	30.27	0.24	0.09	40.92	122.76
3	159951	79.98	41587.26	20.79	0.19	0.07	46.62	139.86
4	281778.5	140.89	73262.41	36.63	0.17	0.06	34.8	104.4
5	244461	122.23	63559.86	31.78	0.12	0.04	46.02	138.06
6	223689	111.84	58159.14	29.08	0.09	0.03	69.12	207.36
7	283505.5	144	73711.43	37.44	0.05	0.02	55.08	165.24
8	208447	104.22	54196.22	27.10	0.29	0.11	45.6	136.8
9	230700.5	115.35	59982.13	29.99	0.16	0.06	37.8	113.4
10	225246	112.62	58563.96	29.28	0.15	0.06	55.04	165.12
11	158812	79.41	41291.12	20.65	0.34	0.13	50.4	151.2
12	141968	70.98	36911.68	18.46	0.19	0.07	35.38	106.14
13	142267.5	71.13	36989.55	18.49	0.14	0.05	44.88	134.64
14	166042.5	83.02	43171.05	21.59	0.16	0.06	39.48	118.44
15	213408	106.7	55486.08	27.74				
16	150797.5	75.4	39207.35	19.60				
17	174070	87.04	45258.2	22.63				
18	186633.5	93.32	48524.71	24.26				
19	205874.5	102.94	53527.37	26.76				
20	109671	54.84	28514.46	14.26				
21	157993	79	41078.18	20.54				
22	151863.5	75.93	39484.51	19.74				
23	166597	83.3	43315.22	21.66				
24	222736	111.37	57911.36	28.96				
25	196881	98.44	51189.06	25.59				
26	182475.5	91.24	47443.63	23.72				
27	197161	98.58	51261.86	25.63				
28	212519	106.26	55254.94	27.63				
29	149770.5	74.89	38940.33	19.47				
30	201006.5	100.5	52261.69	26.13				
Mean	191932	96.04	49902	23.05	0.18	0.068	46.27	138.81

Appendix 8: Summary of carbon stock of *E, globulus* forest plantation

Plot no	AGB (kg ha^{-1})	AGBC (t ha^{-1})	BGB (kg ha^{-1})	BGBC (t ha^{-1})	BL (t ha^{-1})	LC (t ha^{-1})	SOC (t ha^{-1})	SOC (t ha-^{1})2
1	180262	90.13	43262.88	21.14	0.15	0.06	51.97	155.91
2	200018.5	100.01	48004.4	23.46	0.32	0.12	60.14	180.42
3	205016.5	102.5	49203.96	22.97	0.32	0.12	61.65	184.95
4	130055	65.03	31213.19	16.01	0.07	0.03	49.92	149.76
5	126072	63.03	30257.28	16.18	0.12	0.04	62.83	188.49
6	181045	90.5	43450.8	18.67	0.23	0.09	53.72	161.16
7	192238.5	96.12	46137.24	17.18	0.25	0.09	45.36	136.08
8	182562.5	91.3	43815	21.01	0.2	0.07	54.4	163.2
9	178313	89.15	42795.12	16.59	0.06	0.02	53.65	160.95
10	179909	89.95	43178.16	17.23	0.12	0.04	59.6	178.8
11	123307.5	61.65	29593.8	14.28	0.2	0.07	47.52	142.56
12	139471.5	69.73	33473.16	16.35	0.08	0.03	46.85	140.55
13	169968.5	85	40792.4	18.66	0.19	0.07	51.32	153.96
14	198755.5	99.4	47701.32	23.55	0.16	0.06	48.95	146.85
15	175177	87.6	42042.48	22.77				
16	185716	92.86	44571.84	19.35				
17	170085.5	85.04	40820.52	18.94				
18	116365.5	58.18	27927.7	14.53				
19	140383	70.2	33691.92	16.71				
20	162479.5	81.2	38995.08	15.71				
21	141405	70.7	33937.2	13.66				
22	198603	99.3	47664.72	23.65				
23	170119	85.06	40828.56	21.77				
24	191157	95.6	45877.68	23.93				
25	156353.5	78.2	37524.84	18.02				
26	160236.5	80.1	38456.76	19.20				
27	147065.5	73.5	35295.72	17.53				
28	176787.5	88.4	42429	21.67				
29	169840	84.9	40761.6	21.96				
30	158816	79.4	38115.84	20.29				
mean	166919.5	83.46	40060.68	20.03	0.176	0.065	53.42	160.2

9. BIOGRAPHIC SKETCH

The author, Teshome Daka Wedo was born in Wochema rural kebele, Dilla zuria woreda in Gedeo zone of SNNP, Ethiopia in 1976. I was reach age for education attended my education at Hafero-Akesho elementary school from 1 – 6 and Chichu junior high school 7 and 8, then Dilla senior high school 9 to 12 completed. After completed 12 grades, I was attended diploma in General Agriculture at Jimma University College of agriculture and graduate of diploma in 1998. After diploma graduation worked as development agents at Wonago woreda agriculture sector and then attended BSC, degree in Natural Resource Management at Haremaya University from 2001 to 2004. After graduation of BSC degree I was worked as soil and water conservation experts, Natural Resource team leader in woreda agriculture sector and Rural work creating and opportunity youth parts leader in woreda, and then forestry development experts in Gedeo zone environment protection and forestry development office. Since 2010, I was joined the school of Graduate studies of Hawassa University, Wondo Genet College of forestry and Natural Resource to pursue my MSC study. I have been working as expert at Gedeo zone.