EFFECTS OF THINNING FREQUENCY ON BIOMASS AND SOIL ORGANIC CARBON STOCK OF *CUPRESSUS LUSITANICA* PLANTATIONS IN CENTRAL HIGHLAND, ETHIOPIA

MSc. THESIS

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A THESIS SUBMITTED TO THE DEPARTMENT OF FORESTRY, WONDO GENET COLLEGE OF FORESTRY AND NATURAL RESOURCES, SCHOOL OF GRADUATE STUDIES, HAWASSA UNIVERSITY, WONDO GENET, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FORESTRY (*SPECIALIZATION: FOREST RESOURCE ASSESSMENT AND MONITORING*)

MAJOR ADVISOR: MESELE NEGASH (PhD)

OCTOBER, 2018

Approval sheet - I

This is to certify that the thesis entitled “Effects of Thinning Frequency on Biomass and Soil Organic Carbon Stocks of *Cupressus lusitanica* Plantations in Central Highland, Ethiopia” is submitted for the partial fulfillment of the requirement for the degree of Masters of Science with specialization in Forest Resource Assessment and Monitoring, Wondo Genet College of Forestry and Natural Resources, and is a record of original research carried out by Solomon Birhanu, Id.No MSc/FRA&M/R0017/09 under my supervision and no part of the thesis has been submitted for any other degree or diploma. The assistance and help received during the course of his investigation are duly acknowledged. Therefore, I recommend that it accepted as fulfilling the thesis requirements.

Mesele Negash (PhD)	____________________	__________________
Name of principal supervisor	Signature	Date

Approval sheet - II

We, the undersigned, members of the board of examiners of the final open defense by Solomon Birhanu have read and evaluated his thesis entitled "Effects of Thinning Frequency on Biomass and Soil Organic Carbon Stocks of *Cupressus lusitanica* Plantation in Central Highland, Ethiopia." This is, therefore, to certify that the thesis accepted in partial fulfillment of the requirements for the degree of Master of Science in Forest Resource Assessment and Monitoring.

____________________ (PhD) ____________________ ____________________

Name of the chairperson signature date

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Name of major advisor signature date

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Name of internal examiner signature date

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Name of external examiner signature date

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SGS Approval Signature date

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Declaration

I, Solomon Birhanu, hereby declare that this thesis entitled “Effects of Thinning Frequency on Biomass and Soil Organic Carbon Stocks of *Cupressus lusitanica* Plantations in Central Highland, Ethiopia ” submitted for the partial fulfillment of the requirements for the degree of Masters of Science with specialization in Forest Resource Assessment and Monitoring is the original work done by me under the principal supervision of Dr. Mesele Negash and 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 idea of other authors used in this thesis accordingly acknowledged and references listed at the end of the main text. Therefore, it is free for use as far as proper citation and acknowledgement is made.

Solomon Birhanu Tessema	_______________	__________________
Name of student	Signature	Date

Dedication

I dedicate this thesis manuscript to my mother W/ro Tafesu Alemu and my father Mr. Birhanu Tessema for nursing me with affection and love and for their devoted partnership in the success of my life.

Acronyms

AGB	Above Ground Biomass
ANOVA	Analysis of Variance
ARDO	Agricultural and Rural Development Office
BGB	Below Ground Biomass
CDM	Clean Development Mechanism
CRGE	Climate Resilience Green Economy
CSA	Central Statistical Agency
DBH	Diameter at Breast Height
DOM	Dead Organic Matter
FAO	Food and Agriculture Organization
FDRE	Federal Democratic Republic of Ethiopia
GHG	Greenhouse Gases
Ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
MEFCC	Ministry of Environment, Forest and Climate Change
NBP	Net Biome Production
ODW	Oven dries weight
REDD+	Reducing Emission from Deforestation and Forest Degradation, Conservation of forest carbon stock, and Enhancement of Forest Carbon Stocks
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
UNFCCC	United Nation Framework Convention on Climate Change

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ABSTRACT

*Plantation forests can capture and retain carbon in their biomass and soil over time. However, unregulated harvest of plantation would result biomass and carbon removal from the site. So, appropriate management of plantation forest is important to enhance the carbon sink and hence, climate change mitigation. The general objective of this study was to investigate the effects of thinning frequency on biomass and soil organic carbon stocks of Cupressus lusitanica plantations in Central highland, Ethiopia. Two plantations attributing: - once thinned (at Kofele site) and twice thinned (at Shashemene site) were purposively selected for this study. Twenty-two main sample plots (12 from once thinned and 10 from twice thinned site) were laid own for data collection. Nested plots of size 20m * 20m as main plots were systematically established and used for tree inventory. Three 1m * 1m sub-sample plots within the main plots were selected for soil and litter sampling. Data of trees whose DBH (≥ 5 cm) and total tree height were measured in the main plot using diameter caliper and hypsometer respectively. The litter was collected from three sub-sample plots 1 m x 1 m laid randomly within the main plots. To analyze the total biomass carbon stock was analyzed using locally developed biomass allometric equation for Cupressus lusitanica at WGCF-NR was used for determining above ground biomass. This model was selected because the current study sites were located in the vicinity of WGCF-NR. Soil samples for carbon content determination were collected from three randomly selected sub-sample pots 1m * 1m in the main plots from the soil depth 0 - 20 cm, 20 - 40 cm and 40-60 cm using auger method. Similarly, soil samples were taken from 0 - 60 cm soil depth (0 - 20 cm, 20 - 40 cm and 40 - 60 cm in layers) to determine soil bulk density using core method. The result indicated that the average basal area (m^2/ha) in the once thinned site was 33.75 ± 6.50 whereas 24.25 ± 3.25 in the twice thinned. The total mean carbon stocks density of the once thinned site was 207.48 ± 54.12 was higher than 156.80 ± 12.53 t/ha in the twice thinned site. In twice thinned site, relatively the largest carbon stock was observed in soil organic carbon pool (55.69 %). However, it was 50.05 % in once thinned. In both sites, the contribution of litter biomass carbon stocks to the total (ecosystem) carbon stock was less than 1 %. The result of this study showed that as thinning frequency increased from once thinned to twice thinned, the total biomass carbon (t/ha) decreased by 33 % and by 15.90 % in soil organic carbon pools. This much biomass and soil organic carbon variation or loss was due to differences in thinning frequency of the two sites. Therefore, plantation management should minimize thinning frequency to complement climate change mitigation strategy in the tropics to benefit from carbon financing.*

Key words: - Carbon sequestration, litter, organic carbon, silviculture.

1. INTRODUCTION

1.1. Background

Globally, the carbon cycle plays a key role in regulating the Earth’s climate by controlling the concentration of CO_2 in the atmosphere. Forests play a key role in both sources and sinks of carbon dioxide. Forests can be sources of atmospheric CO_2 when disturbed by anthropogenic factors (Shvidenko *et al.*, 2005).

Carbon (C) can potentially be sequestered in forest biomass and soils which represent the largest carbon pool in the terrestrial ecosystem(Lal, 2004). Most terrestrial biomass carbon storage is in tree trunks, branches, foliage, harvested wood products and roots, which often called biomass. Therefore, forest biomass is an important element in the carbon cycle, specifically in carbon sequestration. Additionally carbon is also sequestered in forest soils (Lal, 2004). Globally, the soil carbon stock is nearly three times the amount of the AGB and about twice as large as the carbon stock of the atmosphere (Mäkipää *et al*., 2012)

There are five carbon pools of a forest ecosystem: soil, plant debris (dead wood, dead roots, and leaf litter), AGB, BGB, and herbaceous plants (Ekoungoulou *et al.*, 2014). However; according to Ethiopia’s Forest Reference Level Submission to the UNFCCC, the carbon pools included in the FRL will be above ground biomass (AGB), below ground biomass (BGB), and deadwood. With regard to the soil, this may constitute a very large carbon pool in Ethiopian forests. However, little is known about emissions from soil after forest conversion and data collection in soils is very costly and needs monitoring over an extended period. For this reason, the soil carbon pool is not included in the FRL (MEFCC, 2017).

Planted forest area increased by 66 percent from 167.5 million hectares in 1990 to 277.9 million hectares in 2015 over the past 25 years and now accounts for 7 percent of the world’s total forest area (FAO, 2015). The establishment of monoculture forest plantations with exotic, fast-growing species is common in tropical countries. The purposes of the establishment are to increase the supply of timber products, to protect the natural forest and restore the degraded land (Lemma, 2006).

Four major strategies are available to mitigate carbon emissions from forestry sector: (i) increase forest land area through reforestation and afforestation, (ii) increase the carbon density of existing forests at both stand and landscape level, (iii) expand the use of forest products (iv) reduce emissions from deforestation and degradation (Canadell and Raupach, 2008).

Tree plantations play a great role in controlling environmental degradation and concentration in the atmosphere. Trees can remove carbon dioxide from the atmosphere through the natural process of photosynthesis and store carbon in their aboveground, belowground, litter, dead wood and soil (Canadell and Raupach, 2008).

In Ethiopia, tree planting carried out by different stake holders. Large-scale plantations, mainly monocultures of *Eucalyptus, Cupressus lusitanica and Pinus* species have been established with the aim to increase the supply of timber products, protect the remaining natural forest and achieve an ecological restoration of degraded sites. (Anatoli Poultouchidou, 2012).

Particularly in the past five years, there has been a mass mobilization in soil and water conservation, which include both physical and biological activities. According to the Federal Democratic Republic of Ethiopia, Ministry of Environment, Forest and Climate Change proposal for REDD+ investment in Ethiopia (2017 - 2020), the total forest coverage of the country is 17.2 million ha covering 15.5 per cent of the country (MEFCC, 2015). According to Ethiopia forest sector review (2017), plantation forest coverage of the country is estimated to be 909,500 ha (MEFCC, 2017). *Cupressus lusitanica* is one of the most widely planted species in Ethiopia and similarly this species is the best performing exotic species planted out in the studied areas.

Ethiopia is one of the developing countries, which have designed CRGE to achieve the economic growth as well as to mitigate the climate change impacts. Today, the country has prepared to implement REDD$^+$ as well as CDM through plantation by planned forest coverage enhancement (FDRE, 2011).

In Ethiopia, estimation of carbon stock potential of forest begun in recent years. However, studies on the contribution of forest to climate change mitigation are not much. Ethiopia has limited information about carbon stocks of the forest. However, carbon is varying from forest to forest and soil to soil (Feyissa *et al*. (2013).

Thinning is an important and frequently used silvicultural practice. Intensive silviculture, with shorter harvesting intervals and more intensive logging (i.e., thinning, clear-cuts) generally reduces net carbon storage rates and carbon storage at the stand level, when compared with low-intensity silviculture (e.g., the selection system) (McKinley *et al*., 2011). By ensuring more space and nutrients for remaining trees, thinning improves leaf numbers and diameter increments, and, thus, can increase individual tree volume. Thinning can advance forest maturation and shorten the growth phase prior to harvest (Shen, 2001).

Most previous studies on thinning have focused on the impact of thinning on forest wood products (Malmsheimer, 2013). The role of forests as carbon sinks has clear implications for the CO_2-induced greenhouse effect and climate change, and as a result, the effect of thinning on the ability of forests to sequester carbon has attracted increasing scientific attention (Zasada, *et al*., 2009). Therefore, this study was conducted to investigate the effects of thinning frequency on biomass and soil organic carbon stock of *Cupressus lusitanica* plantation in Central Highland, Ethiopia.

1.2. Statement of the problems

Today, due to concerns of climate in global carbon trade, estimating carbon stored in forests is increasingly important. Climate change is a global alarm that should be addressed. In response to this global worry, the government of Ethiopia has aimed at keeping emissions constant by applying abatement measures in sectors such as forestry, agriculture and industry. Afforestation, reforestation, and deforestation prevention recognized as possible means of offsetting anthropogenic carbon emissions and as a result, developed countries have begun to invest in forestry based carbon offset projects in developing countries. Ethiopia designed CRGE and implementing REDD+ and CDM through plantation by planned of forest coverage enhancement, to achieve the economic growth as well as to mitigate the climate change impacts (Negra, C., 2014).

Unlike the developed countries, Ethiopia has a few carbon inventories and databank to monitor and enhance carbon sequestration potential of different forests subjected to various silvicultural operations. Carbon stock is varying from forest to forest, from soil to soil and the intensity of different silvicultural operations. However, limited number of studies is available regarding carbon stock for the different forest types, the soils underneath and plantations of various species of which *Cupressus lusitanica* is the major one. Only few activities about carbon sequestration potential published recently (Alefu Chinasho *et al*., 2015).

Previous studies on *Cupressus lusitanica* focused on site index functions (Teshome and Petty 2000, growth and yield models (Pukkala and Pohjonen 1993). The role of *Cupressus lusitanica* in the study areas is for industrial purpose and this needs silvicultural option like thinning and pruning. This can affects carbon pools. But no adequate study or lacking in these regards. Therefore, this study was aimed to investigate the effect of thinning frequency on biomass and soil organic carbon stocks of *Cupressus lusitanica* plantations.

1.3. Objectives of the study

1.3.1. General objective

The overall objective of this study was to investigate the effects of thinning frequency on biomass and soil organic carbon stocks of *Cupressus lusitanica* plantations in Central Highland, Ethiopia.

1.3.2. Specific objectives

- To estimate and compare carbon pools of *Cupressus lusitanica* plantations between two thinning frequencies.
- To assess soil physicochemical properties of *Cupressus lusitanica* plantations in the studied thinning frequencies

1.4. Research questions

- How biomass and soil organic carbon stock vary with thinning frequency on *Cupressus lusitanica* plantation?

1.5. Hypothesis

Based on the objectives of this study, the following hypotheses were proposed:

- Thinning frequency has no significant effects on biomass and soil organic carbon stock of *Cupressus lusitanica* plantations.

1.6. Significance of the study

Estimation of total biomass and soil carbon sequestered in any forest system is very important as it gives ecological and economic benefits of the local people. However, Ethiopia does not have adequate carbon inventories and data bank to monitor and enhance carbon sequestration potential.

This information is valuable to policy makers that may formulate policies that will enhance the development of plantation in climate change strategies. Besides, this study will contribute to provide organized document for researchers, government and non-governmental organizations and other concerned bodies who engaged in similar studies elsewhere and for climate change mitigation.

The quantification of above ground, below ground, litter biomass carbon stock and soil organic carbon can be serves as an input for global datasets of IPCC, CDM and REDD+. It is also important for sustainable forest management and ecological as well as economic benefits for local tree growers through carbon trading in the study areas.

2. LITERATURE REVIEW

2.1. Definition and meaning of plantation forests

According to Pearson *et al*. (2005), the decision of what constitutes a forest has implications for what lands are available for afforestation and reforestation activities.

Implications: There are various implications for project eligibility based on which forest definitions are chosen.

Ethiopia adopted a new forest definition of 2015 as follows: Land spanning more than 0.5 ha, attaining a height of more than 2 meters and a canopy cover of more than 20% or trees with the potential to reach these thresholds in situ in due course. Ethiopia is in the process of approving this as its national legal definition (MEFCC, 2016). This forest definition differs from the definition used for international reporting to the Global Forest Resources Assessment (FRA) and from the forest definition used in the NFI, which both applied the FAO forest definition of the thresholds of 10% canopies covers, a 0.5 ha, area and a 5 m height.

The reason for changing the national forest definition is better capturing the natural primary state of Ethiopia's forest vegetation. Specifically, the reason for lowering the tree height of 5 meters to 2 meters is to capture natural forest vegetation types like the dry land forests, which of trees reaching a height of around 2-3 m. The proposed change in forest definition results in the inclusion of what previously classified as Ethiopia's dense woodlands that have a wider distribution in the country. Commercial agriculture is expanding mainly on dense woodlands and Ethiopia desires to enable REDD+ (Reducing Emission from Deforestation and Forest Degradation, Conservation of forest carbon stock, and Enhancement of forest carbon stocks) incentives for its conservation. The reason for increasing the canopy covers threshold from 10 % to 20 % is to avoid acceptance of highly degraded forest lands into the forest definition and in this way provide incentives for protecting quality forest (MEFCC, 2016).

This forest definition differs from the definition used for reporting greenhouse gas (GHG) emissions and removals from the forestry sector within the framework of the (CDM) that submitted to the UNFCCC earlier, which is “A minimum of 0.05 ha of land covered by trees attaining a height of more than 2 m and a canopy cover of more than 20 %. ‟ the difference is an increase in area threshold. The main reason for increasing the area in the FRL is due the limitation of technology for measurement and monitoring to detect changes in small areas of forest (MEFCC, 2016).

2.2. The role of plantation forests carbon stocks on climate change mitigation

Forest ecosystems play an important role in the climate change problem because they can both be sources and sinks of atmospheric CO_2. Forest management affects carbon storage potential of trees. Forests are managed to assimilate CO_2 via photosynthesis, and store carbon in biomass and in soil (Watson *et al*., 2000; Brown, 1998; Brown *et al*., 1996). Forest carbon stocks are grouped into two main components: biotic (vegetation) and pedologic (soil) carbon stock (Bhat *et al*., 2013).

Forests account for 80 % - 90 % of the total global carbon reservoir in the living biomass (Dixon *et al*., 1994), covers 30 % - 40 % of the vegetated area of the earth and exchange carbon with the atmosphere through photosynthesis and respiration (Malhi *et al*., 1999), thus playing an important role in the global carbon cycle. 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; Houghton, 2005), litter, woody debris, soil organic matter and forest products and organic carbon in the soil (Houghton, 2005).

The carbon balance of forest ecosystem [net ecosystem production (NEP)] is the net result of carbon acquisition through photosynthesis and carbon losses through autotrophic and heterotrophic respiration (Malhi et al., 1999). In other words, whether a forest ecosystem is a carbon sink or source depends on the balance of photosynthetic uptake and respiratory release of CO_2 (Malhi *et al*., 1999). The NEP is an important indicator for estimating carbon sinks or source in terrestrial ecosystems and influenced by land use and management through a variety of anthropogenic actions such as deforestation, afforestation, fertilization, irrigation, harvest, and species choice (IPCC, 2005). Disturbances (e.g., harvesting, conversion to non-forest uses, wildfires, etc.), can convert a forest from a sink to a source for atmospheric carbon when NEP and net biome production (NBP) become negative. On the other hand, an area can become a carbon sink if the forest is allowed to regenerate after a disturbance when NEP and NBP become positive (Brown *et al*., 1996).

2.3. Role of plantation forests

Humans have established planted forests for millennia and the area of plantation has been increasing worldwide (FAO, 2010). The growing area of plantations can result from the demand of the world's increasing population for domestic and industrial timbers. With the global population predicted to reach 9.7 billion by 2050, they will continue to play an important role in meeting increased demand for forest products and agricultural commodities (United Nations, 2014).

Planted forest area increased by 66 % from 167.5 million hectares in 1990 to 277.9 million ha in 2015 over the past 25 years and now accounts for 7 % of the world's total forest area (FAO, 2015).

However, African forests and trees seriously threatened by agricultural expansion, commercial harvesting, and increasing exploitation of fuel wood and other products and increasing urbanization and industrialization (IPCC, 2013).. All these problems are aggravated due to inadequate land use planning, inappropriate agricultural systems and drought. Although, Africa is not a major emitter of CO_2 and other greenhouse gases from commercial and industrial energy uses, it accounts for 20 - 30 % of CO_2 emission due to deforestation and land use cover change (IPCC, 2013).

According to Ethiopia forest sector review (2017), plantation forest coverage of the country is estimated to be 909,500 ha. According to this review, the productivity of public plantation of *Cupressus lusitanica's* rotation and mean annual increment (MAI) is 25 years and $13m^3yr^{-1}$ respectively. The summary of public plantations and private wood lots in Ethiopia were shown in (Table 1).

Table 1: Plantations and wood lots in Ethiopia

Resource	Area in ha
Public plantations Oromia	57,700 ha
Public plantations Amhara	32,100 ha
Chip wood plantations, i.e. Tigray and SNPP	15,000 ha
Public plantations other regions	Unspecified sources (est. of 52,000 ha, but not verified)
Peri-urban energy plantations	26,700 ha
Private/community small-scale woodlots	778,000 ha
Total	909,500 ha

Source: Ministry of Environment, Forest and Climate Change, 2017

2.4. Forest plantations and their benefits

There are potential environmental benefits that can arise from the plantation forests. Plantation forests are used to increase the supply of timber products, to protect the natural forest and restore the degraded land (Lemma, 2006).

Increasing the extent of plantation forests has suggested as an effective measure to mitigate elevated atmospheric carbon dioxide (CO_2) concentrations and contribute to the reduction of global warming (Watson *et al.*, 2000, IPCC, 2001a).

The growing area of tree plantations, besides providing direct economic benefits, will promote a large reservoir of carbon in plant biomass and soil that could trade in the international carbon market. Ecological restoration of a degraded land could be achieved by establishing exotic tree species (Mulugeta Lemenih, 2006). Tree plantations have the potential to improve the soil fertility by accumulating biomass, increasing the amount of organic matter content, enhancing plant nutrient availability, decreasing bulk density and the maintenance of biodiversity (Lugo, 1997).

When conditions permit natural forest's patches could be connected with forest plantations and therefore wildlife can disperse seeds from a natural to a plantation forest (Brockerhoff, *et al*., 2008; Mulugeta Lemenih, 2006). Hence, regeneration of native tree species under the canopy of exotic tree plantations can be achieved (Lugo, 1997). Moreover, the establishment of large-scale plantations considered as an effective method to mitigate climate change (House *et al*., 2002).

Afforestation/reforestation projects are included in several climate change mitigation mechanisms such as Reduced Emissions from Deforestation and Forest Degradation (REDD). The idea of REDD+ is that financial incentives given to developing countries in order to reduce emissions from deforestation and forest degradation and enhance C stocks through afforestation/reforestation projects.

Currently, there is growing interest by companies in developed countries to invest in carbon sequestration projects in developing countries to meet their carbon reduction obligation based on the Clean Development Mechanism (CDM) of the Kyoto protocol.

Payment for carbon sequestration via land uses appears to be attractive both for local incomes and for ecosystem services and a ‘win-win’ is possible (FAO, 2004).

With regard to the carbon trade initiative, the Humbo community-managed natural regeneration projects in Wolayita zone, southern Ethiopia, is the first large-scale forestry CDM project in Africa registered by the World Bank in 2010 (International Climate Policy and Carbon Markets 2010).

2.5. Carbon stocks potential of plantation forests

Carbon stock is defined as total carbon stored (absolute quantity) in terrestrial ecosystems at specific time, as above and below-ground, dead wood, litter, harvested wood products and SOC (Moges *et al*., 2010).

Tropical plantation forests have important role in carbon stock in a much higher quantity than any other biome (Bracmort and Gorte, 2009). Studies on carbon stock in tropical forests have been carried out by several researchers (Miyamoto *et al*., 2007) or estimated based on volume data of forest inventories (Brown *et al*., 1989). However, most of the studies focused on the estimation of forest biomass and carbon stock at one occasion.

Forest biomass and carbon stock may be dynamic and changes occur continuously at individual tree and stand levels up to the of harvest losses of carbon during deforestation and degradation. The changes occurring could be caused by human activities and accumulation of carbon during regrowth of (Miyamoto *et al*., 2007).

The mean above ground carbon stock of plantation forests is 123 t/ha (WBISPP, 2005). But this estimation was done using global generic allometric equation which is developed by Brown (1997).

In Ethiopia, according to the Metz *et al*. (2007) report, the total carbon stock of plantation forest is 114.48 t/ha. The productivity of public plantation of *Cupressus lusitanica’s* rotation and mean annual increment (MAI) is 25 years and 13m³/year respectively (FRS, 2011).

2.6. *Cupressus lusitanica*

It originates from the moist mountain 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. *Cupressus lusitanica* is an evergreen coniferous tree. It belongs to the *Cupressaceae* family. It is indigenous to Central America where it grows at altitudes of 1200-3000 m.a.s.l (Azene Bekele, 2007).

It can be used for firewood, timber furniture, construction), poles, posts, shade, ornamental, windbreak, live fences. It is a large evergreen conifer to 35 m in height with a straight trunk. 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, *Cupressus lusitanica* plantations have been badly affected by a cypress aphid and many thousands of trees have died in recent years (Azene, Bekele, 2007).

2.7. Forest Resources of Arsi Branch Forest and Wildlife Enterprise.

According to Arsi branch forest enterprise office data 2018 (Management plan of Arsi branch 2016 - 2020, unpublished data), Oromia Forest and Wild life Enterprise is a public enterprise, was established in 1996 with the objectives (1) to sustainably manage the forest resources, (2) to ensure the sustainable management of biodiversity and (3) to contribute to the improvement of the socio-economic conditions of the local people who live around the forest area. It has nine (9) branches, thirty - eight (38) districts and head office at Addis Ababa. Arsi Forest and Wild life Enterprise is one of the nine (9) branches of Oromia Forest and Wildlife Enterprise and it has six (6) districts. Shashemene district forest and wildlife enterprise is under Arsi branch.

The concession area of Arsi branch is covered by forest which is composed of plantation forest (11,562.02 ha), natural forest (389,017.87 ha), wildlife protection areas (152,209.55 ha) and other land use types (15,258.70 ha) which are occupied by building, river, road and grasses. The total forest area of the enterprise is not in a single ecosystem or continues area rather they are existing on different enterprises' districts (six districts). The total forest coverage and percentages by districts shown in (Table 2).

Table 2: Total land cover and its distribution value of the entire enterprise

District	Plantation (ha)	Natural forest (ha)	Wildlife area (ha)	Other land (ha)	Total (ha)
Adaba-Dodola	1,233.40	289,834	51,350	14,518	356,935.40
Arba-Gugu	1,364.55	62,871.78	7,886	740.7	72,863.03
Chilalo-Galama	2,720.39	0	87,861.31	0	90,581.70
Munessa	2,603.20	30,365.49	4,911.93	0	37,880.62
Gambo	1,341.11	5,811.38	200.31	0	7,352.80
Shashemenne	2,299.37	135.22	0	0	2,434.59
Sum	11,562.02	389,017.87	152,209.55	15,258.70	568,048.14
%	2	68	27	3	100

Source: Management plan of Arsi branch forest enterprise (2016 - 2020, unpublished data).

2.7.1. Forest Composition of the Entire Enterprise

Natural forest: Some of the species in the natural forests having significant and considerable area coverage are the following: *Podocarpus falcatus (Zigba),Yushinia alpine (highland bamboo), Oleo africana (weira), Cordia africana (wanza), Hygenia abyssinica (koso), Croton macrostachyus (Bisana), Ficus vasta (warka), Syzygium gunineese*

(Dokma), Millettia ferruginea (Birbira), Celtis africana (Kewut), Prunus africana (tikurinchet).

Plantation forest species and area coverage: Plantation forest is playing great role as not only a major sources of income and running of the enterprises but it play an important role in environmental protection activities. In the plantation forests, there is periodically planned yearly reforestation or plantation program is going on constantly.

On average yearly 450 to 500 hectares are planted each year of which 90 % of the plantation species used is *Cupressus lustanica*. However, equivalent amount of tree will be harvested yearly mainly for the production of lumber of different grades in volume 50000 - 55000m^3 is an average yearly loaded log to the sawmill based on cutting rate and sawmills processing capacity. The main planned product of the enterprise is to produce products for last long uses, which are environmentally important products. Those are for lumber and construction material like pole for transmission (Management plan of Arsi branch forest enterprise (2016 - 2020).

2.8. Thinning Effects on Stand Growth

Thinning is a silvicultural operation that reduces the number of trees within the stand. A major reason for any thinning operation is the improvement on the light, nutrient, and water supply to increase stand productivity and obtaining better timber from potential crop trees (Yohannes *et.al*. 2013).

According to Boncina *et al*., 2007 stem dimension and stems quality is decisive criteria for valuable timber production. Consequently, forest stands management practices and, especially, thinning is important to the production of high-quality timber.

The main reasons for thinning are:

Increase light penetration to develop crown and accelerate diameter growth, increase the percentage of trees reaching maturity, and improve wood quality, encourage roots development, and maintain ground cover for erosion control.

Similarly according to (Evans, 1992), the major reasons for thinning are:

- To reduce the number of trees in a stand so that the remaining ones have more space for crown and root development encourages stem diameter increment and so reach usable size sooner.
- For stand hygiene both to remove dead, dying, diseased, and any others trees which may be a source of infection for, or cause damage to, the remaining health ones and reduce between tree competition to avoid stress level which may encourage pest and disease attack.
- To remove tree of poor form so that all future increment is concentrated only on the best trees and to favor the most vigorous trees with good form which are likely to make up final crop and to provide an intermediate financial return from the sale of thinning.

Thinning modifies the initial spacing with the objective of maximizing the final desired product, i.e., timber, biomass, fruits, etc. Increased tree spacing allows for maximizing crown diameter, which will positively influence diameter at breast height (DBH). At high competition levels trees show higher sensitivity to changes in water balance, whereas through thinning growth limitation by water and nutrient availability is reduced (Pretzsch, H., 2005).

Knowledge of the interactive effect of thinning and climate on the growth response becomes crucial for the selection of appropriate silvicultural treatments under projected global warming. The question is where, how, and when to intervene with silvicultural measures in valuable wood production systems in order to minimize the effect of droughts, and to increase the resilience of the stands. Moreover, questions on the appropriate thinning methods and thinning intensities for increasing the adaptive capacity of stands need to be evaluating in the light of anticipated climate change (Pretzsch, H., 2005).

2.9. Factors Affecting Forest Carbon Stock

Forest carbon stock could be affected by different environmental factors such as topographical factors like altitude, slope and aspect gradients. According to Houghton, 2005, identifying the factors which are influencing carbon stocks of forest is very important for the management of forest resource sustainably. Carbon stock of a given forest can be influenced by many factors like inherent potential for the tree and the physical ecosystem in which the tree exists. The most important being the species composition, stand age, site quality, genetic variation, stand density, management regime, previous land use and environmental factors such as altitude, slope and aspect gradients (Clark, 2000; Fahey., *et al*. (2010).

Various studies have shown that different forest ecosystems have different biomass and carbon stock potentials (Nair *et al*., 2009). This variability is mainly due to the species composition, growth speed, age, geographical location of the system (Jose, 2009), previous land use (Mutuo *et al*., 2005), climate, soil characteristics, crop-tree mixture, site productivity and management practices (Montagnini and Nair, 2004).

Intensive silviculture, with shorter harvesting intervals and more intensive logging reduces net carbon storage rates and carbon storage at the stand level, when compared with low-intensity silviculture (e.g., the selection system) (McKinley *et al*., 2011). In addition, low intensity silviculture may create stand structures and a composition more suitable for storing carbon, and disturbance resistance that may prevent catastrophic events such as wildfires. According to McKinley *et al*. (2011), high-severity fire can increase soil erosion, alter nutrient cycling, and decrease post-fire seedling recruitment. In general management activity can affect the net carbon exchange of the atmosphere to a large extent, by both affecting the amount of carbon stored in the vegetation and soil, and altering the local productivity pathway to the forest (Bellón *et al*.,1993).

2.10. Carbon pools

Carbon pools are components of the ecosystem that can either accumulate or release carbon. Different authors classified them in to different pools; this might be relating to the type of forest and the objectives of the project. According to Vashum and Jayakumar (2012), there are six carbon pools applicable to afforestation/reforestation LULUCF project activities: AGB, BGB, litter, non-tree vegetation (NTV), dead wood and soil organic matter (SOC). However, not all six pools significantly considered in a given project. The most important pools measured in any projects are AGB and BGB, because trees are simple to measure and contain the major portion of the carbon pool.

There are five carbon pools of a forest ecosystem: soil, plant debris (dead wood, dead roots, and leaf litter), AGB, BGB, and herbaceous plants (Ekoungoulou *et al*., 2014). According to IPCC (2006), carbon pools grouped into five main categories: living AGB, living BGB, DOM in wood, litter and soil. In a tropical forest ecosystem, the living biomass of trees, the understory vegetation and the deadwood, woody debris and soil organic matters constitute the main carbon pool.

Estimation of total carbon stock of the area is calculated by summing the carbon stock densities of the individual carbon pools of the site using the Pearson, 2005 formula. In addition, it is recommended that any individual carbon pool of the given formula can be ignored if it does not contribute significantly to the total carbon stock (Bishma *et al*., 2010).

2.10.1. Aboveground Biomass (AGB)

AGB of woody vegetation is one of the largest carbon pools. It comprises all woody stems, branches, and leaves of living trees, creepers, climbers, and epiphytes as well as herbaceous under growth. It is mainly the largest carbon pool and directly affected by deforestation and forest degradation.

The most direct way of quantifying the carbon stored in AGB is to harvest all trees in a known area, dry them and weigh the biomass. According to different researchers, this method is accurate for a particular location; it is prohibitively time consuming, expensive, destructive and impractical for country level analyses. The method of estimating biomass stocks based on inventory data and carbon concentration to establish the corresponding carbon stock is employed by many countries (Somogyi *et al*., 2007). Carbon is 50 % of the dry biomass of an individual tree (Zhu *et al*., 2010; Gibbs *et al*., 2007; Pearson *et al*., 2005; FAO, 2004 and Brown, 1997).

The other way of estimating carbon in AGB is grouping all species together and using generalized allometric relationships, stratified by broad forest types or ecological zones, is highly effective for the tropics because DBH alone explaining more than 95 % of the variation in above ground tropical forest carbon stocks, even in highly diverse regions (Gibbs *et al.*, 2007).

2.10.2. Belowground Biomass (BGB)

Measuring below ground tree biomass (roots) is not as easy as the above ground biomass. It is more complex, time consuming, destructive and almost never measured, but instead it is included through a relationship to above ground biomass (usually a root-to-shoot ratio) (Geider *et al.*, 2001). It is derived from AGB. Thus, it may be more efficient and effective to apply a regression model to estimate it. BGB of the forest is defined as those greater than 2 mm in diameter. However, it is recognized that most of the annual plant growth is dependent on fine or thin roots. Roots play an important role in the carbon cycle as they transfer considerable amounts of carbon to the ground, where it may be stored for a relatively long period. Root biomass is often estimated from root: shoot ratios (R/S).

The measurement of above ground biomass is relatively established and simple. Belowground biomass, however, can only be measured with time-consuming methods. Consequently, it is more efficient and effective to apply a regression models to determine below ground biomass from knowledge of above ground biomass (Pearson *et al*. 2005). According to Brown (2002), the root-to-shoot ratio did not vary significantly from latitudinal zone (tropical, temperate, and boreal), soil texture (fine, medium and coarse), or tree type (angiosperm and gymnosperm).

Ponce-Hernandez (2004) described that some roots can extend to great depths, but the greatest proportion of the total root mass is within the first 30 cm of the soil surface. This author described that carbon loss in the ground is intense in the top layer of soil profiles (0 – 20 cm). Therefore, sampling should concentrate on this section of the soil profile accumulation. Gibbs *et al*. (2007) and Ponce-Hernandez (2004) stated that root biomass typically is estimated to be 20 % of the above ground forest carbon stocks. However, the globally recommended one is differing from this ratio. Below ground, biomass estimated by using the globally averaged simple root: shoot ratio, which is 26 % of above ground tree biomass, i.e. root-to-shoot ratio values of 1:4 (Cairns *et al*. 1997).

2.10.3. Litter

The DOM litter carbon pool includes all non-living biomass with a size greater than the limit of soil organic matter (SOM), commonly 2mm, and smaller than that of DOM wood, 10 cm diameter. Dead wood with a diameter of < 10 cm and length < 0.5 m is included in the litter layer (Brown *et al*., 2004; Zhu *et al*., 2010). The decay of litter is one of the main sources of SOC (Lemma *et al*., 2007). Similarly, MacDicken (1997) indicated that the dead litter carbon pools consists of all non-living biomass with greater than the limit of soil organic matter (SOM) ≥ 2 mm to 10 cm diameter and contains the biomass in various states of decomposition prior to complete fragmentation and decomposition where it is transformed to SOM. As a result, litter is generally distinguished from SOM by its low degree of decomposition or fragmentation.

Litter at least occasionally accumulates on top of the soil, but litter may also include newly dead roots in the soil. Many estimates of the dead litter pool in forests use quadrats to assess the litter mass per unit area at a given point in time (Ordóñez *et al.*, 2008).

Similarly Brown *et al.* (2004) defines the duff layer as decomposing organic material, decomposed to the point at which there are no identifiable organic materials such as pine straw, leaves, twigs, or fruits. It is the organic material layer between the uppermost soil mineral horizon and the litter layer. Both layer combined as one pool and sampled together using small sub-plots. It also includes live fine roots less than 2 mm in diameter, as these cannot distinguish empirically from the litter and dead wood (Zhu *et al.,* 2010).

2.10.4. Soil

Globally, the soil carbon stock is nearly three times the amount of the AGB and about twice as large as the carbon stock of the atmosphere (Mäkipää *et al.*, 2012). Soil organic matter is the main source of soil organic carbon while vegetation is the main source of SOM. Therefore, any factor that influences SOM has impact on soil organic carbon (SOC).

The more carbon stocks in the soil would be a good opportunity to preserve carbon in long-term. Soil carbon sequestration could also be more preferred than biomass carbon that ultimately decomposes. Besides, soil carbon sequestration enhances the food productivity, nutrition security, sustaining water flow and quality, and improving biodiversity (Lal *et al.*, 2015).

According to Mäkipää *et al.* (2012), in broad geographic areas, the role of climate and natural vegetation on the levels of SOM is very important. Generally, in similar moisture conditions and comparable soils and vegetation, the SOM is higher in cooler climates than in warmer ones. Moreover, high rainfall promotes vegetation growth and hence production and accumulation of SOM. Since plants (particularly natural vegetation) are the major source of soil organic matter, vegetation types and their density influence the SOC stock.

The 2006 IPCC guideline recommended using a default 0-30 cm layer is sufficient. Within this layer, the influence of management practices are more pronounced than in the deeper soil layers. To obtain an accurate inventory of organic carbon stocks in mineral or organic soil, three types of variables must be measured: (1) depth, (2) bulk density (calculated from the oven-dried weight of soil from a known volume of sampled material), and (3) the concentrations of organic carbon within the sample (Pearson *et a*l., 2005).

3. MATERIALS AND METHODS

3.1. Description of the study areas

3.1.1. Location of the study districts

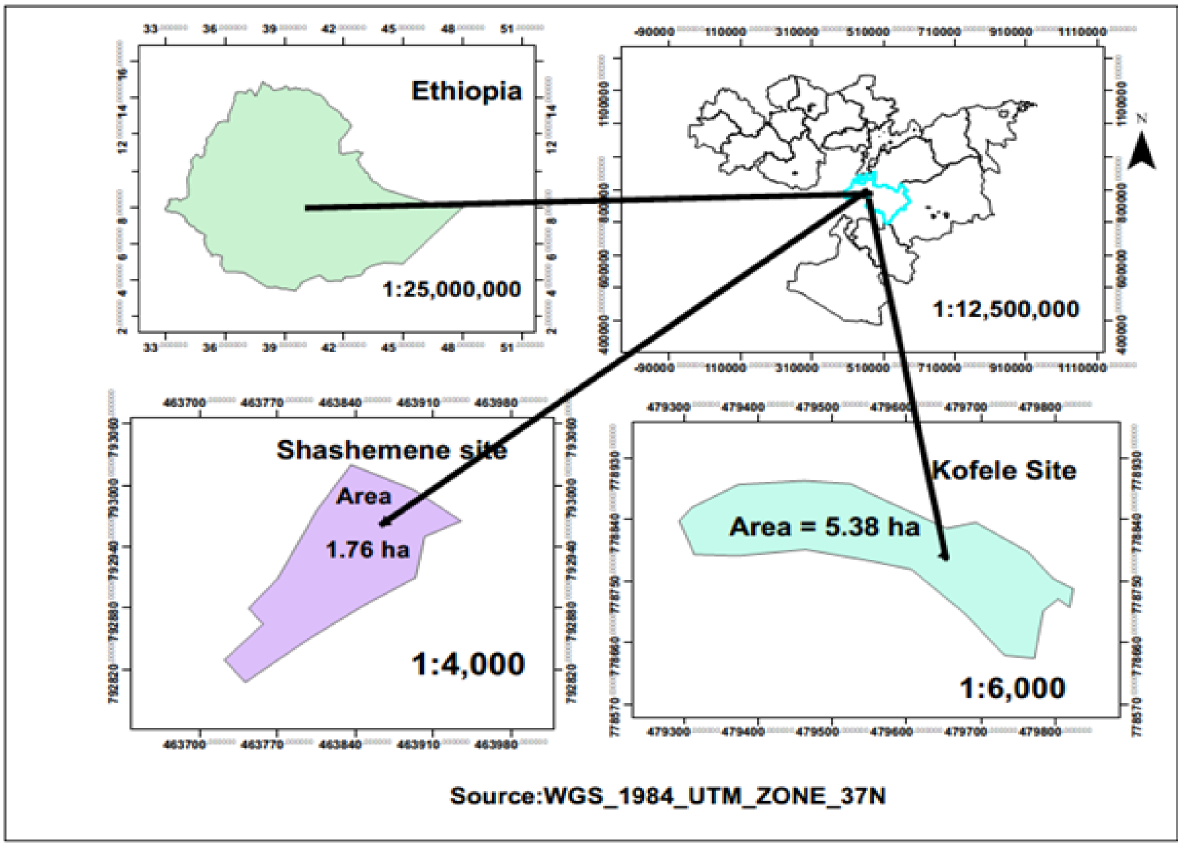
The study was carried out in pure stands of *Cupressus lusitanica* plantations located in two selected districts i. e. Shashemene (twice thinned) and Kofele (once thinned site) in west Arsi zone of Oromia regional state, central highland, Ethiopia (Appendix 1).

Geographically Shashemene district extends from 08^0 10' to 08^0 43' N latitude and 40^0 28' to 40^0 50' E longitude. The district is one of the 13 administrative districts in West Arsi zone of oromia regional state. The district is about 250 km southeast of Addis Ababa. The district shares bounder line of Shalla district in the west, Arsi Nagele in the north and north east, Kofele district in the Southeast, Wondo Genet, Bishan Gurracha and southern people nation and nationalities regions state in the south (SWAO, 2018 unpublished data).

The district has 37 Kebeles and covers an area of 58,011.70 ha. The major landscape of Shashemene includes mountains, farm land, plantation forests, settlement and plain divided by valleys. From the total area of the district, 66 % is arable or cultivable, 15 % pasture, 2.4 % forest, and the remaining 16.6 % considered as swampy, degraded or otherwise unusable (SWAO, 2018 un published data).

Geographically Kofele district extends from 08^0 10' N to 08^0 43' N latitude and 38^0 45' E to 38^0 58' E longitude. According to Kofele woreda agricultural office (KWAO, 2018), the district is about 271 km southeast of Addis Ababa. It is bordered on the south by the Kokosa district, on the west by the Southern Nations, Nationalities and Peoples' Region, on the northwest by the Shashamene, on the north by Kore, on the east by Gedeb Asasa, and on the south east by Dodola districts. The major landscape of Kebele includes mountains, natural forest, farm land, plantation forests, settlement and plain divided by valleys. Out of the total area of the district (118,766 ha), 30 % is arable or cultivable, 29 % pasture, 2.9 %

forest, and the remaining 38.1 % is considered swampy, mountainous or otherwise unusable (KWAO, 2018 unpublished data).



Source:WGS_1984_UTM_ZONE_37N

Figure 1: Location map of the study sites.

3.1.2. Topography, climate and soil

According to Shashemene district agricultural office (SWAO, 2018 unpublished data), the altitude of the district ranges between 1500 and 2700 m.a.s.l. The agro-climatic classification of the district includes Dega (10 %), Weynadega (75 %) and Kolla (15 %). However, there is a slight variation on temperature from month to month. October to May is the hottest months while June to September is the coldest and the rainy months in the year. The mean monthly temperature is about 19.7^{0}c. The annual rainfall varies from 800 – 1000 mm. (SWAO, 2018). The soils are classified as Mollic Andosols (FAO, 1998) with their parent material originating from volcanic lavas, ashes and pumices (Mesfin, 1998). The soils in the study area are considered to be relatively fertile and have a potential to give high yields (Lemenih, *et al*., 2008). However, the productivity is relatively low due to continuous cultivation without fallow periods and low inputs of nutrients.

According to Kofele woreda agricultural office (KWAO), 2018 unpublished data), the altitude of the district ranges between 2000 and 3050 m. The agro ecology of the district includes Dega (30 %) and Weynadega (70 %). The annual rainfall varies from 900 – 1200 mm. The mean monthly temperature of the district is 14.5 ^{0}C and it ranges between 7 ^{0}C and 20 ^{0}c. The soil type of the district is Mollic Andosols (FAO, 1998).

3.1.3. Vegetation

According to Lemenih *et al.,* 2004, Shashemene natural forest is a tropical dry Afromontane forest situated at the eastern escarpment of the Rift Valley. The most common tree species include *Afrocarpus falcatus, Celtis africana, Olea hochstetteri, Prunus africana* and *Croton macrostachys* (Tolera *et al*. 2008). *Eucalyptus* species, *Cupresuss lustanica* and *Gravelea robusta* are the dominant plantation species grown in the district (SWAO, 2018).

Kofele forest is part of Shshashemene district forest and Wildlife Enterprise. Therefore, according to Lemenih, 2004, the forest is a tropical dry Afromontane forest. Eucalyptus species and *Cupressus lusitanica* are the dominant plantation species while *Juniprusus procera, Highland bamboo, Ekebergia capensis, Croton macrostachyus, Podocarpus falcatus*, and *Albizia gummifera* are some of the dominant natural forests grown in the district (KWAO, 2018).

3.1.4 History of the plantation and stand characteristics

As summarized in Table 3 below, the plantations were established in both districts in 1995 at a spacing of 2.5 m × 2.5 m (growing space per tree was 6.25 m^2) and the initial stocking was 1600 trees/ha. Management practices such as site clearing and pitting precede planting. Planting is followed by spot hoeing, weeding, climber cutting, replacement planting based on survival rate, and Pruning and thinning activities were done for the studied sites.

Thinning was conducted at the same ages (7 years after planting for the first thinning in both stands). However, it was 15 years after planting for the second thinning. Both stands have been similarly treated with silvicultural activities except for thinning. Thinning intensity was 37.5 % in once thinned and 25 % in the twice thinned site.

Previously the land use type of once thinned site was grassland while *Cupressus lusitanica* plantation in the twice-thinned site. These plantations are under the the concession area of Oromia forest and wildlife enterprise, Arsi branch at Shashemene forest and wildlife enterprise district. The studied sites were covered only by *Cupressus lusitanica* with no understory vegetation.

In both sites, disturbance factors like illegal cuttings, intensive grazing, fire wood collection and cleared areas for agricultural cultivation were observed. The pressure on the remaining forest is high. There is a steady decline in quality and quantity of the forest. In areas where natural forest has been converted to agricultural land some indigenous tree species can be found scattered in the agricultural fields (Lemenih et al., 2004; Tolera et al., 2008).

Table 3: Study site or compartments/stands information of *Cupressus lusitanica* plantation

Site	Comp. No	Area (ha)	Planting year	Age	Planting Space	Initial stocking	Altitudinal range(m)	Remark
Once thinned	14a	5.38	1995	23	2.5mx2.5m	1600	2561-2612	Thinned (1st only)
Twice thinned	18	1.76	1995	23	2.5mx2.5m	1600	2232-2280	Thinned (1st &2nd)

Source: Shashemene forest and wildlife enterprise office and researcher field visit, 2018

3.2. Methodology

3.2.1. Study site selection / stand selection

Prior to data collection, a reconnaissance survey was conducted in the *Cupresuss lusitanica* plantation stands to gather information on the time of planting, age of the stands, planting density, location of the specific sites and management practices. The compartment's history of the studied forest obtained from Shashemene forest and wildlife enterprise. Two *Cupressus lusitanica* plantation stands namely, once thinned at Kofele stand and twice thinned at Shashemene stand were selected as treatments.

The study stands have different thinning frequency and hence the effect of thinning on biomass production and carbon stocking was captured. So, these stands were selected purposively based on criteria like: - their differences in thinning frequency, same stand age (planted in 1995), and same species. Other parameters like altitude, slope, and aspect were not considered in this study due to time and budget constraints. The studied sites were not adjacent to each other; because it was not possible to get two sites close to each other having different thinning frequencies.

3.2.2. Sampling design

As indicated in (Figure 2), to determine the number of sample plots required, the boundary of the study sites were tracked using GPS and the outer boundary map of the study sites were produced. Then, systematic sampling was employed to place transect lines and sampling points. Nested plot design was used, as they tend to include more of the with-in plot heterogeneity, easier to identify and count trees in the plot once plot boundary is established in the ground (UNFCCC., 2015).

Transect lines were laid down paralleling at the interval of 50 m to each other. On each transect line, larger square plots of size 20 m x 20 m were systematically laid down after avoiding only 10 meters (the border effect) at the starting and at the end of the transect lines because of small area of the plantation forests (Pearson *et al.*, 2005).

The distance between each sample plot to next was 60 m for once thinned site and 30 m for twice-thinned site. This is due to small forest area in twice-thinned plantation site. Therefore, the reduction in the distance between sample plots in twice thinned site was to have enough sample plots for determining above ground biomass. Hence, the number of sample plots laid in the study sites was determined after measuring all transect lines based on their distance between each sample plots.

Therefore, for once thinned site 3 transects with 12 sample plots and for twice-thinned site 2 transects with 10 sample plots were established. In general, 22 main plots were established. The larger sample plots were laid using compass and measuring tape for tree inventory. Three sub-sample plots 1 m x 1 m within larger plots were randomly laid down to collect litter and soil sampling. One sub-sample plot of size 1 m x 1 m at the center of larger plots was laid down for bulk density determination.

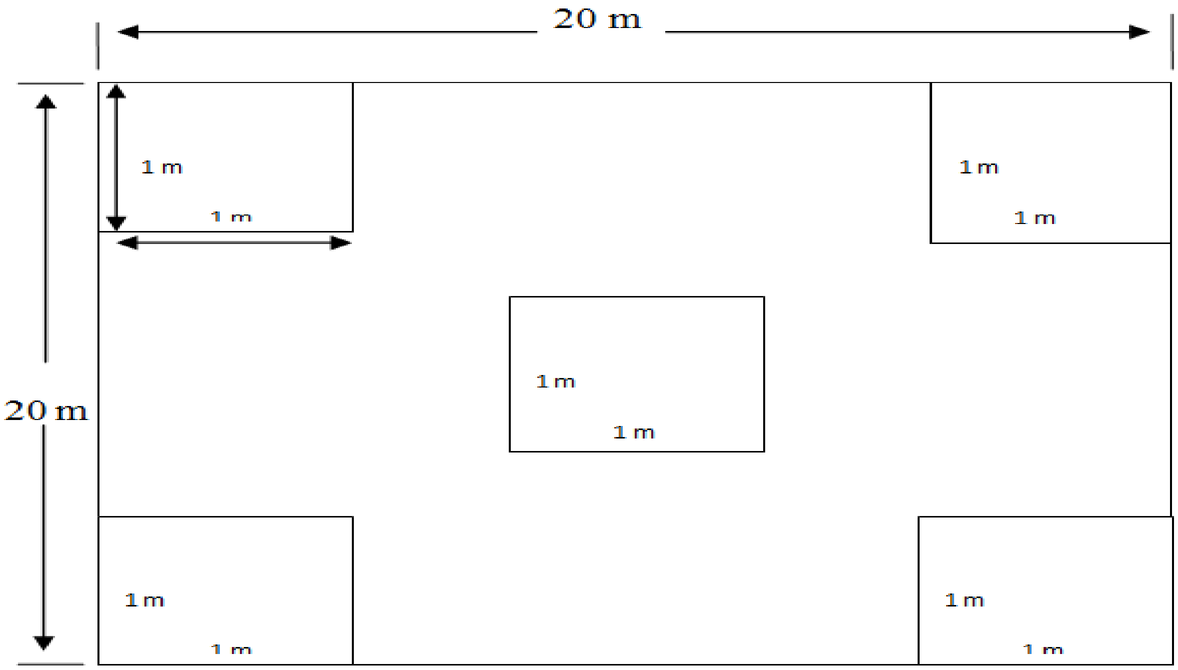


Figure 2: Sampling design (plot design and size for tree inventory, litter and soil sampling)

3.2.3. Methods of data collection

3.2.3.1. Inventory of trees

Trees with DBH, (≥ 5cm) and total tree height were measured in the main plot using diameter caliper and hypsometer respectively (Photo 1). In addition, trees which their trunks outside but inclining into the plots were excluded, and trees with their trunks inside the sampling plot and inclined outside were included. Tree diameters were recorded in two perpendicular directions and average values were used for further calculation (MacDicken, 1997). During data collection, dead wood and stumps were not found since as soon as trees cut as thinning, the local communities even dig out the stump and used for fuel wood.

Photo 1: Tree DBH measurement at Shashemene site (photo by: Bogale Mamo, 2018)

3.2.3.2. Litter biomass sampling

The litter was collected from three sub-sample plots 1 m x 1 m laid of randomly within the main plots. A 1 m x 1 m wooden frame (1 m^2) was used for litter sample collection. In total 66 litters sample (36 in once and 30 in twice thinned site) were collected from the 22 plots.

To determine oven dry mass to fresh weight ratio, a composite of 100 gram of evenly mixed or homogenized sub-sample were labeled and brought to WGCF-NR soil laboratory to analyze moisture content, dry mass content and organic matter content from which percentage of carbon was calculated. (Snowdon *et al.,* 2002).

Photo 2: Litter sample collection at Shashemene site (photo by: Solomon Birhanu, 2018)

3.2.3.3. Soil Sampling

Two set of soil samples of size 1m^2 were taken. Soil samples were taken below the forest floor up to a depth of 60 m. Firstly; sample pits (60 cm long x 50 cm wide) were dug.

Soil samples for carbon content determination were collected from three randomly selected sub-sample pots in the main plots from the soil depth categories of 0 - 20 cm, 20 - 40 cm and 40-60 cm using auger method. All collected soil samples were handled individually by plastic bags (Photo 3) (Muthuvel and Udayasoorian, 1999). A total of 66 composite soil samples (36 in once and 30 in twice thinned site) were collected from 22 plots of the two sites in 3 soil depths. Then for each layer representative of 200 gram of soil samples were brought to WGCF-NR soil laboratory for carbon content determination.

The same number of soil samples (66) were collected separately for bulk density analysis from 1 m x 1 m plot size in the center of the main plot (representative even though they might not be necessary similar) using 4.5cm diameter and 20cm height soil core sampler (Vol = 318.13 m^3) from similar soil depth of 0 - 20 cm, 20 – 40 cm and 40 – 60 cm. A metallic ruler was used to measure the depth of the forest floor.

Photo 3: Soil sample collection at Kofele site (photo by: Bogale Mamo, 2018)

3.3. Method of data analysis (field and laboratory data)

3.3.1. Estimation of above ground biomass carbon stocks.

In this study, a non-destructive method, species specific and locally developed allometric equation for *Cupressus lusitanica* at WGCF-NR (Genene, 2009) was used to calculate AGB; this model is selected because the current study sites were located in the vicinity of WGCF-NR. The general equation that was used to calculate the above ground biomass was given below:

AGB = 0.0319 x D$^{1.8903}$ x H$^{0.9194}$ (Genene, 2009)………..……………..…....Equation (1)

Where, AGB = above ground biomass (kg/tree), D is diameter at breast height in cm and H is tree height in meter.

The biomass density was extrapolated or converted in to hectare basis (t/ha) by multiplying the dry mass by an expansion factor (BEF). The expansion factor calculated as the area of a hectare in square meters divided by the area of the sample in square meters (Pearson *et al.* 2005), (i.e.):

$$\mathbf{Expansion\ Factor} = \left[\frac{\mathbf{10{,}000m2}}{\mathbf{Area\ of\ plot(m2)}}\right]$$ **……………………….…………………..…. (2)**

The carbon content in tree biomass was estimated multiplying AGB by 48% assuming it is carbon in the biomass as per Genene, 2009:

AGB Carbon Stock = AGB * 0.48 ……………………..……………….......Equation (3)

Where, AGB = Above Ground Biomass (kg/tree)

The data of the forest product (volume) extracted from thinning in both frequencies were not found from concerned office (it was not documented). So, it was not considered in this analysis.

3.3.2. Estimation of below ground biomass carbon stocks

Below ground biomass was estimated by using globally averaged simple root: shoot ratio, which is 26% of the AGB (Cairns *et al.* 1997).

BGB= AGB x 26%..Equation (4)

Where, BGB is below ground biomass, AGB is above ground biomass, 0.26 is conversion factor (or 26 % of AGB). In addition, the carbon content of the below ground biomass was about 48% by dry weight (Genene, 2009). The carbon stock in the below ground biomass was estimated using the formula:

BGB carbon stock = BGB x 0.48 ………………………….....................Equation (5)

Where, BGB is below ground biomass.

3.3.3. Estimation of litter biomass carbon stocks

The carbon stock of litter biomass, litter samples were air dried for one day and then oven dried at 70 °C for 24 hours to determine biomass ratio (Ullah and Al-Amin, 2012; Negash and Starr, 2015). According to Pearson *et al.* (2005), the dry biomass of litter was calculated by using the following formula:

$$\mathbf{LB} = \frac{\text{W Field}}{\text{A}} \times \frac{\text{W sub-sample(dry)}}{\text{W sub-sample (fresh)}} \times \frac{1}{10000} \text{……………………………} \textbf{Equation (6)}$$

Where; LB = Litter (biomass of litter in ton/ ha)

W field = weight of wet field sample of litter sampled within an area of size 1m^2 (g).

A = size of the area in which litter was collected in (ha)

W sub-sample, dry = weight of the oven-dry sub-sample of litter taken to the laboratory to determine moisture content (g), and W sub-sample, fresh = weight of the fresh sub-sample of litter taken to the laboratory to determine moisture content (g).

Therefore, the total carbon content of litter (t/ha) =total dry litter biomass * carbon fraction. The carbon content of litter biomass is about 37% by dry weight (IPCC, 2006) and was estimated using the following formula:

CL = LB × 0.37%……………...……………………...….....………….….….…Equation (7)

Where, CL is total carbon stocks in the dead litter in t/ha and LB is litter biomass.

3.3.4. Estimation of soil organic carbon

Soil bulk density

Soil chemical and physical analyses were conducted at WGCF-NR by following the standard laboratory procedure. Soil samples were air-dried at room temperature, homogenized and passed through a 2 mm sieve for chemical and physical analysis. To estimate the soil organic carbon stock per ha, bulk density samples were oven dried at 105 °C for 24 hours. After that, each bulk density sample was washed with water and passes through a 2 mm sieve to separate coarse fragments.

The carbon stock of soil was calculated by using the following formula, which is recommended by Pearson *et al*. (2005) from the volume of core sampler and bulk density of the soil.

$\mathbf{V = h \times \pi r^2}$ **……………....……………………...…...……..………..Equation (8)**

Where, V is volume of the soil in the core sampler in cm^3, h is the height of core sampler in cm and r is the radius of core sampler in cm.

Soil bulk density was then calculated by using the following formula (Pearson *et al*., (2007).

$BDsoil = \dfrac{ODW}{CV - \dfrac{Mcoarse\ frag}{Densrock\ frag}}$ **…………….……………..…………Equation (9)**

Where: BDsoil - soil bulk density (g/cm^3),

ODW - oven dry weight of soil (< 2 mm fraction) (g/cm^3),

CV - soil core volume (cm^3),

Mcoarse frag - mass of coarse fragments (g), and

Densrock frag - density of rock fragments (g/cm^3)

In this analysis, coarse fragment (stone) was not found.

The analysis of SOM (soil organic matter) from which SOC was made using titrimetric method (Walkley and Black, 1934). The pH values were determined by potentiometric method. Soil texture was also measured by the hydrometer method of the selected soil profiles of the study sites.

SOC = BD x D x % C…………………………………………………...Equation (10)

Where, SOC= soil organic carbon stock per unit area (t/ha),

BD = soil bulk density (g/cm^{-3}),

D = the total depth at which the sample was taken, cm and

%C = Carbon concentration (%).

3.3.5. Estimation of total carbon stocks density

Total carbon stock density was calculated by summing the carbon pools (Pearson *et al.*, 2005):

Carbon density(C) = CAGB + CBGB + CLB + SOC……………………Equation (11)

Where: Carbon density(C) - carbon stocks density of all carbon pools (t/ha),

CAGB - carbon in above ground tree biomass (t/ha),

CBGB - carbon in below ground biomass (t/ha),

CLB - carbon in litter biomass (t/ha)

SOC - soil organic carbon (t/ha).

4. STATISTICAL ANALYSIS

The data which were collected from the field inventory were organized and recorded in micro soft excel 2007 data sheet. The variation in carbon stocks for each thinning frequency was described by the mean and standard deviation using descriptive statistics. To test for the differences in soil carbon stocks between the two studied thinning frequencies, General Linear Model and for biomass carbon one-way ANOVA were performed ($p = 0.05$).

Levene’s test was used to check for the homogeneity of variances (homogenous in all cases or normally distributed). SPSS Statistics software (version 16.0) was used for the statistical analysis. Tukey HSD used for mean comparison. All statistics evaluated at 95 % confidence level.

5. RESULTS

5.1. Forest stand characteristics

Stand characteristics of the studied sites were shown in (Table 4). The average DBH of trees in twice-thinned site was significantly higher than that of once thinned site (P = 0.002). In the twice-thinned site, more trees were located in 22.5-28 cm diameter class, on the other hand the least number of trees were found in 10-16 cm diameter class. Similarly, in the once thinned site, large numbers of trees were located in 16.5-22, but the least number of trees were found in 10-16 cm and > 40 diameter classes (Figure 3).

The average heights of trees in the twice-thinned site were not significantly different (p = 0.293) from once thinned site. The basal area, which is the cross-sectional area of tree stems at breast height, was calculated for each tree. It indicated or measured the relative dominance (the degree of coverage of tree stems as an expression of the space they occupy in a forest). The estimated average basal area (m^2/ha) in once thinned site was significantly higher (p = 0.001) than the twice thinned site. The basal area in once thinned was by 28.15 % higher than that of twice-thinned site.

Table 4: Stand characteristics (mean ± SD of 22 sample plots).

Stand characteristics	Once thinned	Twice thinned	p- value
DBH (cm)	20. 53 ± 1.90^a	23.08 ± 1.20^b	0.002
Height (m)	20.78 ± 1.37^a	20.24 ± 0.86^a	0.293
Stems /ha	958 ± 26.83^a	563 ± 29.46^b	0.001
Basal area (m^2/ha)	33.75 ± 6.50^a	24.25 ± 3.25^b	0.001

Different letters in the same row are significantly different ($P < 0.05$)

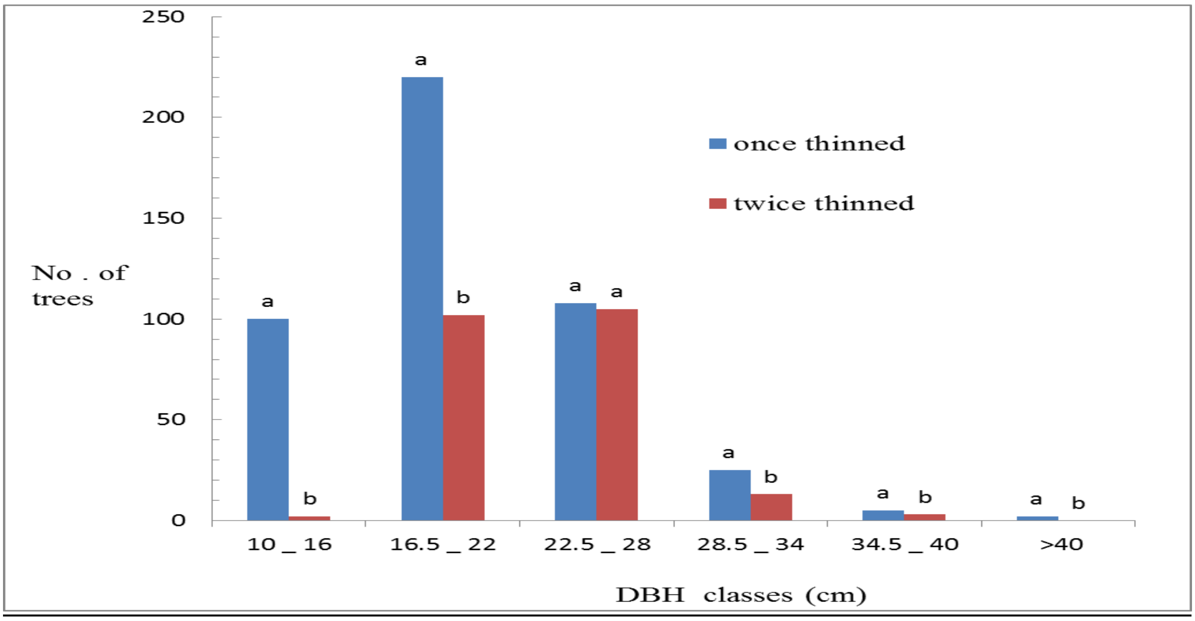


Figure 3: Tree DBH distributions in once thinned (counted trees in 12 plots) and in the twice-thinned site (counted trees in 10 plots).

Different letters within in DBH class are significantly different ($P < 0.05$)

The total number of stems in once thinned site was ranged from 925 to 1000 and 525 to 600 per ha in twice-thinned site. In once thinned site 37.5 % (600 stems per ha) were removed in the first thinning and additional 25 % (400 stems per ha) were removed in the second thinning in the twice thinned site. The mean stem number in once thinned site was significantly different ($p = 0.001$) from twice thinned site (Figure 4).

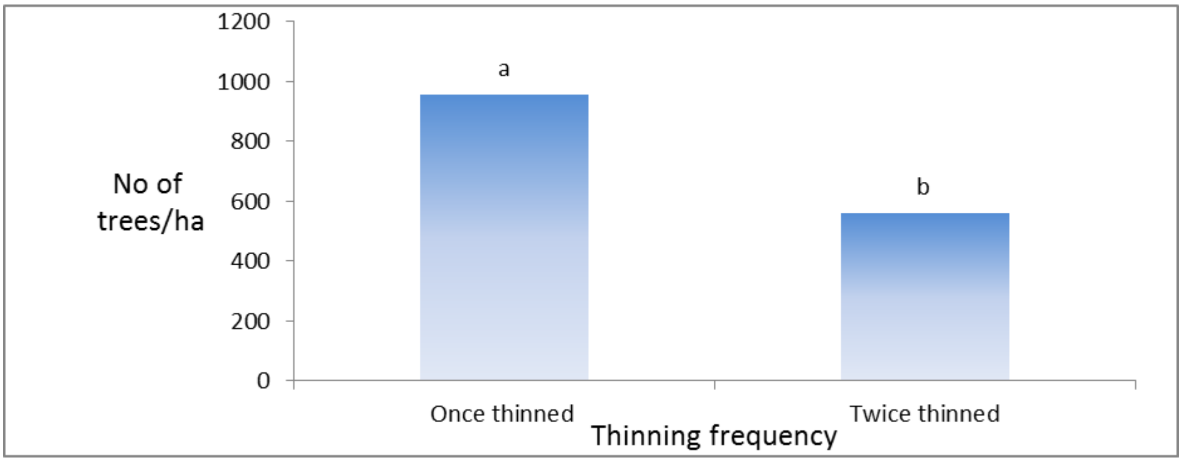


Figure 4: Number of stems per hectare in once and twice thinned sites.

Different letters between once and twice thinned sites are significantly different ($P < 0.05$)

5.2. Soil physicochemical properties

The results of soil texture, as presented in **Error! Reference source not found.** revealed that the particle size distribution of the soil (0 - 60 cm depth) of once thinned site was dominated by sand 57.06 % followed by silt 27.28 % and clay 15.67 %. Similarly twice thinned site was dominated by sand 53.53 % followed by silt 27.53 % and clay 18.80 %. Relatively lower percentage of clay fraction was observed in both sites.

The contribution of the soil textural class in the once thinned site (sandy clay loam 13.89 %, sandy loam 52.78 % and loam 33.33 %) and in the twice thinned site (sandy clay loam 27.00 %, sandy loam 50.00 % and clay loam 3 % and loam was 20 %) (Appendix 3). Generally, the texture class of soil (0 - 60 cm) in both sites was sandy loam (Table 5).

Laboratory results showed that, there was no significant variations in soil pH between the two sites (p = 0.073). However, there was significant variation on soil depth (P = 0.019) of the two sites. There was a significant difference in soil bulk density of the two sites (P = 0.000). There was no also significant variation (p = 0.003) in bulk density with soil depth.

The bulk density of the soil profile in the once thinned site was ranged from 0.620 g cm^{-3} of minimum to 0.840 g cm^{-3} of maximum value with the average value of 0.750 g cm^{-3} (Appendix 4). The bulk density of the soil profile in the twice-thinned site was ranges from 0.490 g cm^{-3} of minimum to 1.12 g cm^{-3} maximum value of the average value of 0.900 g cm^{-3} (Appendix 4).

Table 5: Soil conditions (Soil pH and textural class) of the study sites

Site	pH	Sand (%)	Silt (%)	Clay (%)	textural class
Once thinned	6.10 ± 0.39^{a}	53.17 ± 4.96 ^{a}	25.56 ± 4.39 ^{a}	21.27 ± 3.00 ^{a}	Sandy loam
Twice thinned	6.27 ± 0.35^{a}	51.09 ± 4.99 ^{a}	26.97 ± 3.79 ^{a}	21.94 ± 3.87 ^{a}	Sandy loam
P – Value	0.073	0.092	0.172	0.257	

Means with the same letters across column is not significantly different (P < 0.05).

5.3. Biomass carbon stocks

The mean above ground, below ground and litter biomass of once thinned site was significantly different (p = 0.001) from twice thinned site (Table 6). The dry biomass obtained by using allometric equation was converted into carbon except for soil, which usually measures carbon directly. The estimated above ground biomass carbon stocks ranged from 55.74 to 125.04 in once thinned and 39.91 to 67.05 t-ha^{-1} in the twice thinned site.

The estimated mean above ground biomass carbon stock in the once thinned site was significantly higher than the twice-thinned site (P = 0.001). The mean above ground biomass carbon stock in the once thinned site was 82.20 ± 20.88 t/ha and 55.12 ± 9.39 t/ha in the twice thinned site (Table 6).

Similar to the above ground biomass, below ground biomass of once thinned was significantly different from twice thinned site (p = 0.001). The below ground biomass carbon stocks ranged from 14.49 to 32.51 t/ha in once thinned site (Appendix 5) and 10.38 to 17.43 t/ha in twice thinned site (Appendix 5). The mean below ground biomass carbon stock in the once thinned site was 21.37 ± 5.43 t/ha and 14.33 ± 2.44 t/ha in the twice thinned site. The mean below ground carbon stock of once thinned site was significantly higher than the twice thinned site (P = 0.001).

The litter biomass of once thinned site was significantly different from twice thinned site (p = 0.000). The mean litter biomass carbon stock in the once thinned site was significantly higher than twice-thinned site (P = 0.000). The mean litter biomass carbon was 0.08 ± 0.010 in once thinned site and 0.03 ± 0.004 (t/ha) in twice thinned site (Table 6 and (Appendix 2).

Table 6: Mean (± SD) aboveground, belowground and litter biomass and carbon stocks (t. ha^{-1}) of the two studied thinning frequencies of *Cupressus lusitanica* plantation.

Carbon stock	Site		P- value
	Once thinned	Twice thinned	
AGB	171.24 ± 43.50^{a}	114.83 ± 19.57^{b}	0.001
AGBC	82.20 ± 20.88^{a}	55.12 ± 9.39^{b}	0.001
BGB	44.52 ± 11.31^{a}	29.86 ± 5.10^{b}	0.001
BGBC	21.37 ± 5.43^{a}	14.33 ± 2.44^{b}	0.001
LB	0.22 ± 0.040^{a}	0.09 ± 0.010^{b}	0.000
LBC	0.08 ± 0.010^{a}	0.03 ± 0.004^{b}	0.000

Means followed by the same letter in a row are not significantly different ($p < 0.05$)

5.4. Soil carbon stock

The present study finding showed that the soil bulk density varied significantly between the two sites (p = 0.000). The SOC stocks for 0 – 60 cm layer in once thinned site was ranged between 60.07 and 174.09 t-ha^{-1} (Appendix 5).

As indicated in Table 7, the mean soil carbon stock of once thinned site (0 - 60 cm) was 103.83 ± 36.07 t-ha^{-1}). Soil layer's contributions in the once thinned site for 0 – 20 cm layer accounting for 47.99 %, layer 20 - 40 cm accounting for 31.07 % and layer 40 - 60 cm accounting for 20.94 %. There was a significance difference among the soil layers in soil carbon stocks (p = 0.000).

SOC stocks for 0 – 60 cm layer in twice thinned site ranged between 78.62 and 96.69 t-ha^{-1} (Appendix 5). The mean soil carbon stock of twice thinned site (0 - 60 cm) was 87.32 ± 5.94 t-ha^{-1} (Table 7). Soil layer's contributions in twice thinned site for 0 - 20 cm layer accounting 46.84 %, layer 20 - 40 cm accounting 29 % and layer 40 - 60 cm accounting

24.16 %. In the twice thinned site, there were significance differences among the soil layers in soil carbon stocks (p = 0.000).

Table 7: Mean (± SD; n=22) soil carbon result of two-way ANOVA (t-ha^{-1}) for both the studied plantation sites at ($p < 0.05$) have significance difference.

	Carbon stocks (ton/ha)		
Soil layer	Once thinned	Twice thinned	P - value
0–20 cm	49.83±16.39^{a}	40.90±5.84^{b}	0.000
20–40 cm	32.26±14.65^{a}	25.32±3.85^{b}	0.000
40–60 cm	21.74±11.71^{a}	21.10±3.70^{b}	0.000
0–60 cm	103.83± 36.07^{a}	87.32 ±5.94^{b}	0.000

Means with different letter in a rows are significantly different ($p < 0.05$)

5.5. Ecosystem carbon stocks

The carbon stock of the ecosystem was obtained by summing all the carbon stocks in each carbon pools (biomass, litter, and soil 0 – 60 cm) for each site (Table 8). The ecosystem carbon stock (total biomass carbon, litter carbon and SOC 0 – 60 cm) in once thinned site was ranged from 139.67 to 309.27 and 141.07 to 171.40 t/ha in the twice thinned site (Appendix 5). The mean ecosystem carbon stock in once thinned site (207.48 ± 54.12) was significantly higher (P= 0.001) than twice thinned site (156.80 ± 12.53).

The contribution of SOC stock to the total carbon stock in the once thinned site (103.83 ± 36.07) was 50.05 % and in the twice thinned site (87.32 ± 5.94) it was 55.69 %. The contribution of SOC stock to the total carbon stock in the twice thinned site was relatively higher than biomass carbon stocks (44.31 %) as compared to once thinned site.

Similarly, the contribution of litter carbon to total ecosystem carbon stocks was relatively higher in the once thinned (0.04 %) than twice thinned site (0.02 %), showing that the litter carbon stocks followed the trend of biomass carbon stocks (Table 6).

Table 8: Total ecosystem carbon stocks biomass plus soil (0 – 60 cm depth) (t ha-1) for each site, n=22 (Mean ± SD).

Carbon pools	Site		P - value
	Once thinned	Twice thinned	
TBC	103.65 ± 26.30^a	69.48 ± 11.84b	0.000
SOC	103.83 ± 36.07^a	87.32 ± 5.94^b	0.000
Total	207.48 ± 54.12^a	156.80 ± 12.53^b	0.000

Means followed by different letters in a row are significantly different ($p < 0.05$).

6. DISCUSSION

6.1. Biomass carbon stocks

Estimating carbon storage at different thinning frequency is essential for determining the role of forest ecosystems in regional and global carbon management. There was a variation in carbon storage between once and twice thinned *Cupressus lusitanica* plantation. This variation might be due to reduction of higher number of stems (biomass) per ha in the twice-thinned as compared to once thinned site. The higher number of stems per hectare in the once thinned site contributed to the reduction of carbon from the atmosphere via photosynthesis. The result of this study is also in agreement with McKinley *et al*., (2011) study in plantation forests of United State, where intensive silviculture, with shorter harvesting intervals and more intensive logging (i.e., thinning, clear-cuts) generally reduces net carbon storage rates and carbon storage at the stand level, when compared with low-intensity silviculture (e.g., the selection system).

The total biomass should be the biomass of the extracted wood from the thinning trees plus the biomass of the remaining stand. If it was used for firewood, carbon simply lost. But data of the forest product (volume) extracted from thinning in both frequencies were not found (no documented data). Even it was not known as for what purpose the biomass of the extracted wood from the thinning was used (firewood or other purpose).

The mean total biomass at once thinned site was larger than 33 % as compared to twice-thinned site. This has its own effect on the total biomass carbon stocks of the forest. Consequently, the carbon stocks stored in total biomass carbon was higher in the twice thinned site (Table 6), which indicates that the forest in once thinned site has high potential to accumulate carbon in both above and below ground biomass and mitigate climate change.

According to Tibebu and Teshome (2015), largest trees have much more potential to produce larger quantities of below ground biomass than smallest trees. This contradicts with the results recorded in the twice thinned site. This is due to small number of trees per hectare in the twice thinned site that accumulate less biomass carbon than once thinned one.

The present result of AGBC in once and twice thinned sites were smaller than the Ethiopian plantations forest AGBC which is 123 t-ha^{-1} (WBISPP, 2005). But this estimation was done using global generic allometric equation which is developed by Brown (1997). Another justification for the present finding's small value AGBC might be due to low organic matter accumulation through litter fall from trees which increase the soil organic matter accumulation for biomass production. The variation with other studies could be due to variation in stand structure and composition, topography, elevation, disturbance level such as forest fire and human interventions including livestock free grazing, wood harvest, and climatic factors (Chave *et al*., 2004). The reason for the present study results variation is might be due to wood harvest as thinning.

The total biomass carbon storage of *Cupressus lusitanica* in the once thinned site (103.57 t.ha^{-1}) found in this study excluding litter biomass carbon was comparable with a study conducted on 24 years old *Cupressus lusitanica* plantation by Genene (2009) at Wondo Genet 102.41 t.ha^{-1}. Both are once thinned. However, the result of twice thinned site total biomass carbon (69.45 t-ha^{-1}) was lower than Genene's result. In general, in the present studied sites as thinning frequency increased, the total biomass carbon stock was decreased.

6.2 Litter biomass carbon

The study results indicated that, the carbon stocks of litter biomass in both studied stands were estimated to be very small. In both sites, the contribution of litter biomass carbon stocks to the total (ecosystem) carbon stock was less than 1%. However, relatively higher litter biomass carbon accumulation was observed in the once thinned as compared to twice thinned site. This is might be due to illegal cuttings, intensive grazing, fire wood collection and wood harvest as thinning.

The mean litter biomass in once thinned site was higher than by 59 % twice thinned site. This might be due to low fuel wood collection and higher accumulation of litter biomass in the once thinned as compared to twice-thinned site. Another reason might be due to high rate of decomposition rate in the twice-thinned than in the once thinned site. This may be due to lower temperature in once thinned site that helps to accumulate more carbon by limiting decomposition rates (Hobbie *et al*., 2000; Negash and Starr, 2013).

The carbon stock in litter biomass of the present study was lower than the range reported for mean litter carbon of tropical forests, which varies between 2–16 t/ha (Brown, 1997). The variation is might be due to the difference in rate of litter decomposition. The increase in temperature would increase the decomposition rate and vice versa. But this can only be true if there is also an optimum moisture contact in substrate (for normal functioning of microorganisms). Moreover, forest vegetation characteristics (species, age and density) and elevation could be attributed to the variation of litter accumulation (Fisher and Binkley, 2000).

6.3. Soil carbon stocks

The soil carbon pool is affected by soil properties, forest management practices, litter input, and root turnover (Jandl R, *et al*, .2007). According to Genene (2009), the presence of sandy nature of the soil in low nutrient availability and low pH are inhibiting soil microbial processes, which can lead to the formation of a thick forest floor layer in the plantation sites. The concentration (%) and stock of soil organic carbon were opposite to bulk density results.

The amount of carbon stocks decreased with increasing soil depth. This revealed that major carbon accumulation was observed in the upper soil layers, where input from above ground litter was largest. This can be justified with the presence of lower accumulation of organic matter resulting from lower below ground root biomass in the sub-surface layer.

The present studied results showed that in the 0 - 20 cm soil depth, the soil carbon stored was the highest followed by 20 - 40 cm and 40 - 60 cm. This result was also in consistent with the findings of Chowdhury *et al.*, (2007) who found that more SOC was stocked at the upper depth of the soil. The presence of the highest SOC in the top layer of the soil might be due to higher accumulation of tree litter in the top soil.

According to (Sitaulal et al., 2004), the quantity of biomass returned to the soil also varies among forest species and exerts considerable control over SOC quantities. For instance, the conifer needles are more resistant and take longer time to decompose and thereby favoring more organic carbon concentrations (Vesterdal *et al*., 2002). Coniferous species have also a shallow rooting condition and tend to accumulate more carbon in the forest floor, but less in the mineral soil compared with deciduous trees. The rooting depth is relevant for soil carbon because root growth is the most effective way of introducing carbon to the soil (Jobbágy and Jackson, 2000; Rothe *et al.*, 2002).

The mean soil organic carbon at once thinned site was larger than by 15.90 % at twice-thinned site. It revealed that higher organic matter accumulated in once thinned site and fuel wood collection and high decomposition rate in twice thinned site. The amount of carbon sequestered largely depends on the management practices, decomposition rates, previous land use type, soils and climate (Prasad *et al*. 2012). This is in agreement with the present study i.e. once thinned site was previously covered by grasses. However, twice thinned site was covered by *Cupressus lusitanica.*

The estimated result of SOC stocks in the two studied sites was lower than that of the tropical mean SOC stocks of 122 t.ha^{-1} (Prentice, 2001). This might be due to low organic matter accumulation, illegal wood harvest, and high rate of decomposition. However, it was higher than a study conducted on *Cupressus lusitanica* plantation 26.49 t.ha^{-1} by (Genene, 2009) at Wondo Genet from the soil depth of 0 - 20 cm, in which more carbon was in the standing tree biomass (89 %). The small soil carbon could be due to difference in soil depth; since in the present study the soil depth was 0 – 60 cm.

Higher density of stems contributed higher litter and root biomass in the once thinned as compared to twice thinned site, which resulted in higher soil organic carbon. Besides, according to Sanou (2010), fine roots and litter deposition resulted in higher soil organic carbon content.

6.4. Total carbon stocks

The soil carbon pool constituted higher carbon stock than biomass carbon in twice thinned site. This is in line with the report of Chinasho *et al*., (2015) and Asaye and Asrat (2016) who stated that soil is the largest pool of organic carbon in the terrestrial biosphere. However, our result contradicts with the findings of Genene (2009), who found that high carbon in the standing tree biomass (89 %) in the *Cupressus lusitanica* stand 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 ecosystem carbon estimated in the present study was higher than the average value for carbon storage of *Cupressus lusitanica* plantation (128.36 t-ha^{-1}) at Wondo Genet Genene, (2009). This variation is might be due to differences in soil depth between the two studied areas. In Ethiopia, according to Metz *et al*. (2007) report, the total carbon stock of plantation forest is 114.48 t-ha^{-1}. However, in both sites the finding of the present study was greater than Metz *et al*. (2007) report.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

Forest store CO_2 through carbon sequestration in to biomass and soil organic matter. Plantation forests are important for emission reduction and hence to benefit from carbon financing through afforestation and reforestation programs.

Thinning represents an important and frequently used silvicultural technique that improves forest wood products and has obvious effect on forest carbon stocks. Thinning of *Cupressus lusitanica* plantation was carried out in the study areas in order to increase productivity of the trees and raise the economic value of timber.

The findings from this study showed that, the average DBH size of trees in twice thinned site was greater than the once thinned site. However, due to higher number of stems per ha in the once thinned site, the total above ground biomass, below ground biomass, litter and soil organic carbon in once thinned site was significantly higher in twice thinned site.

The higher soil organic matter content in once thinned can potentially improve the soil physical properties such as soil structure and total porosity and soil pH. This, in turn, increases accumulation of organic matter on the soil surface that may reduce the volume, velocity, and erosive capacity of surface run-off.

Soil organic carbon content decreased with soil depth. The soil organic carbon content is significantly lower in the twice thinned compared to the once thinned site.

In general, as the present study results indicated that, thinning frequency was reduced the biomass and soil organic carbon stocks of *Cupressus lusitanica* plantation stands. Therefore, if the intention is to enhance carbon sequestration, plantation forest owners should consider these issues in forest management.

7.2. Recommendations

The following points were forwarded as recommendation based on the above findings.

- If the management goal for plantation forests is to create carbon sequestration; forest managers should reduce thinning frequency from twice into once thinned as part of climate change mitigation strategies and for carbon finance.
- If the aim is to enhance carbon sequestration, the effect of other management practices like pruning is also needed to be determined. Since pruning is also removes the biomass of trees as in the case of thinning.
- Since *Cupressus lusitanica* plantation forest plays an important role in carbon cycle, it is important to plant it as afforestation and reforestation to increase carbon sequestration that makes it carbon sinker rather than a source.
- In the twice thinned site there was high fuel wood collection and hence the litter fall and contribution for SOC was lower. Therefore, forest protection is recommended in his site.
- Further research should focus on other parameters like altitude, slope, and aspect to see their effect on biomass and soil organic carbon stocks which were not included in this study and inclusion of forest product (volume) extracted from thinning is recommended.

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APPENDICES

Site									
Once thinned					Twice thinned				
Transect	Plot No	Altitude (m)	Latitude	Longitude	Transect	Plot No	Altitude (m)	Latitude	Longitude
1	1	2594	479767	778700	1	1	2265	463804	792858
	2	2587	479736	778649		2	2260	463836	792857
	3	2581	479708	778677		3	2258	463865	792857
	4	2582	479675	778710		4	2260	463895	792858
	5	2583	479647	778742		5	2256	463779	792908
	6	2588	479618	778776	2	1	2243	463808	792907
	7	2587	479586	778808		2	2242	463839	792908
	8	2581	479557	778837		3	2249	463867	792908
	9	2579	479528	778867		4	2250	463899	792907
2	1	2583	479502	778898		5	2270	463775	792857
	2	2590	479552	778928	Total	10	2265	463804	792858
3	1	2594	479602	778958					
Total	12	2270	463775	792857					

Appendix 1: Location of plots of study sites

Site							
Once thinned				Twice thinned			
Plot No	$LB = \frac{W\ Field}{A} \times \frac{W\ sub\text{-}sample(dry)}{W\ sub\text{-}sample\ (fresh)} \times \frac{1}{10000}$	% C IPCC, 2006 default value	Litter Carbon (t)/ha	Plot No	$LB = \frac{W\ Field}{A} \times \frac{W\ sub\text{-}sample(dry)}{W\ sub\text{-}sample\ (fresh)} \times \frac{1}{10000}$	% C IPCC, 2006 default value	Litter Carbon (t)/ha
1	0.2	0.37	0.06	1	0.08	0.37	0.03
2	0.2	0.37	0.06	2	0.09	0.37	0.03
3	0.2	0.37	0.09	3	0.11	0.37	0.04
4	0.2	0.37	0.09	4	0.09	0.37	0.03
5	0.3	0.37	0.1	5	0.1	0.37	0.04
6	0.2	0.37	0.06	6	0.08	0.37	0.03
7	0.2	0.37	0.07	7	0.09	0.37	0.03
8	0.2	0.37	0.07	8	0.1	0.37	0.04
9	0.2	0.37	0.09	9	0.08	0.37	0.03
10	0.3	0.37	0.1	10	0.08	0.37	0.03
11	0.2	0.37	0.09	Sum	0.9	0.37	0.334
12	0.2	0.37	0.09	Mean	0.09	0.37	0.03
Sum	2.6	0.37	0.96	SD	0.01	-	0.004
Mean	0.22	0.37	0.08				
SD	0.039	-	0.015				

Appendix 2: Summary of litter biomass and carbon stocks of study sites

Site															
Once thinned								Twice thinned							
Plot	Sample Code	Lab code	pH value	% sand	% clay	% silt	Textural class	Plot	Sample Code	Lab code	pH value	% sand	% clay	% silt	Textural class
1	P1_L_ 0-20	28	5.01	72	8	20	sandy loam	1	P1_L_ 0-20	6	6.02	44	20	36	Loam
	P1_L_20-40	44	6.4	46	16	38	loam		P1_L_20-40	4	6.08	56	10	34	Sandy loam
	P1_L_ 40-60	43	6.43	46	18	36	loam		P1_L_ 40-60	10	5.58	53	15	32	Sandy loam
2	P2_L_ 0-20	41	5	68	12	20	sandy loam	2	P2_L_ 0-20	12	6.73	52	20	28	Loam
	P2_L_20-40	27	5.03	54	16	30	sandy loam		P2_L_20-40	11	6.55	54	15	31	Sandy loam
	P2_L_ 40-60	33	6.94	54	20	26	sandy clay loam		P2_L_ 40-60	3	5.96	49	27	24	sandy clay loam
3	P3_L_ 0-20	26	5.01	64	8	28	sandy loam	3	P3_L_ 0-20	2	6.55	56	18	26	sandy loam
	P3_L_20-40	21	5.09	54	16	30	sandy loam		P3_L_20-40	7	6.45	50	25	25	sandy clay loam
	P3_L_ 40-60	39	5.11	48	20	32	loam		P3_L_ 40-60	1	6.32	38	26	36	Loam
4	P4_L_ 0-20	16	5.5	60	8	32	sandy loam	4	P4_L_ 0-20	5	6.51	50	18	28	sandy loam
	P4_L_20-40	29	5.04	58	14	28	sandy loam		P4_L_20-40	9	6.74	54	22	24	sandy clay loam
	P4_L_ 40-60	32	5.77	50	18	32	loam		P4_L_ 40-60	8	6.74	53	28	19	Sandy clay loam
5	P5_L_ 0-20	45	5.65	64	14	22	sandy loam	5	P5_L_ 0-20	49	6.72	50	12	38	Loam
	P5_L_20-40	23	5.59	52	20	28	loam		P5_L_20-40	50	5.96	53	14	33	Sandy loam
	P5_L_ 40-60	36	6.31	56	22	22	sandy clay loam		P5_L_40-60	51	6.53	62	14	24	sandy loam
6	P6_L_ 0-20	47	6.4	46	28	26	sandy clay loam	6	P6_L_ 0-20	52	6.05	61	19	20	sandy loam
	P6_L_20-40	17	6.36	50	22	28	loam		P6_L_20-40	53	6.74	63	15	22	sandy loam
	P6_L_ 40-60	25	6.08	52	20	28	loam		P6_L_40-60	54	5.34	51	16	33	Loam
7	P7_L_ 0-20	18	5.82	60	18	22	sandy loam	7	P7_L_ 0-20	55	6.75	52	22	26	sandy clay loam
	P7_L_20-40	35	6.48	54	20	26	sandy clay loam		P7_L_20-40	56	6.35	53	20	27	sandy clay loam
	P7_L_ 40-60	22	5.89	46	26	28	loam		P7_L_ 40-60	57	5.98	60	13	27	Sandy loam
8	P8_L_ 0-20	14	6.23	64	14	22	sandy loam	8	P8_L_ 0-20	58	6.54	57	25	18	sandy clay loam
	P8_L_20-40	19	5.39	52	20	28	loam		P8_L_20-40	59	5.55	56	18	26	sandy loam
	P8_L_ 40-60	38	5.66	56	18	26	sandy loam		P8_L_40-60	60	6.04	39	33	28	clay loam
9	P9_L_ 0-20	31	5.7	74	4	22	sandy loam	9	P9_L_ 0-20	61	6.35	53	23	24	sandy clay loam
	P9_L_20-40	46	6.27	66	12	22	sandy loam		P9_L_20-40	62	6.56	65	18	17	sandy loam
	P9_L_ 40-60	48	5.93	68	6	26	sandy loam		P9_L_ 40-60	63	5.98	58	10	32	sandy loam
10	P10_L_ 0-20	42	6.8	66	18	16	sandy loam	10	P10_L_ 0-20	64	5.55	56	19	25	sandy loam
	P10_L_20-40	30	5.37	52	22	26	sandy clay loam		P10_L_20-40	65	6.02	52	11	37	Loam
	P10_L_ 40-60	20	5.62	48	22	30	loam		P10_L_40-60	66	5.55	56	18	26	sandy loam
11	P11_L_ 0-20	37	5.83	58	10	32	sandy loam								
	P11_L_20-40	15	6.09	48	12	40	loam								
	P11_L_ 40-60	34	5.51	48	22	30	loam								
12	P12_L_ 0-20	24	5.02	72	2	26	sandy loam								
	P12_L_20-40	13	5.2	68	8	24	sandy loam								
	P12_L_ 40-60	40	5.12	60	10	30	sandy loam								

Appendix 3: Soil textural class and pH of study sites

Site											
Once thinned						Twice thinned					
Plot No	Samples layer's code	Depth (cm)	BD (g/cm3	% C	SOC (t/ha)	Plot No	Samples layer's code	Depth	BD (g/cm3	% C	SOC (t/ha)
1	P1_L_ 0-20	20	0.83	4.51	74.80	1	P1_L_ 0-20	20	0.75	2.92	43.77
	P1_L_20-40	20	0.85	3.43	58.08		P1_L_20-40	20	0.79	1.36	21.52
	P1_L_ 40-60	20	0.87	2.37	41.21		P1_L_ 40-60	20	0.84	1.24	20.86
	0-60				174.1	0-60					86.15
2	P2_L_ 0-20	20	0.85	3.31	55.99	2	P2_L_ 0-20	20	0.68	3.5	47.78
	P2_L_20-40	20	0.91	2.8	50.89		P2_L_20-40	20	0.79	1.56	24.78
	P2_L_ 40-60	20	0.97	1.89	36.69		P2_L_ 40-60	20	0.84	1.44	24.12
	0-60				143.6	0-60					96.69
3	P3_L_ 0-20	20	0.88	3.23	56.6	3	P3_L_ 0-20	20	0.64	3.2	40.88
	P3_L_20-40	20	0.99	1.62	32.1		P3_L_20-40	20	0.7	1.77	24.79
	P3_L_ 40-60	20	1.09	1.01	22.12		P3_L_ 40-60	20	0.8	0.81	12.95
	0-60				110.8	0-60					78.62
4	P4_L_ 0-20	20	0.83	4.51	75.09	4	P4_L_ 0-20	20	0.62	4.09	50.37
	P4_L_20-40	20	1.03	2.1	43.20		P4_L_20-40	20	0.66	1.3	17.23
	P4_L_ 40-60	20	1.1	0.66	14.54		P4_L_ 40-60	20	0.71	1.17	16.61
	0-60				132.8	0-60					84.22
5	P5_L_ 0-20	20	1.03	2.2	45.24	5	P5_L_ 0-20	20	0.74	2.85	41.95
	P5_L_20-40	20	1.09	0.71	15.37		P5_L_20-40	20	0.79	1.9	30.13
	P5_L_ 40-60	20	1.11	0.58	12.88		P5_L_ 40-60	20	0.82	1.32	21.67
		0-60			73.48	0-60					93.76
6	P6_L_ 0-20	20	0.82	1.75	28.64	6	P6_L_ 0-20	20	0.64	2.67	34.18
	P6_L_20-40	20	0.99	1.28	25.44		P6_L_20-40	20	0.77	1.68	26.01
	P6_L_ 40-60	20	1.07	0.82	17.45		P6_L_ 40-60	20	0.83	1.23	20.42
		0-60			71.53	0-60					80.6
7	P7_L_ 0-20	20	0.98	2.11	41.32	7	P7_L_ 0-20	20	0.67	2.55	34.22
	P7_L_20-40	20	1.06	1.08	22.9		P7_L_20-40	20	0.68	1.87	25.51
	P7_L_ 40-60	20	1.12	0.54	12.16		P7_L_ 40-60	20	0.71	1.64	23.29
		0-60			76.38	0-60					83.02
8	P8_L_ 0-20	20	0.98	1.75	34.51	8	P8_L_ 0-20	20	0.73	2.6	37.73
	P8_L_20-40	20	1.03	0.66	13.62		P8_L_20-40	20	0.77	1.75	26.92
	P8_L_ 40-60	20	1.04	0.61	12.69		P8_L_ 40-60	20	0.82	1.42	23.23
	0-60				60.82	0-60					87.87
9	P9_L_ 0-20	20	0.86	3.9	67.08	9	P9_L_ 0-20	20	0.74	2.3	33.86
	P9_L_20-40	20	0.93	1.7	31.62		P9_L_20-40	20	0.8	1.91	30.45
	P9_L_ 40-60	20	1.01	0.59	11.86		P9_L_ 40-60	20	0.81	1.54	24.82
	0-60				110.6	0-60					89.13
10	P10_L_ 0-20	20	1	1.56	31.06	10	P10_L_ 0-20	20	0.69	3.2	44.22
	P10_L_20-40	20	1.03	0.71	14.52		P10_L_20-40	20	0.72	1.8	25.96
	P10_L_ 40-60	20	1.05	0.69	14.49		P10_L_ 40-60	20	0.82	1.4	22.99
		0-60			60.07	0-60					93.17
11	P11_L_ 0-20	20	0.66	3.88	51.23						
	P11_L_20-40	20	0.69	2.59	35.74						
	P11_L_ 40-60	20	0.75	1.49	22.28						
	0-60				109.3						
12	P12_L_ 0-20	20	0.49	3.72	36.26						
	P12_L_20-40	20	0.66	3.31	43.73						
	P12_L_ 40-60	20	0.68	3.13	42.51						
	0-60				122.5						

Appendix 4: Soil carbon stock estimation in layers of study sites

Site																	
Once thinned									Twice thinned								
Plot No	AGB (t/ha)	AGC (t/ha)	BGB (t/ha)	BGC (t/ha)	LB (t/ha)	LC (t/ha)	SOC (t/ha)	TCS (t/ha)	Plot No	AGB (t/ha)	AGC (t/ha)	BGB (t/ha)	BGC (t/ha)	LB (t/ha)	LC (t/ha)	SOC (t/ha)	TCS (t/ha)
1	223.40	107.23	58.08	27.88	0.20	0.07	174.09	309.27	1	97.64	46.87	25.39	12.19	0.08	0.03	86.15	145.23
2	216.48	103.91	56.28	27.01	0.20	0.07	143.56	274.56	2	115.24	55.32	29.96	14.38	0.09	0.03	96.69	166.42
3	165.29	79.34	42.98	20.63	0.20	0.07	110.82	210.86	3	139.68	67.05	36.32	17.43	0.11	0.04	78.62	163.14
4	160.36	76.97	41.69	20.01	0.20	0.07	132.83	229.89	4	134.85	64.73	35.06	16.83	0.09	0.03	84.22	165.81
5	116.13	55.74	30.19	14.49	0.30	0.11	73.48	143.82	5	128.31	61.59	33.36	16.01	0.10	0.04	93.76	171.40
6	146.85	70.49	38.18	18.33	0.20	0.07	71.53	160.42	6	100.10	48.05	26.03	12.49	0.08	0.03	80.60	141.17
7	152.91	73.40	39.76	19.08	0.20	0.07	76.38	168.94	7	95.93	46.05	24.94	11.97	0.09	0.03	83.02	141.07
8	192.25	92.28	49.99	24.00	0.20	0.07	60.82	177.17	8	120.03	57.61	31.21	14.98	0.10	0.04	87.87	160.50
9	160.69	77.13	41.78	20.05	0.20	0.07	110.56	207.82	9	133.40	64.03	34.68	16.65	0.08	0.03	89.13	169.84
10	131.44	63.09	34.17	16.40	0.30	0.11	60.07	139.67	10	83.14	39.91	21.62	10.38	0.08	0.03	93.17	143.48
11	260.50	125.04	67.73	32.51	0.20	0.07	109.25	266.87	Sum	1,148.32	551.19	298.57	143.31	0.90	0.33	873.23	1,568.07
12	128.59	61.72	33.43	16.05	0.20	0.07	122.51	200.35	Mean	114.83	55.12	29.86	14.33	0.09	0.03	87.32	157.20
Sum	2,054.89	986.35	534.26	256.44	2.60	0.96	1,245.9	2,489.65	SD	19.57	9.39	5.09	2.44	0.01	0.00	5.94	12.53
Mean	171.24	82.20	44.52	21.37	0.22	0.08	103.83	209.32									
SD	43.50	20.88	11.31	5.43	0.04	0.01	36.07	54.12									

Appendix 5: Summary of total biomass and soil carbon stocks of study sites