COMPARING RELATIVE IMPORTANCE OF BIOMASS AND SOIL CARBON ESTIMATION METHODS: THE CASE OF DELIMA DRY EVERGREEN MONTANE FOREST, NORTH WEST ETHIOPIA

MSc. THESIS

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A THESIS SUBMITTED TO HAWASSA UNIVERSITY DEPARTMENT OF FORESTRY,
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MASTER OF SCIENCE IN FORESTRY

SPECIALIZATION: (FOREST RESOURCE ASSESSMENT AND MONITORING)

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Approval Sheet- I

This is to certify that the thesis entitled "*Comparing Relative Importance of Biomass and Soil Carbon Estimation Methods: The Case of Delima Dry Evergreen Montane Forest, North West Ethiopia"* submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in ***Forest Resource Assessment and Monitoring*** of the Graduate Program of the school of Environment and Forestry, Wondo Genet College of Forestry and Natural Resources, and is a record of original research carried out by ***Kurabachew Tenaw Demissie*** **Id. No** ***MSc/FrAM/R009/09***, under my supervision, and no part of the thesis has been submitted for educational institutions for achieving any academic awards.

The assistance and help received during the course of this investigation have been duly acknowledged. Therefore, I recommended to be accepted as fulfilling the thesis requirement.

1. Mesele Negash (PhD) ____________________ _______________

Principal Supervisor Signature Date

2. Zerihun Girma (PhD) _____________ ________________

Graduate program coordinator Signature Dat

Approval Sheet-II

We, the undersigned, members of the Board of examiners of the final open defense by *Kurabachew Tenaw Demissie* have read and evaluated his thesis entitled "*Comparing Relative Importance of Biomass and Soil Carbon Estimation Methods: The Case of Delima Dry Evergreen Montane Forest, North West Ethiopia"* and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science with specialization in *Forest Resource Assessment and Monitoring*.

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Name of Chairman	Signature	Date
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Name of External Examiner	Signature	Date

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Finally, my special deepest gratitude goes to my family for their inspiration, love and support throughout my life especially my wife Eskedar Alem Taye.

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Declaration

I, the undersigned declare that this Thesis is my original work and it has not been presented in other universities, colleges or institutes for a degree or other purpose. All sources of the materials used have been duly acknowledged.

Name: Kurabachew Tenaw Signature: ___________________ Date: _____________

This work has been done under my supervision.

Principal Supervisor

Name: __________________________ Signature: __________________ Date: ___________

Acronyms and Abbreviations

AGBC	Aboveground Biomass Carbon
ANOVA	Analysis of Variance
BD	Bulk Density
BGBC	Belowground Biomass Carbon
CDM	Clean Development Mechanism
CRGE	Climate Resilient Green Economy
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization
GHGs	Greenhouse Gasses
GOFC-GOLD	Global Observation of Forest Change – Global Observation of Land Dynamics
GPS	Global Positioning System
IPCC	Inter Governmental Panel on Climate Change
LBC	Litter Biomass Carbon
REDD$^+$	Reducing Emission from Deforestation and Forest Degradation and Conservation of forests, Sustainable Forest Management, Enhancing forest carbon stocks
SOC	Soil Organic Carbon
TCD	Total Carbon Density

UNFCCC	United Nations Frame Work of Convention on Climate Change
WBISPP	Woody Biomass Inventory Strategic Planning Project

SYMBOLS

Gt	Giga Tone
Kg	Kilogram
MG ha^{-1}	Mega gram per Hectare
T/ha	Ton per Hectare

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ABSTRACT

Reliable estimates of biomass and soil carbon stock are needed to understand the effect of forests in climate change mitigation. While a few studies have been conducted, in this forest any carbon related scientific research and Comparing relative importance of biomass and soil carbon estimation methodological tiers was not yet studied. The studies were assessed (a) estimate and compare biomass and soil carbon stocks using the three tiers, (b) to determine relationship and relative accuracy of each tier for the case of Delima forest and (c) To identify the stand characteristics of Delima Dry Evergreen Montane forest. Systematic plot sampling method was conducted to estimate carbon stock. A total of 30 plots sized 20m x 20m were inventoried, litter and soil samples were collected. 90 composited soil samples for SOC and 90 un-composited BD samples from (0-20 cm, 20-40 cm and 40-60 cm) depth class were collected. The AGBC and BGBC of forest and high woodland stratum were 19.53 ± 3.44, 7.67 ± 1.48 and 5.1 ± 0.89, 2 ± 0.38 ton ha^{-1} respectively with the p-value of 0.004, which was highly significant among stratums. The AGBC and BGBC of Tier 1, 2 and 3 were 140 and 37.8 Mg ha^{-1}, 113 and 28 Mg ha^{-1}and 13.61± 11.74 and 3.54 Mg ha^{-1} respectively. The LBC of Tier 1, 2 and 3 were 5.2, 4.35 and 0.01± 0.06 Mg ha^{-1}. The SOC of Tier 1, 2 and 3 were 63 Mg ha^{-1}, 94 Mg ha^{-1} and 113.2± 11.75 Mg ha^{-1}. The share of total SOC stock of Tier 3 was higher than Tier2 and 3 by 44.35% and 16.96%. The total carbon stock density of Tier 1, 2 and 3 were 246 Mg ha^{-1}, 239.35 Mg ha^{-1} and 153.76 Mg ha^{-1}. This study reveals that the present study biomass and soil carbon stocks of the forest different among methods applied.

Key words and phrases: Allometric equations, carbon stock, relative accuracy, soil carbon, Tiers

1. INTRODUCTION

1.1. Background of the study

Forest plays an important role in global carbon balance through carbon sequestration. Currently, there is great interest in assessing forest carbon stock (Djomo *et al.*, 2016; Gibbs *et al.*, 2007), since forests are cleared and the carbon in their biomass is converted to carbon dioxide in the atmosphere (Condit, 2008) Developing countries are required to produce robust estimates of forest carbon stocks for successful implementation of climate change mitigation policies related to reducing emissions from deforestation and degradation (Sassan *et al.*, 2011). Accurate estimation of forest biomass is crucial for commercial uses (e.g., fuelwood and fiber), national development planning, as well as for scientific studies of ecosystem productivity, carbon and nutrient flows and for assessing the contribution of changes in forest lands to the global C cycle (Basuki *et al.,* 2009). Particularly in the estimation of the aboveground biomass with a sufficient accuracy to assess the variations in C stored in the forest is becoming increasingly important (Ketterings *et al.,* 2001; Chave *et al.,* 2005).

Biomass and soil carbon stock estimates for tropical forest species enhance our understanding of the importance of tropical forests in the global carbon cycle and how to manage these forests for sustainable production and fuel wood harvesting. In developing countries, about 38 % of primary energy consumption comes from forest biomass (Sims 2003); in Ethiopia, biomass supplies 93 % of total household energy consumption (Shiferaw *et al.,* 2010). To successfully implement mitigating policies and take advantage of the Reducing Emissions from Deforestation and Forest Degradation (REDD+) program of the United Nations Framework Convention in Climate Change (UNFCCC) (Chaturvedi *et al.,* 2011), these countries need well authenticated estimates of forest carbon stocks.

Non-destructive or indirect method attempts to estimate tree biomass by measuring variables that are more accessible and less time-consuming to assess (e.g., wood volume and density) (Peltier *et al*., 2007). On the small amount of forest resource, high species diversity and the current forest conservation policy by the state, it is nearly impossible to undertake destructive sampling for the development of allometric functions (Kibruyesfa *et al*., 2016). Since, choosing of the most accurate allometric equations is not a simple task, assessing the character of available published and recommended equations is a mandatory and prior step before applying them (Henry et al., 2013; Melson *et al*., 2011).

However, for calculating biomass and soil carbon stock of forests, the IPCC has established a Tier system reflecting the degrees of certainty or accuracy of the carbon stock assessment. Tier1 uses (IPCC, 2003 and IPCC, 2006) default values (i.e. biomass in different forest biomes, etc.) and simplified assumptions; it may have an error range of +/- 50% for aboveground pools and+/- 90% for the variable soil carbon pool. Tier 2 uses default emission factors but it uses country specific emission factor and better in error than Tier 1. Tier 3 requires highly specific inventory data on carbon stocks in different pools, and repeated measurements of key carbon stocks through time, which may also be supported by modeling (IPCC, 2003). The IPCC recommends that countries aspire to Tier 3 where possible for the measurement of key carbon stocks, sources and sinks.

The aim of investigation was verifying relative importance of biomass and soil organic carbon stock estimations by IPCC methodological tiers. Therefore, this study was conducted in Amhara National Regional State, East Gojjam Zone, Machakel Woreda, in Delima dry evergreen montane natural forest.

1.2. Statement of the problem (It looks back ground)

Currently the demand of reliable information regarding forest carbon stock at both country and global levels is growing (Genene Asseffa *et al.*, 2013). This calls researchers to direct their interests to quantify forest carbon stocks following standardized carbon stock accounting method. Therefore, measuring and estimating carbon stocks and changes in various pools are very important for carbon trading (Yitebitu Moges *et al.*, 2010).

Therefore, the existing organizations for carbon credit allocation based on carbon stock performance require accurate estimates of carbon stocks of land use system (Gurney and Raymond, 2008). Organizations such as Reducing Emissions from Deforestation and forest Degradation (REDD), Clean Development Mechanism (CDM) and voluntary organizations can only be harnessed if estimation of carbon stock is accurate. Additionally, improved estimates provide essential data that would enable the extrapolation of biomass stocks to ecosystems and allow reliable emission estimates from land use and land cover change scenarios (Houghton and Goodale, 2004).

Delima dry Evergreen montane forest is one of the remnant natural forest found in Amhara region. While a few studies have been conducted, in this forest any carbon related scientific research was not yet studied. However, three methodological Tiers developed by UNFCCC to measure forest carbon stocks, but the relative importance of carbon stock estimation methods not studied in Ethiopia, particularly in the present study area. Therefore, this study was proposed with the following objectives.

1.3. Objectives of the study

1.3.1. General objective

- The purpose of this study was to Camparing relative importance of biomass and soil carbon estimation methods in the case of Delima Dry Evergreen Montane Forest, North West Ethiopia.

1.3.2. Specific objectives

- To estimate and compare biomass and soil carbon stocks of Delima Dry Evergreen Montane forest using the three methodological Tiers in the study area.
- Relationship and relative accuracy of Tier 2 and Tier 3 in reference to Tier 1
- To identify the stand characteristics of Delima Dry Evergreen Montane forest.

1.4.Hypothesis

The biomass and soil carbon stock estimation varies with methods applied.

1.5. Significance of the study

In most REDD+ systems, it is proposed that developed countries would pay developing countries for emissions reduced below a certain reference level, thus linking finance to performance (Jodie Keane *et al.*, 2010). The existing organizations for carbon credit allocation based on carbon stock performance require accurate estimates of carbon stocks of land use system (Gurney and Raymond, 2008). Therefore, this study will contribute reliable biomass and soil carbon estimations to reduce over and under estimation of the reported carbon. On the other hand researchers related to this study topics will use as a reference for further research. It will also assist to GTP-2 for indicating the gap of the forest carbon estimation methods and how much forest carbon stock really available.

2. LITERATURE REVIEW

2.1.Carbon Cycle

Forests are a large carbon sinks, but they are ecosystems that gain and lose carbon continually. Trees in a forest have important contribution to the global carbon cycle, because of their large biomass per unit area of land *(*Feyissa *et al.*, 2013). The primary CO_2 fluxes between the atmosphere and ecosystems are uptake by plant through photosynthesis and released by respiration, decomposition, and combustion of organic matter. Therefore, a forest shows a net gain or loss of carbon based on the balance of these processes. The CO_2 absorbed by plants is transformed into carbohydrates that are then stored in plant tissues during their growth in their life cycle. Photosynthesis is the driving process behind carbon storage as a biomass, and the stored biomass eventually ends up in soils and dead organic matter pools.

2.2. The Effect of Climate Change on Forest Ecosystem

Climate change also poses a threat to forest ecosystems, resulting in changes to species composition and potentially threatening preservation of plants and biodiversity more generally. It will have impacts on sustainable forest management, creating challenges for foresters and decision makers (Kant and Berry, 2005).

Therefore, assessment of the amount of carbon sequestered by a forest gives us an estimate of the amount of carbon emitted into the atmosphere when this particular forest area is deforested or degraded. Furthermore, it can help us to quantify the carbon stocks which will enable us to understand the current status of carbon stocks and also derive the near future changes in the carbon stocks. Estimation of AGB is an important step in identifying the amount of carbon in terrestrial vegetation pools and is central to global carbon cycle because much of the flux takes place in above the ground of forest structure.

In addition, UNFCCC requires that all Parties to the Convention commit themselves to develop, periodically update, publish, and make information available to the Conference of Parties (COP) their national inventories of emissions by sources and removals by sinks of all GHGs using comparable methods. Forestry is one sector for which a national inventory of sources and sinks of GHGs must be developed. If carbon stocks can be measured accurately and precisely at some intervals using the same approaches, it provides the necessary information to determine the changes in carbon stocks as required by the UNFCCC and forestry projects for mitigating carbon emissions.

2.3. Roles of forest and soil in climate change mitigation

Mitigation is defined as anthropogenic intervention to reduce net greenhouse gases emission that would lessen the pressure on natural and human system from climate change (IPCC, 2014). Forests exchange large quantities of carbon with the atmosphere through photosynthesis and respiration, and can switch between being a sink or a source (of atmospheric carbon) as consequence of human and natural causes depending on the stage of succession, specific disturbance or management regime and activities. The rate at which a forest removes CO_2 from the atmosphere (sink), or release it (source) and the quantity of carbon retained as a reservoir (carbon stock) is fundamental to assess for better defining the role of forest in carbon cycle. Studying carbon fluxes and carbon stocks in total and tree components (e.g. parameters like diameter at breast height) and in soil (e.g. analyzing soil cores) are the main steps to estimate forest carbon cycle (Marziliano *et al.*, 2014). Protecting carbon stocks in the existing forests and getting the new carbon stocks through afforestation and reforestation have become the important measures to enhance the carbon sequestration capacity in the terrestrial ecosystems and mitigate the increasing carbon dioxide concentration in the atmosphere Lal, (2005).

2.4.Forest Carbon Stock Pools

2.4.1. Above Ground Biomass (AGB) and Below Ground Biomass (BGB)

AGB consists of all biomass of living vegetation, above the soil. Carbon stored in the AGB is directly impacted by deforestation and degradation. It is expressed as tones of biomass or ton/ ha (IPCC, 2006). BGB is biomass in living roots of trees excluding fine roots < 2 mm diameter (IPCC, 2006). It is an important component in carbon and nutrient cycling in forests, consisting of 20–26% of the total biomass (Cairns *et al.*, 1997). The carbon stored in the aboveground living biomass of trees is typically the largest pool and the most directly impacted by deforestation and degradation. Thus, estimating aboveground forest biomass carbon is the most critical step in quantifying carbon stocks and fluxes from tropical forests (Brown. 2001).

The most direct way to quantify the carbon stored in aboveground living forest biomass (referred to as forest carbon stocks) is to harvest all trees in a known area, dry them and weigh the biomass. The dry biomass can be converted to carbon content by taking half of the biomass weight (carbon content ≈50% of biomass (Westlake, 1966). While this method is accurate for a particular location, it is prohibitively time-consuming, expensive, destructive and impractical for country-level analyses. Biomass and carbon stock are estimated from Diameter at Breast Height (DBH) or a combination of DBH and total height using locally relevant allometric equations (Brown *et al.,* 2004).

2.4.2. Dead wood biomass (DWB)

In most cases dead wood is less abundant than live trees. Standing dead trees, fallen stems, and fallen branches with a DBH and/or diameter ≥ 2.5 cm measured within the whole 400

m^2 plot. The amounts of biomass found in dead wood measured according to the types of dead wood (Bhishma *et al.,* 2010). For standing dead wood which have branches it is recommended to be measured using the allometric equation selected for estimation of above ground biomass. Whereas, if this standing dead wood have not leaves, subtracting out the biomass of leaves (about 2–3 % of aboveground biomass for hardwood/ broad leaf species and 5–6 % for softwood/conifer species) is recommended (Pearson *et al.,* 2005).

2.4.3. Litter biomass (LB)

The litter biomass is defined as all dead organic surface material on top of the mineral soil. Dead wood with a diameter of less than 10 cm and greater than 2mm is included in the litter layer (Pearson *et al*., 2005)**.** 100 grams of evenly mixed sub-samples was brought to the laboratory placing in a sample plastic bag to determine moisture content, from which total dry mass can then be calculated (Bhishma *et al.,* 2010).

2.4.4. Soil Organic Carbon (SOC)

Roots help in accumulation of SOC by their decomposition and supply carbon to soil through the process known as rhizodeposition (Rees *et al*., 2005). The importance of carbon storage in soil is becoming increasingly recognized following observations that the soil carbon store contains three times as much as that of vegetation (IPCC, 2000). There is also some debate over the depth to which carbon storage in soils should be measured for carbon accounting. The default value specified in the IPCC guidelines is 0-30cm (IPCC 2006). Different factors (biotic or abiotic) will control carbon stocks and the balance between inputs and outputs of carbon to and from the soils in different ecosystems. In this emerging understanding, organic matter inputs to soils consist of fresh plant litter (leaves, stems, roots and rhizosphere) and fire residues; inputs from roots and the rhizosphere are significant(Schmidt *et al,* 2011).

2.5.Forest Carbon accounting

By definition, Carbon accounting is the practice of making scientifically robust and verifiable measurements of net GHG emissions. Forest carbon accounting identifies the carbon density of areas, providing information for low carbon impact land use planning. It prepares territories for accounting and reporting of emissions from the forestry sector. It also allows comparison of the climate change impact of the forestry sector relative to other sectors, as well as allowing comparison between territories. Furthermore, it enables trade of project emission reductions on carbon markets (Assefa *et al.*, 2013). The IPCC Good Practice Guide (GPG) and Agriculture, Forestry and Other Land Use (AFOLU) guidelines present three general approaches for estimating emissions/removal of greenhouse gases, namely; Tier 1, using default values of forest biomass and forest mean annual increment from the IPCC emission factor database. Alike Tier 1, Tier 2 uses country specific data (i.e. collected within the national boundary), and measuring forest biomass at finer scales through the delineation of more detailed strata. Tier 3, is a hybrid approach which uses actual inventories with repeated measurements of permanent plots to directly measure changes in forest biomass and/or uses well parameterized models in combination with plot data.

Direct and indirect methods are used to estimate the biomass of wood. Destructive methods directly measure the biomass by harvesting the tree and measuring the actual mass of each of its compartments, (e.g., roots, stem, branches and foliage). Indirect methods are attempts to estimate tree biomass by measuring variables that are more accessible and less time-consuming to assess (e.g., wood volume and gravity) (Peltier *et al*. 2007). Tier 3, involves two options to estimate carbon stock of a tree and/or a forest area. These are: Biomass Expansion Factors (BEF) or Biomass Conversion and Expansion Factor (BCEF) method, and Allometric equation method. Both are widely used in forest carbon stock estimation. These are used to convert data obtained through field inventory into stand biomass and carbon stock.

2.6. Carbon stock estimation methods and their limitations

There are three general approaches for estimating emissions or removals of greenhouse gasses set by IPCC (GOFC-GOLD, 2009). These are called Tiers which range from 1-3 increasing level of data requirement and analytical complexity. According to this author, despite they differ in approaches three of them addresses the IPCC good practice concepts of transparency, completeness, consistency, comparability, and accuracy.

Tier 3 is the most rigorous approach associated with highest level of effort. It uses actual inventory data with repeated measures on the permanently established plots in order to know direct measures of changes in forest biomass and/or uses well parameterized models in combination with plot data. This approach can thus be expensive in developing country, particularly where only a single objective (estimating GHG emission) supports implementation costs. It often focuses on measurements of trees only, and uses forest or region specific default data and modeling other pools. It requires long term commitment of resource and personnel, generally involving the establishment of a permanent organization to house the program (GOFC-GOLD, 2009).

Tier 2 employs static forest biomass information, but it also improves on that approach by using country specific data (i.e. collected within the national boundary), and by resolving forest biomass at finer scales through the delineation of more detailed strata. Done well, a Tier 2 approach can yield significant improvements over Tier 1 in reducing uncertainty, and though not as precise as repeated measures using permanent plots that can focus directly on stock change and increment, Tier 2 does not require the sustained institutional backing (GOFC-GOLD, 2009).

Tier 1 does not require new data collection to generate estimate of forest biomass. Rather, forest biomass and forest biomass mean annual increment (MAI) can be taken from IPCC emission factor data base (EFDB), cross ponding to broad continental forest types (African tropical rain forest). Thus it provide limited resolution of how forest biomass varies sub-nationally and has an error of ± 50% or more for growing stocks in developing countries (GOFC-GOLD, 2009).

2.7. Allometric Equations for Biomass Estimation

The most widely used method for estimating biomass of forest is through allometric equations. The allometric equations are developed and applied to forest inventory data to assess the biomass and carbon stocks of forests. Many researchers have developed generalized biomass prediction equations for different types of forest and tree species (Navar j., 2009, Basuki., *et al.*, 2009). The allometric equations for biomass estimation are developed by establishing a relationship between the various physical parameters of the trees such as the diameter at breast height, height of the tree trunk, total height of the tree, crown diameter, tree species, etc. Equations developed for single species and for mixture of species give the estimate of biomass for specific sites and for large-scale global and regional comparisons (Basuki., *et al.*, 2009).

In Africa the absence of species-specific or mixed-species allometric equations has led to broad use of pan tropical equations to estimate tree biomass. This lack of information has raised many discussions on the accuracy of these data, since equations were derived from biomass collected outside of Africa (Djomo *et al.,* 2010).

Species-specific allometric equations are preferred, because tree species may differ greatly in tree architecture and wood density (gravity) (Ketterings *et al*., 2001).

2.8. Dry afromontane Forest and grass land complex vegetation in Ethiopia

Dry afromontane Forest is a very complex vegetation type occurring in an altitudinal range of 1500-2700 m, with average annual temperature and rainfall of 14-25° C and 700-1100 mm, respectively (Friis, 1992). It is inhabited by the majority of the Ethiopian population and represents a zone of sedentary cereal based mixed agriculture for centuries. This type of forest develops in areas of relatively high humidity, but not much rain, and where there is a prolonged dry season. The forests have diminished due to human interference and replaced by bush lands in most areas. Soils have become shallow as a result of soil erosion that has been taking place for centuries (Zerihun Woldu 1999).

3. MATERIALS AND METHODS

3.1. Description of the Study Site

3.1.1. Geographical location of the Study Area

This study was conducted at Delima dry afromontane forest which is found in Machakel Woreda, East Gojjam Zone, Amhara regional state, Ethiopia. This study site is located 328 km far from Ethiopian capital city, Addis Ababa and 243 km from the capital city of Amhara region, Bahir dar. The study area lies between 10^{0} 23′ 15″ N to 10^{0} 37′ 52″N and 37^{0} 32′ 45″E to 37^{0} 46’ 57″E with an altitude range between 1500 and 4023 masl. The Machakel Woreda has an area of 79,556 hectares with 23 rural kebeles in the administrative center of Amanuel, (Machakel Woreda administrative unpublished report, 2015). The study site is found in between three Kebeles of the Woreda they are known as Amary Yewubesh, Embuli Tahisas Dar and Abebe Delima. Delima forest is found in the North Western highlands of the country.

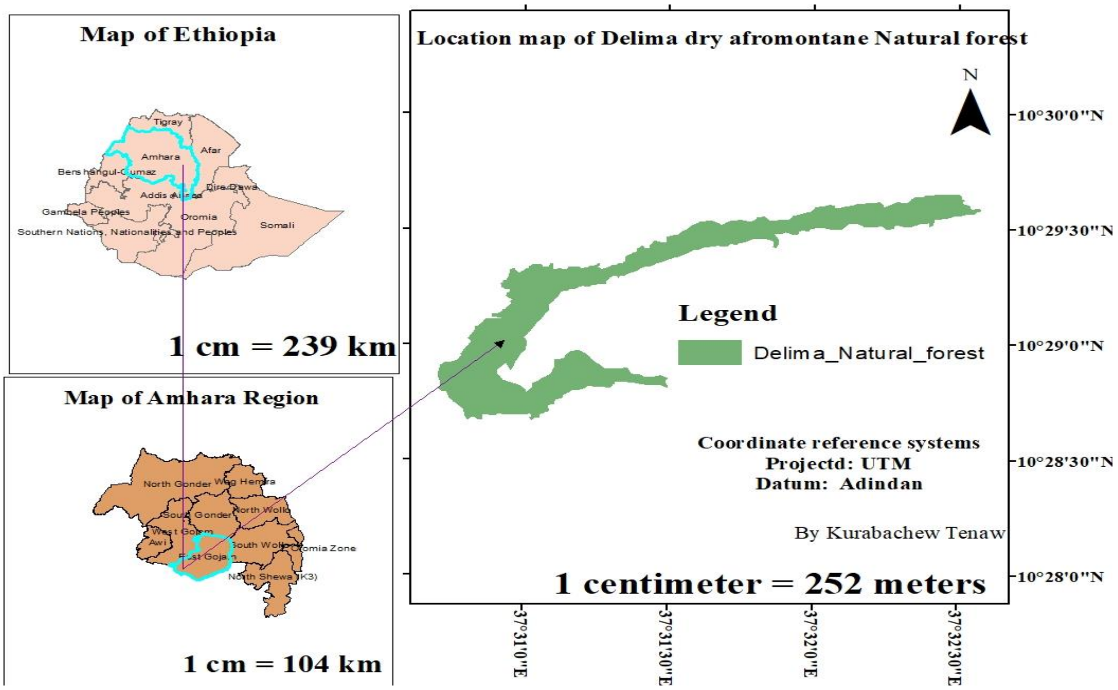

Figure 1: Location map of Delima dry Afromontane forest

3.1.2. Topography, Climate and Soil

According to Machakel Woreda administration office unpublished report, (2015) the topography of the Woreda is 35% plain, 47% undulating, 3% valley and the remaining is hilly. The elevation range of the Woreda is 1500-4023 masl. The agro ecology condition of the Woreda is 59% (Woyna Dega), 35 %(Dega) and the remaining is Wurch, Machakel Woreda administrative unpublished report, (2015). The average annual rain fall and temperature of the Woreda are between 900mm to 1800mm and 18°C and 25°C respectively. The area is characterized by mono modal rainfall distribution with the rainy season extends from early June to late September, and the distribution of rainfall is irregular in nature. The major soil type includes Nitosols, and Andisols. Generally, the soil types of the study area are characterized with shallow, moderate to deep and very deep and clay texture types (Bireda Alemayehu, 2015).

3.1.2. Population

The total human population of the Machakel Woreda is 135,218, of which 66, 830 males and 68, 388 are females. From the total population 6,670 males and 6261 females lived in town, the remaining lives in rural areas, CSA Population projection, (2014-2017).

3.1.3. Livelihoods

The main economic activities of the local communities are mixed farming involving the cultivation of crops and rearing animals. Different cereals, fruits and vegetables are also commonly grown by small holders to generate income and food security families. The local communities practiced subsistence farming with agroforestry practices, Machakel Woreda administrative unpublished report, (2015).

3.1.4. Vegetation type and structure of the study site

The forest is very narrow from north to south; while it is long east - west ward, as indicated by the map. The Vegetation type of Delima forest falls under dry afromontane forest (Sebsebe Demissew *et al*., 2010). The dominant species of the study site are *Croton macrostachyus*, *Acacia abyssinica*, and *Albizia gummifera*. The total area of Delima natural forest is 107.39 ha.

3.2. Methodology for the study

3.2.1. Delineation and stratification of the study area

Before stratifying the study area reconnaissance survey was conducted to determine the number of transects, a number and location of forest stratums. The boundaries of the study forest area were delineated to facilitate accurate measurement and accounting of the forest carbon stock. GPS points were used for delineation of boundary of the study area.

In order to maintain homogeneity and minimize the spatial variation of the study area and obtain accurate data from the fieldwork, the study area was stratified by forest canopy coverage. Therefore, stratified systematic sampling approach was used. Accordingly, the total forest area categorize in to two forest stratums. Stratum one consists forest structure that is land with relatively continuous tree cover, which are evergreen or semi-deciduous, only being leafless for a short period, and then not simultaneously for all species (FAO, 2014). The canopy should preferably have more than one story. The stratum two consists of high woodland ≥ 5 m tree height and crown tree cover > 20% (FAO, 2014).

3.2.2. Sampling layout

The boundary of study area was traced using GPS for sample plot determination. The total forest area was stratified in to two stratums based on structures that are stratum one (forest) and stratum two (high woodland). The forest area is narrow and long therefore, one transect line was aliened systematically at the center of forest.

3.2.3. Shape and size of sample plots

15 sample plots from stratum one and 15 sample plots from stratum two totally 30 sample plots were determined. 90 sub-samples for BD from (0-20, 20-40 and 40-60 cm) depth class and then, 90 composited sub-samples for SOC from three depth class and 30 composited samples for Litter biomass carbon were measured. The shapes of the sample plots were square with smaller soil and litter sub samples. The size of the bigger plots for tree inventory was 20 m x 20 m, 400 m^2 in total. 5 smaller sub-plots of $1m^2$ in size were established, one at the middle and four at the corners in each bigger plots to collect leaf litter and soil samples. 150 m was the distance between each sample plots. There is only one transects line to forest and wood land, because of the forest is narrow and long in shape.

3.3. Data collection methods

3.3.1. Woody species inventory

In each plot all standing living trees and shrubs with a DBH $\geq$ 5 cm diameter were recorded with in a sample area of 20 m x 20 m. Those trees on the border were included when $\geq$ 50 % of their basal area fell within the plot and excluded if < 50 % of their basal area fell outside the plot. Trees overhanging into the plot were excluded, but trees with their trunks inside the sampling plot and branches outside were included (Bhishma *et al*., 2010). The trees that were found on a slope, always measured on the uphill side. If the tree has fallen but is still alive, were then placed the measuring stick towards the bottom to measure at DBH. Trees are considered alive if there are green leaves present (Pearson *et al.*, 2005).

The diameters were in two perpendicular directions. In the case of multi-stemmed plants (more than 2 stems per plant), each stem was measured and the equivalent diameter of the plant was calculated as the square root of the sum of diameters of all stems per plant (Snowdon *et al*., 2002).

$$d_{e=}\sqrt{\sum_{i=1}^{n} d_i^2} \text{ --eq. (1)}$$

Where: d_e is diameter equivalent (at breast or stump Height) (cm) and di is diameter of the i^{th} stem at the measurement height (cm).

Marking of counted trees were done to prevent double counting. During counting, local name of trees were recorded by local language by the aid of key informants. The scientific name of trees were identified at field, and those trees whose species name were not known identified by the aid of ‘’Useful Trees and Shrubs for Ethiopia” (Azene Bekele, 2007). For buttressed stems measurement were taken at the end away from buttressed (Pearson *et al.,* 2005).

3.3.2. Stand structure surveying

The stand structure of the Delima forest was surveyed by stratifying the whole forest in two stratums. The identification of tree families, species and average DBH, Height, stem per ha and basal area of the total studied stand was measured and identified.

3.3.3. Litter sampling

Litter samples were collected from 3 out of five 1m^2 quadrat sub-plots of each main plot by lottery method and were collected, weighed and recorded as field wet weight on the field, and 100g of evenly mixed sub-samples for each plot were taken to laboratory to determine dry biomass. Dead wood was not considered in this study due to the absence of deadwood in the study site because the local communities obtained their sources of fuel wood from the forest.

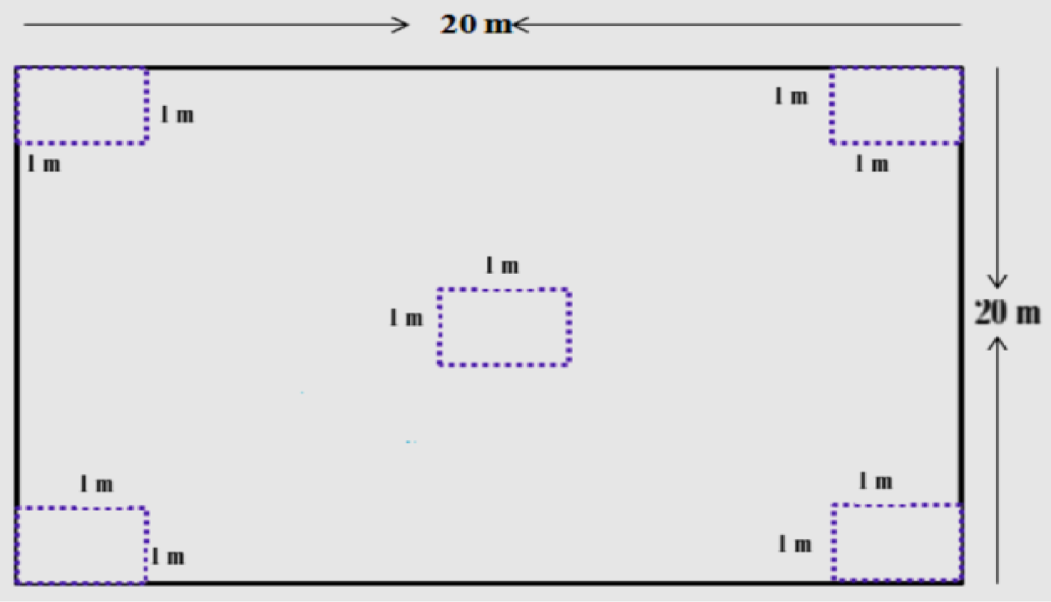

Figure 2 Design and size of main and sub-plots for sampling of tree inventory litter and soil samples

3.3.4. Soil sampling

The soil samples for organic carbon determinations were collected from depth of (0-20 cm, 20-40 cm and 40-60 cm) layers from each of 20 x 20 m tree inventory plot in the sub-samples used for litter sampling. The soil samples were collected by auger from each specified depth classes and composited them by layer to take representative samples. Then all the collected and composited soil samples handled individually by plastic bags, tagged, coded per depth class, and were sent to laboratory for SOC analysis.

Soil carbon concentration was analyzed using standard method, by Walkey-Black procedure (1934).

The soil bulk density samples were collected from the center of the plot and at depth class similar to SOC samples with the core samplers (6 cm dia. X 20 cm tall, 565.2 cm^{-3} volumes). The collected individual samples were then inserted to individual plastic bags coded and sent to Debre Markose soil laboratory.

The bulk density samples were oven-dried at 105 °C for 48 h and weighed (Pearson *et al*., 2005).

The above methodologies were for Tier 3, but for Tier 1 and Tier 2 the default mean biomass and soil organic carbon emission factor was used from (IPCC, 2003, IPCC, 2006 MEFCC, 2017 and luke, 2018). That means for Tier 1 all emission factor was used from IPCC, 2003 and IPCC, 2006, but for Tier 2 the AGBC and BGBC was used from MEFCC, 2017 (forest emission reference level submitted for to UNFCCC). The litter biomass carbon (LBC) and SOC of default emission factor was used from Luke, (2018) (Finland project studied Ethiopian SOC and LBC). The activity data for estimating removals was Delima dry afromontane forest for both Tier1, 2 and 3.

3.4. Data Analysis Methods

3.4.1. Estimation of Above and Below Ground Biomass Carbon Stock

The above ground biomass consists of all living tree biomass above the soil, inclusive of stems, stumps, branches, bark, seeds and foliage. The selection of the appropriate allometric equation is crucial in estimating aboveground tree biomass carbon (AGBC). (Bhishma *et al*., 2010) defined allometric equation as a statistical relationship between key characteristic dimensions of trees that are fairly easy to measure, such as DBH or Height and other properties that are more difficult to assess, such as above ground biomass carbon. There are different allometric equations that have been developed by many researchers to estimate the above ground biomass carbon. These equations are different depending on the types of species, geographical locations, forest stand types, climate and others (Baker *et al*., 2004).

Although, many allometric equations had been developed globally, no African site had been included in previous efforts (Chave *et al*., 2005) except the pan tropical AGB model developed by Chave *et al*. (2014), included sites from Africa by considering 58 study sites of woody vegetation, excluding plantations and agroforestry systems with a total of 4004 trees and DBH ranging from 5 to 212cm, spanning a wide range of climatic conditions and dry tropical forest types. The model was found to hold across tropical vegetation types, with no detectable effect of region or environmental factors (Chave *et al*., 2014; Victor, 2015). According to Henry *et al*. (2010), equations that integrate more than one tree dimension improve the reliability of forest biomass estimation. Therefore, the model of Chave *et al*. (2014) was used by many studies and has been the best model for carbon stock assessment in Africa (MEFCC, 2016; Victor, 2015) on the basis of climatic condition, DBH of trees and forest type of the study area to determine biomass of tree species having $\geq$ 5 cm DBH. This study uses the following equations to calculate AGB (stem plus bark, branches and foliage) of trees. The model that was used to calculate the above ground biomass is given below:

AGB (kg) =0.0673x (WDxDBH^2xHt) ^0.976 --eq. (2)

Where AGB = above ground biomass in (kg/tree)

DBH = diameter at breast height in (cm)

WD =wood density, in (gcm^{-3})

Ht =total height of trees in (m)

DBH of trees were measured directly, but total height of trees was measured by regression using DBH of some directly measured tree species as indicated by chave et al., (2014). Height of 11 trees was measured directly and the other measured by using linear regression equation of:

$y = 0.2894x + 1.1404$--eq. (3)

$R^2 = 0.5455$

Where Y = dependent variable (Ht.)

X= independent variable (DBH), therefore the remaining total height of tree was measured using the above equations.

According to IPCC (2006), the biomass stock density of a sampling plot is converted to carbon stock densities by default carbon fraction of 0.47, as the dry biomass contains 47% organic carbon in the tropical and sub-tropical region.

Basic wood densities of 21 tree species out of 23 studied tree species were used. According to Chave et al. (2014) the inclusion of country specific wood density in the equation significantly improves biomass estimation. Wood specific densities of the collected woody plant species were collected as secondary information from ICRAF wood density database (www.worldagroforestry.org) and Global wood density database (Zanne *et al*., 2009). In this study, total numbers of 23 woody plant species were recorded. Of which the basic wood density of 21 (91.3 %) woody plant species were used basic wood density but the other two species of *Rosa abyssinica* and *Phytolacca dodecantra* were used average wood density of 0.612 gcm^{-3}, (Ponce-Hernandez, 2004).

Basic wood specific density plays a great role predicting accurate biomass carbons in all regressions models (Chave *et al.*, 2005).

The second methods to estimate biomass and soil carbon stock was by using Tier 1 and Tier 2, which uses the IPCC default values and country level specific data respectively.

3.4.2. Carbon stocks in the litter biomass

According to Pearson *et al.,* (2005), estimation of the amount of biomass in the litter can be calculated by:

$$LB= \frac{wfield}{A} x \frac{Wsub_{sample(dry)}}{Wsub_{sample(fresh)}} x \frac{1}{10,000} \text{ --- } eq. (4)$$

Where;

LB = Litter biomass of litter (Mg ha^{-1})

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

A = size of the area in which litter was collected in (m^2)

W sub-sample, dry = the oven dry weight of sub-sample litter taken from 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).

A composited and 100g of fresh weight was oven dried at 70℃ for 24 hours to determine dry to fresh weight ratios (Ullah and Al-Amin, 2012; Negash and Starr, 2015).

Once the litter biomass is obtained, then Carbon stock in dead litter biomass was calculated by using the following formula.

LC = LB × 0.37 -- eq. (5)

Where, LC is total carbon stocks in the dead litter in ton/ha, 0.37 is carbon fraction (IPCC, 2006), LB is oven dry mass of litter biomass.

3.4.3. Soil sample analysis

3.4.3.1. Soil Carbon determination

SOC stocks (Mg ha^{-1}) for Tier 3 were calculated as the product of carbon content (%), bulk density (gcm^{-3}) and layer thickness (cm). The SOC stocks values for the three layers (0-20, 20-40 and 40-60 cm) were summed to give the SOC stock for the entire 0-60 cm layer. The SOC stock of the forest in Tier 1 and tier 2 were taken the default mean SOC from IPCC, 2003 and MEFCC, 2017 (Ethiopian Forest Emission Reference Level, 2017) respectively. Therefore, the SOC stock in depth class were calculated for only Tier 3, but for Tier 1 the Mean SOC Mg ha^{-1} was taken directly from IPCC, 2003 and 2006 emission factor data base. Tier 2 default emission factor was taken from Luke, (2018). For Tier 1 the values of AGBC, BGBC, LBC and SOC were 140, 37.8 5.2 and 63 Mg ha^{-1} respectively. For Tier 2 the values of AGBC, BGBC, LBC and SOC were 113, 28, 4.35 and 94 Mg ha^{-1} respectively.

SOC = BD x D x % C x 100 --eq. (6)

BD (gcm^{-3}) = (oven dry weight of the soil) / (volume of the core) ---------------------eq. (7)

Volume of the core $(V) = h \times \pi r^2$---eq. (8)

Where, V is volume of the soil in the core sampler in cm^3, h is the height of the core sampler in cm which is 20, and r is the radius of core sampler in cm that is 3.

3.4.4. Estimation of Total Carbon Stock Density

The total carbon stock density of a study area was calculated by summing the carbon stock densities of the individual carbon pools. The forest total carbon stocks are defined as the sum of the total biomass carbon and SOC stocks.

CT = AGBC + BGBC + LBC + SOC --eq. (9)

The total carbon stock was then converted to tons of CO_2 equivalent by multiplying it by 44/12 or 3.67 of molecular weight ratio of CO_2 to O_2 (Pearson *et al*., 2007).

According to EFRL, (2017) the basic formula adopted by the IPCC greenhouse gas balance calculation is based on activity data (extent to which a human activity takes place) and emission factors (coefficients which quantify the emissions or removals per unit of activity). Therefore, Emission or Removal = AD x EF, Where AD is activity data, and EF is emission factor.

3.5. Statistical Analysis

After Data collection accomplished the data of DBH, Height and frequency of each species, fresh weight and dry weight of soil were organized and analyzed by using Microsoft excel 2010 and Statistical Package for Social Science (SPSS version 20). To test the differences in Carbon stocks AGBC, BGBC and LBC between stratums, one-way ANOVA was used. Multiple comparisons of means for each variable (carbon stocks among stratums, soil depth, and soil carbon,) were carried out using F test. To test differences between soil carbon stocks within each stratum, two ways ANOVA was computed. To analyze carbon stocks in each Tiers descriptive statistics was used.

4. RESULTS

4.1.Stand characteristics

In total, 17 families with 23 tree species were recorded in the Delima Forest. Among families, *Fabaceae* and *Euphorbiaceae* was the most diverse having four and three species. *Moraceae* and Myrsinaceae were also diverse having two species, while the remaining families had only one species. Totally, 316 trees having DBH ≥ 5 cm were recorded .The average basal area was 6.91 m^2 ha^{-1} ranged from 0.22 and 20.21 m^2 ha^{-1}. *Acacia abyssinica* and *Croton macrostachyus* altogether accounted for 55.3 % of the total basal area. The lowest basal area of the species was *Milicia excelsa (0.005* m^2 ha^{-}1). The average density or number of stems per ha. across the sites was 263.

Croton macrostachyus was the most frequently occurred tree species in the study area (in 24 plots out of 30) and *Buddleia polystachya* (in 11 plots out of 30). *Vernonia amygdalina, Acacia abyssinica* and *Rosa abyssinica* were also recorded in equal frequencies in the study area (in 8 plots out of 30 each) (App. 1) below.

To see the contribution of each species for the carbon stock in the study area, the largest carbon stock was observed in *Albizia gumifera* (0.50 Mg per single tree). *Acacia abyssinica, Ficus sur* and *Prunus africana* also showed high carbon stock than the rest of the species recorded in the forest area (0.22 Mg, 0.21 Mg and 0.16 Mg per single tree), respectively. The least above ground carbon stock were recorded for, *Dovyalis abyssinica* and *Milicia excelsa* with a value of 0.01 and 0.003 Mg per single tree.

4.2. DBH and Height Distribution of Delima dry afromontane forest

DBH of trees was measured and their distributions classified in to five classes, 5-10 cm, 10 -20 cm, 20 -30 cm, 30 -40 cm and ≥ 40 cm. More DBH class was found in10 -20 cm with the share of (41.77%, 132 out of 316 trees). The second highest number was recorded from

5-10 cm which covers (29.75%, 94 out of 316 trees), while the least distribution was recorded in ≥ 40 cm DBH which covers (1.27%, 4 out of 316 trees).

Likewise DBH, Height of measured trees was identified into five classes. The height distribution shows that species such as *Accacia gumifera*, *Urera hypselodendron, Ficus sur*, *Dombeya torrida*, and *Prunus africana* were found in the higher height classes dominating the upper canopy (App.1) below. The rest lower height distribution is mainly covered by shrubs and small trees. The highest number of trees was found in 2-5 m height class (143 trees out of 316) followed by 5-10 m (128 trees), 10 -15 m (35 trees), 15-20 m (7 trees) and ≥ 20 m (2 trees out of 316) respectively.

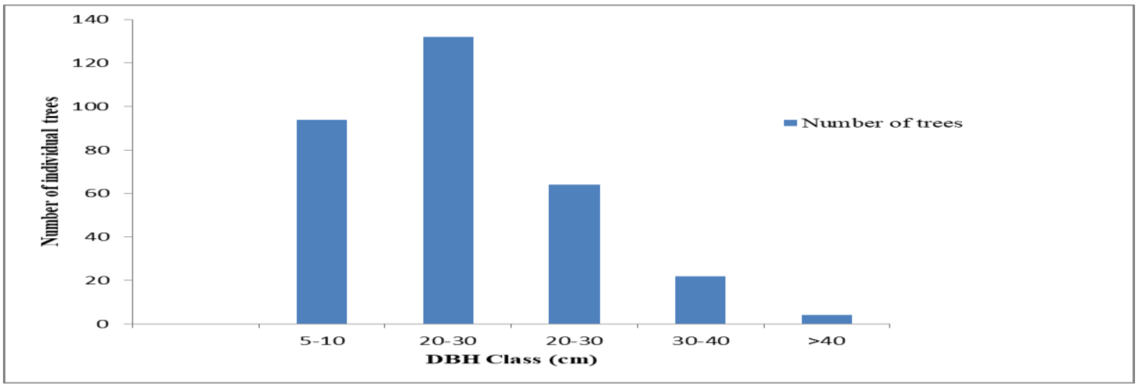

Figure 3: DBH class distributions of the tree species in the study area of Delima forest.

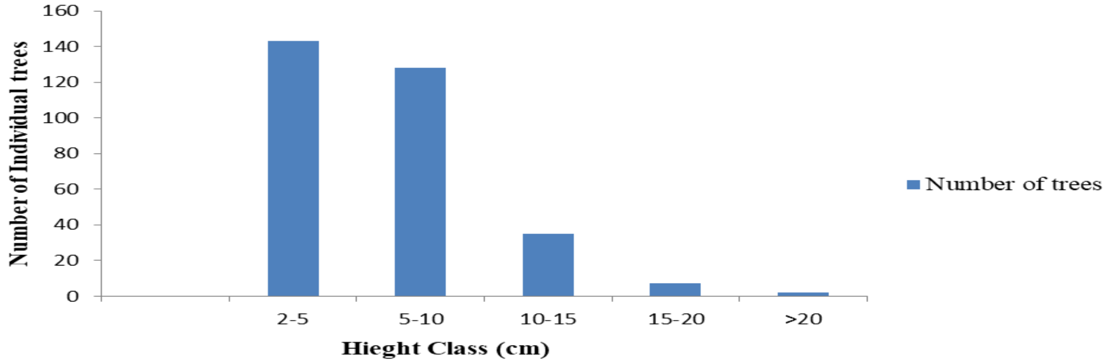

Figure 4: Height class distributions of the tree species in the study area of Delima forest.

4.3. Biomass Carbon Stock estimates in the three Tiers

The total biomass carbon stock Mg ha^{-1} of Tier 1, 2 and 3 are presented in table 1 below. The carbon stock (in percentage) under Tier 3 was lower than Tier 1 and Tier 2 by 90.55 % and 88.1 % respectively.

Biomass Carbon Stock estimates in Tier 3

Table 1: Mean biomass carbon stock (± SD) using three methodological Tiers

Biomass carbon stock	Methodological Tiers		
	Tier 1	Tier 2	Tier 3
AGBC Mg ha^{-1}	140	113	13.61 ± 11.74
BGBC Mg ha^{-1}	37.8	28	3.67 ± 3.05
LBC Mg ha^{-1}	5.2	4.35	0.0082 ± 0.005
Total biomass carbon Mg ha^{-1}	183	145.35	17.29

4.4.SOC stock estimates among the three Tiers

The total SOC stock of Tier 1, 2 and 3 were 63, 94 and 136.47 Mg ha^{-1}. Of which the amount of carbon stock in percentage of Tier 3 was higher than Tier 1 and Tier 2 by 44.35 %, and 16.96 % respectively.

Table 2: Mean SOC stocks (± SD) among three methodological Tiers.

Depth, cm	SOC Stock per each Tiers		
	Tier 1	Tier 2	Tier 3
0-20	Nd	nd	50.01 ± 6.77^a Mg ha^{-1}
20-40	Nd	nd	46.01± 4.28^b Mg ha^{-1}
40-60	Nd	nd	40.45 ± 4.93^c Mg ha^{-1}
Total	63 Mg ha^{-1}	94 Mg ha^{-1}	136.47 ±11.75 Mg ha^{-1}

The bulk density of the soil profile found in the study site was ranged from 0.52 g cm^{-3} to 0.79 g cm^{-3} with the average value of 0.68 g cm^{-3}. The mean soil bulk density of Tier 3 per depth class 0-20 cm, 20-40 and 40-60 cm were significantly different (P= 0.000**) (Table 3) below.

Table 3: Mean Soil Bulk Density ± SD with soil depth and P-value in Tier 3

	Soil bulk density per Soil depth class				P-value
	0-20 cm	20-40 cm	40-60 cm	0-60 cm	
Mean ± BD gcm^{-3}	0.64±0.04^a	0.68±0.04^b	0.72±0.04^c	0.68±0.05	0.000**

The mean difference of Tier 3 was significant at the 0.05 level by two ways ANOVA.

The mean soil organic carbon in depth difference of 0-20 cm, 20-40 cm and 40-60 cm were 50.01 ± 6.77Mg ha^{-1}, 46.01± 4.28 Mg ha^{-1} and 40.45 ± 4.93Mg ha^{-1} respectively (Table 2) above. Soil depth 0-20 cm was significantly different to the soil depth of 20-40 cm and 40-60 cm soil depth ($P<0.05$) with the P= 0.002** and 0.000**. The result of total soil carbon stock of 0-60 cm depth was 136.47± 11.75 (Table 4) below. The 0-60 cm SOC content of Tier 3 accounted 86.84 % as compared to total carbon stock. The SOC content was decreased down to the soil depth increases.

Table 4: Mean Soil Organic Carbon ± SD versus soil depth and P-value in Tier 3

Variables	Soil Depth in cm				P-value
	0-20	20-40	40-60	0-60	
SOC Mg ha^{-1}	50.01 ± 6.77^{a}	46.01± 4.28^{b}	40.45± 4.93^{c}	136.47±11.75	0.000**

The mean difference of Tier 3 was significant at the 0.05 level with two ways ANOVA.

4.5. Ecosystem carbon stock among the three tiers (biomass plus soil)

The greater carbon stock of Tier 3 was contributed by the soil carbon pool, which accounted 86.84 %, to the total biomass carbon stock (Table 5) below.

Table 5: Mean Ecosystem carbon stock (± SD) estimates using three methodological Tiers

Ecosystem carbon stock Mg ha^{-1}	Methodological Tiers		
	Tier 1	Tier 2	Tier 3
Biomass carbon	183	145.35	17.29
SOC stock	63	94	136.47±11.75
Total carbon stock	246	239.35	153.76
Sources	(IPCC, 2003 & IPCC, 2006)	Luke ,2018 & MEFCC, 2017	Present study

The mean biomass and soil organic carbon stock default emission factor of Tier 1 was taken from IPCC, 2003, and for Tier 2 taken from Luke, 2018 & MEFCC, 2017.

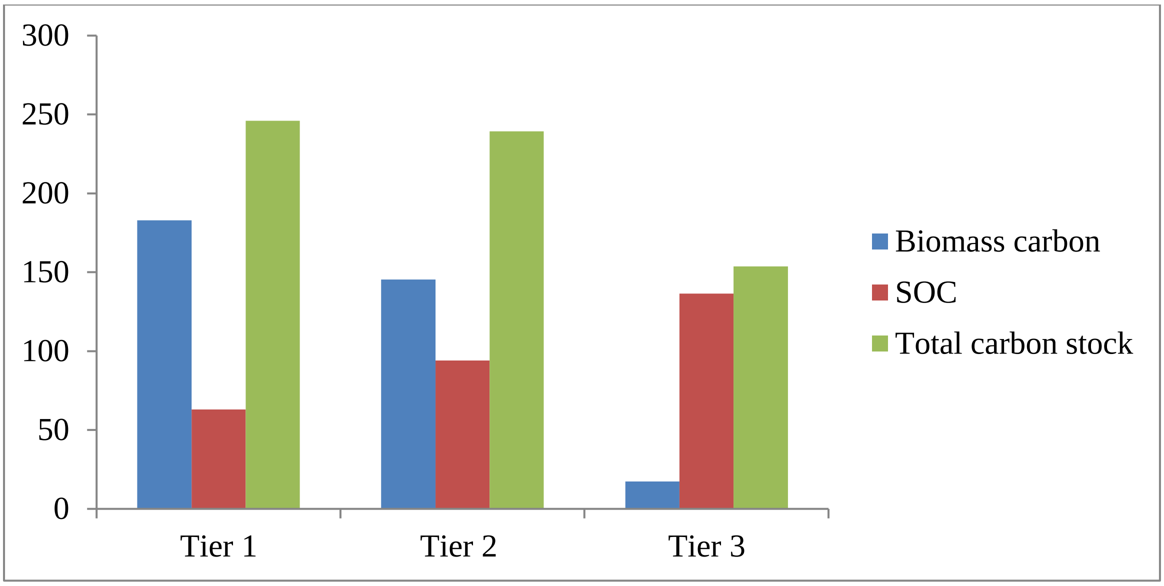

Figure 5 : Total Carbon Stocks in different Tiers.

5. DISCUSSIONS

5.1. Stand characteristics

Delima dry afromontane forest comprises 17 families and 23 total tree species. The DBH distribution of trees / shrubs showed an inverted J-shaped distribution, indicating that there were high numbers of young trees and shrubs in the lowest diameter class, Whereas, smaller number of trees and shrubs were found under the highest diameter class. It is obviously known that the smaller DBH of trees sequester less amount of carbon than higher DBH of trees. The DBH of trees in an individual tree depends on the tree's size (Hairiah *et al.,* 2011).

5.2. Biomass carbon stock estimates in the three Tiers

The mean above ground carbon stock of Delima dry afromontane forest with Tier 3, (13.61 ± 11.74 Mg ha^{-1}) was very smaller than previously studied similar forest type of Ethiopia, at Banja forest (338.72±236.41 Mg ha^{-1}), at Jelo muktar forest (185.80 ± 36.83 Mg ha^{-1}), and at Meskel Gedam dry afromontane forest (146.34 Mg ha^{-1}) (Dagnachew Tefera 2016, Ermias Bekure 2012; Fentahun Abere, 2016). The variation could be due to the intensive human and animal disturbance on this studied forest, altitude, topography, stand structure and microclimate of the forest area. The disturbance may accelerate soil erosion and may damage tree biomass directly. This may affect directly the amount of biomass and soil carbon stock of the present studies lowers than previous studies.

The variation of above ground carbon stock of the present study also may be due to the allometric model used to calculate the carbon stock. The allometric model used at Jelo-Muktar and Meskel Gedam forest was Brown *et al.,* (1989). Some of previous studies use the allometric model of developed by Brown *et al.,* (1989). The tree variable used by this model only DBH, but the present study has employed Chave *et al.,* (2014) for three variables; DBH, Ht. and WD. According to Henry *et al*. (2010), equations that integrate more than one tree dimension improve the reliability of forest biomass estimation. Not only measured variables may affect the variation, the Ecological zones represented by the Brown *et al.,* 1989 wasn't representing tropical Africa. The use of existing generalized biomass equations across wider ecological zones can lead to a bias and error in estimating biomass for particular species and sites (Henry *et al.,* 2011). Although, many allometric equations had been developed globally, no African site had been included in previous efforts (Chave *et al*., 2005) except the pan tropical AGB model developed by Chave *et al*. (2014). As stated by Yitebitu Moges *et al.* (2010), the different types of models used for biomass estimation have an impact on the value of carbon estimated in a given forest.

On the other hand the carbon fraction may also be one reason for the variation in the present study of above ground carbon stock as compared to previous studies. The carbon fraction used to calculate AGB to AGC by previous studies (Marshet Tefera, 2013) was 0.5, but our result was calculated using 0.47 (IPCC, 2006).

The mean below ground carbon stock of the present study (3.67 ± 3.05 Mg ha^{-1}) was very smaller than previous studies, (at Jelo-Muktar, and Banja forest) but similar with Biheretsige Park by Marshet Tefera, 2013 (4.3 Mg ha^{-1}) with a little variation.

The mean litter carbon stock of the present study was lower than previous studies at Meskel Gedam, forest (3.03 Mg ha^{-1}) and Menagesha Suba State Forest (5.26 Mg ha^{-1}) (Dagnachew Tefera 2016; Mesfin Sahile, 2011). The reason for lower litter biomass carbon may be as similar to aboveground and below ground biomass carbon of minimum stem per hectare and basal area contributes very low litter biomass carbon. The amount of litter fall and its carbon stock of the forest can be influenced by the forest vegetation (species, age and density) and climate (Fisher and Binkly, 2000).

The mean biomass carbon stock of the Delima forest by Tier 2 which is 145.35 Mg ha^{-1} (MEFCC, 2017) was lower than Brazilian Amazon forest (186 Mg ha^{-1}). The mean total biomass carbon stock of the present study by Tier 1 (183 Mg ha^{-1}) was higher than biomass carbon stock of Sub-Saharan Africa and Tropical Asia (143, and 151 Mg ha^{-1}) respectively, Brown (1997); Achard *et al*. (2004). The variation could be the type of forest and level of accuracy during data collection.

5.3. SOC stock estimates among the three tiers

The total soil organic carbon stock of present study of Tier 3 (136.47 ±11.75 Mg ha^{-1}) was lower than previous studies at similar depth class at south-eastern Rift Valley escarpment (186.4, 177.8 and 178.8 Mg ha^{-1}) for Enset, Enset-Coffee and Fruit-Coffee) by (Negash M, and Starr M., 2015). The variation could be because of vegetation type, rate of decomposition and climatic condition. The agroforestry systems sequester considerably more C than forest ecosystems generally do in the tropics (Negash and Starr, 2015).

The present study of SOC stock was in line with the same forest biome at Meskele Gedam Dry afromontane natural forest (131.79 ± 44.52 Mg ha^{-1}) but higher than Menagesha Suba State Forest (121.28 ± 38.45 Mg ha^{-1}) (Dagnachew Tefera, 2016; Mesfin Sahile, 2011).

The top soil depth (0-20) cm soil depth contained significantly higher SOC as compared to the depths below. The SOC content showed decreases a tread with depth. As the soil depth increases the soil carbon decreases and soil bulk density increases with soil carbon (Su ZY *et al.,* 2006). This is because of the top soil is rich in litter decomposition and other dead organic matters.

In Tier 2 as indicated by luke (2018), the average soil organic carbon in Ethiopia ranges from 90 - 133 Mg ha^{-1}, of which the Dry afromontane forest soil organic carbon was 94

Mg ha^{-1} was lower than the present study. Even if the forest biome is similar, the variation could be due to the differences in sample area and number of plots.

The SOC stock of 0-60 cm layer for tropical forest and tropical savanna has been reported to be 121-123 Mg ha^{-1} and 110-117 Mg ha$^{-1,}$ respectively (Lal, 2004). Therefore, the present study of SOC (136.47 ±11.75 Mg ha^{-1}) under Tier 3 was similar to tropical savanna and tropical forest.

The share of soil carbon stock of Tier 3, was higher than Tier 2 and Tier 1 by 59.21% and 68.42 %, and the total SOC stock of Tier 2 was higher than Tier 1 by 33%.

5.4. Ecosystem carbon stocks among the three tiers (biomass plus soil)

The total carbon stock density of Tier 1, 2 and 3 were 246 Mg ha^{-1}, 239.35 Mg ha^{-1} and 153.76 Mg ha^{-1}.The total carbon stock of Tier 1 and Tier 2 was higher than Tier 3, by 88.71 % and 83.61% respectively. The total carbon stock of Tier 1 was higher than Tier 2 by 2.7%.

The total carbon density of the present study was 153.76 Mg ha^{-1} which has the share of (24.06 %) as compared to Tier 2, (38.49 %) and Tier 1 (37.45 %), which was lower by 176.29 Mg ha^{-1} and 182.94 Mg ha^{-1} from Tier 2 and 1 respectively. The total carbon stock density of Tier 2 was lower than 6.65 Mg ha^{-1} from Tier 1.

From the total carbon stock of Tier 3 (153.76 Mg ha^{-1}) the soil carbon stock share was 86.84 Mg ha^{-1}. The soil carbon stock contains three times as much carbon as that of vegetation (IPCC, 2000).

The total carbon density of the present study was lower than Gera Afromontane Rainforest, Selected Church Forest and Meskele gedam forest. These may be because of the present study forest characterized as lower basal area and stem per hectare as compared to similar biome studied at Meskele gedam forest by Dagnachew Tefera (2016) and Nesru Hassen, (2015). In addition, the biomass and carbon stock of the study site (130.36 Mg ha^{-1}) was almost proportional with a little bit variation to selected church forests (122.85 Mg ha^{-1}) and Menagesha Suba State Forest (133.00 Mg ha^{-1}) (Tulu Tolla, 2011 and MesfinSahile, 2011).

5.5. Relationship and relative accuracy of Tier 2 and Tier 3 in reference to Tier 1

There are three general approaches (methods) for estimating emissions or removals of greenhouse gasses set by IPCC (GOFC-GOLD, 2009). These are called Tiers which range from 1-3 increasing level of data requirement and analytical complexity.

Tier 1 does not require new data collection to generate estimate of forest biomass. Rather, forest biomass and forest biomass mean annual increment (MAI) can be taken from IPCC emission factor data base (EFDB), corresponding to broad continental forest types (African tropical rain forest). Thus it provide limited resolution of how forest biomass varies sub-nationally and has an error of ± 50% or more for growing stocks in developing countries (GOFC-GOLD, 2009).

Tier 2 employs static forest biomass information, but it also improves on that approach by using country specific data (i.e. collected within the national boundary), and by resolving forest biomass at finer scales through the delineation of more detailed strata (IPCC, 2006).

Tier 3 is the most rigorous method associated with highest level of effort. More detailed information results in more accurate calculations, which are essential to achieving real greenhouse gas reductions. Thus, the higher the Tier levels the better is the accuracy; however, more detailed information is generally more costly to collect and requires greater expertise and resources to manipulate, Daniel *et al.,* (2011).

Therefore, according to Daniel *et al.*, (2011), Tier 3 was relatively more accurate than Tier 1 and Tier 2.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

Estimation of forest carbon stock is very important to know the change of carbon stock over time and to monitor and evaluate conservation strategies and management of forest resources in the country. Moreover, it enables to benefit from carbon finance resulted from REDD+ activities.

The total carbon stock of Delima dry afromontane forest at Tier 3 in relation to was significantly different. The total carbon stock of the forest with Tier 1 and Tier 2 was higher than Tier 3, by 88.71 % and 83.61% respectively, and Tier 1 was higher than Tier 2 by 2.7%. Carbon stock in all pools was varied with biomass and soil estimation methods applied.

Tier 3 is the most rigorous method associated with highest level of effort over the three Tiers. The higher the Tier the better was the estimation accuracy observed. Even if all estimation Tiers difference in accuracy and approaches three of them addresses the IPCC good practice concepts of transparency, completeness, consistency, comparability, and accuracy.

6.2. Recommendations

The necessities of reliable estimates of biomass and soil carbon stocks with sound carbon estimation methods were well recognized. So many approaches should be included to improve carbon estimation methods.

- Species specific allometric models should be promoted to improve shortage of allometric models in Ethiopia.
- Attention should be given for carbon estimation Tiers, because the same forest area may give great result difference using different estimation methods.

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APPENDIXES

Appendix 1: Family and scientific name of species with stand characteristics of Delima forest

No	Family Name	Botanical Name	Local name (Amharic)	habit	No of stems per ha	Ave. DBH (cm)	Ave. Height (m)	Frequency (occurrence)	Basal area m^2 per ha
1	Fabaceae	*Acacia abyssinica*	Yehabesha girar	Tree	39	24	8.5	8	1.762
2	Fabaceae	*Acacia nilotica*	cheba	Tree	1	14	6	1	0.013
3	Fabaceae	*Accacia gumifera*	Yehabesha sesa	Tree	5	33.7	13.66	2	0.445
4	Icacinaceae	*Apodytes dimidiata*	Dong	Tree	8	19.3	8.55	3	0.22

5	Meliantaceae	*Bersama abyssinica*	Azamira	Shrub	8	7.4	3.9	4	0.036
6	Euphorbiaceae	*Bridelia micrantha*	Yenebir tifir	Shrub	8	7.4	3.9	4	0.036
7	Loganiaceae	*Buddleia polystachya*	Anfar	Shrub	26	10.9	4.48	11	0.24
8	Apocynaceae	Carissa spinarum	Agam	Shrub	2	8.5	6.5	2	0.009
9	Euphorbiaceae	*Croton macrostachyu*	Bisana	Tree	71	15.6	6.63	24	1.353
10	Sterculiaceae	*Dombeya torrida*	Wulkifa	Tree	4	21.8	8.8	4	0.155

11	Flacourtiaceae	*Dovyalis abyssinica*	Koshim	Tree	2	10	3	2	0.013
12	Meliaceae	*Ekebergia capensis*	Lol	Shrub	1	16	4	1	0.017
13	Myrsinaceae	*Embelia schimperi*	Enkoko	Shrub	3	12.5	6	2	0.031
14	Euphorbiaceae	*Euphorbia abyssinica*	Kulkual	Shrub	28	10.9	5.48	3	0.258
15	Moraceae	*Ficus sur*	Shola	Tree	8	27	11.78	2	0.429
16	Celastraceae	*Maytenus senegalensis*	Koba	Tree	3	16	2.27	2	0.05
17	*Moraceae*	*Milicia excelsa*	Digita	Shrub	2	6	2.5	2	0.005

18	*Fabaceae*	*Millettia ferruginea*	Birbira	Tree	1	18	7	1	0.021
19	Rosaceae	*Prunus africana*	Homa	Tree	6	19.7	8.43	3	0.178
20	Rosaceae	*Rosa abyssinica*	Qega	Shrub	18	7.4	5	8	0.075
21	Asteraceae	*Vernonia amygdalina*	Girawa	Shrub	17	13.6	5.89	8	0.241
22	Phytolaccaceae	*Phytolacca dodecantra*	Indod	Shrub	4	9	8.7	2	0.026
23	Myrsinaceae	*Urera hypselodendr*	Lankusso	Liana	2	11	12	2	0.016

Appendix 2: Plot wise above and below ground biomass carbon stock of Delima forest.

Plot number	AGB kg Plot^{-1}	AGB kg/ha	AGB t/ha	AGC t/ha	AGC co^2 e t/ha	BGB t/ha	BGC t/ha	BGC co^2 e t/ha
1	1724.24	43106.00	43.11	20.26	74.35	11.21	5.27	19.34
2	2542.05	63551.20	63.55	29.87	109.62	16.52	7.77	28.52
3	4694.24	117356.00	117.36	55.16	202.44	30.51	14.34	52.63
4	1598.64	39966.10	39.97	18.78	68.92	10.39	4.88	17.91
5	1064.54	26613.60	26.61	12.51	45.91	6.92	3.25	11.93
6	515.10	12877.50	12.88	6.05	22.20	3.35	1.57	5.76
7	1253.62	31340.60	31.34	14.73	54.06	8.15	3.83	14.06
8	1730.47	43261.70	43.26	20.33	74.61	11.25	5.29	19.41
9	267.63	6690.73	6.69	3.14	11.52	1.74	0.82	3.01
10	555.90	13897.60	13.90	6.53	23.97	3.61	1.70	6.24
11	2298.94	57473.40	57.47	27.01	99.13	14.94	7.02	25.76
12	1243.60	31090.00	31.09	14.61	53.62	8.08	3.80	13.95
13	3064.10	76602.40	76.60	36.00	132.12	19.92	9.36	34.35
14	1292.52	32313.10	32.31	15.19	55.75	8.40	3.95	14.50
15	1087.62	27190.50	27.19	12.78	46.90	7.07	3.32	12.18
16	1786.01	44650.20	44.65	20.99	77.03	11.61	5.46	20.04
17	725.85	18146.30	18.15	8.53	31.31	4.72	2.22	8.15
18	1017.76	25443.90	25.44	11.96	43.89	6.62	3.11	11.41
19	523.77	13094.30	13.09	6.15	22.57	3.40	1.60	5.87
20	6.73	168.37	0.17	0.08	0.29	0.04	0.02	0.07
21	466.75	11668.80	11.67	5.48	20.11	3.03	1.43	5.25
22	1418.33	35458.20	35.46	16.67	61.18	9.22	4.33	15.89
23	985.09	24627.30	24.63	11.57	42.46	6.40	3.01	11.05
24	801.11	20027.80	20.03	9.41	34.53	5.21	2.45	8.99
25	75.35	1883.69	1.88	0.89	3.27	0.49	0.23	0.84
26	601.97	15049.20	15.05	7.07	25.95	3.91	1.84	6.75
27	354.28	8857.01	8.86	4.16	15.27	2.30	1.08	3.96
28	397.78	9944.50	9.94	4.67	17.14	2.59	1.22	4.48
29	410.73	10268.30	10.27	4.83	17.73	2.67	1.25	4.59
30	240.44	6010.99	6.01	2.83	10.39	1.56	0.73	2.68

Appendix 3: Plot wise litter biomass and carbon stock of Delima evergreen montane forest:

PLOT no	fresh wt at field (g)	Area (m^2)	Fresh wt sample (g)	oven dry wt (g)	LB (t/ha)	LBC (t/ha)	LBC co^2 e (t/ha)
1	450	1	100	83.58	0.04	0.02	0.07
2	360	1	100	85.00	0.03	0.01	0.05
3	500	1	100	83.80	0.04	0.02	0.07
4	350	1	100	85.64	0.03	0.01	0.05
5	450	1	100	84.55	0.04	0.02	0.07
6	360	1	100	84.00	0.03	0.01	0.05
7	400	1	100	83.20	0.03	0.02	0.06
8	455	1	100	83.00	0.04	0.02	0.07
9	420	1	100	84.50	0.04	0.02	0.06
10	385	1	100	82.06	0.03	0.02	0.06
11	410	1	100	83.00	0.03	0.02	0.06
12	400	1	100	83.15	0.03	0.02	0.06
13	420	1	100	82.90	0.04	0.02	0.06
14	385	1	100	84.00	0.03	0.02	0.06
15	450	1	100	86.00	0.04	0.02	0.07
16	105	1	100	92.55	0.01	0.01	0.02
17	100	1	100	92.75	0.01	0.00	0.01
18	120	1	100	92.88	0.01	0.01	0.02
19	100	1	100	92.50	0.01	0.00	0.01
20	100	1	100	93.34	0.01	0.00	0.01
21	105	1	100	93.38	0.01	0.01	0.02
22	110	1	100	94.50	0.01	0.01	0.02
23	100	1	100	93.00	0.01	0.00	0.01
24	110	1	100	94.00	0.01	0.01	0.02
25	105	1	100	93.80	0.01	0.01	0.02
26	105	1	100	93.70	0.01	0.01	0.02
27	110	1	100	93.45	0.01	0.01	0.02
28	100	1	100	93.50	0.01	0.00	0.01
29	105	1	100	93.55	0.01	0.01	0.02
30	110	1	100	93.15	0.01	0.01	0.02
Mean					0.02	0.01	0.04

Appendix 4: Plot wise soil organic carbon stock of Delima evergreen montane forest:

Plot	SOC t/ha 0-20 cm	SOC co2 e (t/ha) 0-20 cm	SOC (t/ha) 20-40 cm	SOC co2 e (t/ha) 20-40 cm	SOC (t/ha) 40-60 cm	SOC co2 e (t/ha) 40-60 cm
1	53.28	195.54	50.40	184.97	42.84	157.22
2	58.72	215.50	58.52	214.77	53.72	197.15
3	53.60	196.71	49.84	182.91	47.52	174.40
4	55.81	204.82	48.58	178.29	38.62	141.74
5	54.26	199.13	49.70	182.40	49.64	182.18
6	47.58	174.62	44.16	162.07	41.04	150.62
7	62.01	227.58	49.91	183.17	41.86	153.63
8	55.44	203.46	48.85	179.28	39.20	143.86
9	62.21	228.31	48.84	179.24	45.28	166.18
10	58.50	214.70	50.37	184.86	40.15	147.35
11	58.46	214.55	49.64	182.18	38.92	142.84
12	54.92	201.56	46.48	170.58	40.32	147.97
13	50.18	184.16	44.94	164.93	38.59	141.63
14	49.14	180.34	43.40	159.28	38.06	139.68
15	50.52	185.41	45.63	167.46	40.96	150.32
16	49.40	181.30	49.82	182.84	39.20	143.86
17	47.50	174.33	42.00	154.14	39.96	146.65
18	44.14	161.99	42.90	157.44	40.80	149.74
19	47.60	174.69	45.44	166.76	42.92	157.52
20	46.12	169.26	42.00	154.14	35.50	130.29
21	52.14	191.35	45.56	167.21	36.98	135.72
22	48.68	178.66	47.88	175.72	39.74	145.85
23	42.92	157.52	42.84	157.22	35.64	130.80
24	40.50	148.64	45.50	166.99	32.16	118.03
25	43.47	159.53	41.40	151.94	32.56	119.50
26	52.26	191.79	44.30	162.58	42.66	156.56
27	47.88	175.72	44.20	162.21	46.80	171.76
28	38.66	141.88	35.99	132.08	30.36	111.42
29	39.60	145.33	43.52	159.72	40.88	150.03
30	36.50	133.96	39.56	145.19	40.71	149.41
Where: SOC is soil organic carbon						

Appendix 5: Location data of each plot center of the Delima dry evergreen forest:

Plot No.	Transect line	Altitude (m)	Latitude (X), (UTM) (m)	Longitude (Y), (UTM) (m)
1	1	2283	339919	1160076
2	1	2293	339766	1160020
3	1	2278	339594	1160107
4	1	2286	339471	1160024
5	1	2295	339251	1159973
6	1	2286	339100	1159982
7	1	2298	338962	1159921
8	1	2292	338833	1159920
9	1	2307	338693	1159861
10	1	2314	338565	1159783
11	1	2329	338444	1159697
12	1	2299	338297	1159663
13	1	2279	338147	1159632
14	1	2280	338001	1159598
15	1	2294	337858	1159554
16	1	2280	337708	1159548
17	1	2264	337558	1159550
18	1	2291	337505	1159252
19	1	2291	357545	1159252
20	1	2301	337487	1159113
21	1	2293	337376	1159013
22	1	2305	337315	1157386
23	1	2295	337206	1158773
24	1	2299	337184	1158526
25	1	2325	337321	1158564

26	1	2317	337472	1158558
27	1	2313	337616	1158520
28	1	2306	337616	1158565
29	1	2326	337882	1158671
30	1	2298	338032	1158533

Appendix 6: Basic wood densities of studied tree species

No	Botanical Name	Local name (Amharic)	WD (g/cm3)	Reference
1	*Acacia abyssinica*	*Yehabesha girar*	0.826	average of genus (ICRAF database)
2	*Acacia nilotica*	*cheba*	0.723	Vreugdenhil et al., 2012
3	*Albizia gumifera*	*Yehabesha sesa*	0.58	Getachew Desalegn et al., 2012
4	*Apodytes dimidiata*	*Dong*	0.61	http://db.worldagroforestry.org//wd/genus/Apodytes
5	*Bersama abyssinica*	*Azamira*	0.671	http://db.worldagroforestry.org//wd/genus/Bersama & also global database
6	*Bridelia micrantha*	*Yenebir tifir*	0.54	http://db.worldagroforestry.org//wd/genus/Apodytes
7	*Buddleia polystachya*	*Anfar*	0.4	Vreugdenhil et al., 2012
8	*Carissa spinarum*	*Agam*	0.65	*Carissa spinarium* http://www.hindawi.com/journals/tswj/2012/790219/tab1/
9	*Croton macrostachys*	*Bisana*	0.56	Getachew Desalegn et al., 2012
10	*Dombeya torrida*	*Wulkifa*	0.451	*Vreugdenhil et al., 2012*
11	*Dovyalis abyssinica*	*Koshim*	0.579	http://db.worldagroforestry.org//wd/species
12	*Ekebergia capensis*	*Lol*	0.58	Getachew Desalegn et al., 2012

13	*Embelia schimperi*	*Enkoko*	0.775	http://db.worldagroforestry.org//wd/species/Erythrina_abyssinica
14	*Euphorbia abyssinica*	*Kulkual*	0.471	http://db.worldagroforestry.org//wd/species
15	*Ficus sur*	*Shola*	0.441	http://globalspecies.org/ntaxa/869708
16	*Maytenus senegalensis*	*Koba*	0.713	http://db.worldagroforestry.org//wd/genus
17	*Milicia excelsa*	*Digita*	0.57	Getachew Desalegn et al., 2012
18	*Millettia ferruginea*	*Birbira*	0.738	Average Millettia, Africa
19	*Prunus africana*	*Homa*	0.85	Getachew Desalegn et al., 2012
20	*Rosa abyssinica*	*Qega*	0.612	Total average
21	*Vernonia amygdalina*	*Girawa*	0.413	average (http://db.worldagroforestry.org//wd/genus/Vernonia)
22	*Phytolacca dodecantra*	*Indod*	0.612	Total average
23	*Urera hypselodendr*	Lankusso	0.775	average of genus (http://db.worldagroforestry.org//wd/genus/Urera)

Appendix 7: Instruments and equipment used for field data collection

No	Instruments and equipment	Purpose
1	GPS	For demarcation and tracking
2	SUNTO Hypsometer	For measuring tree height
3	Rope	For lay outing plots
4	Meter	For measuring distances and lay outing plots
5	Caliper	For measuring tree diameter
6	Spring scale	For measuring litter weight
7	Camera	For capturing photographs
8	Sticker	For giving code
9	Soil Auger	For SOC sample soil collection
10	Soil Core Sampler	For BD soil sample collection
11	Hammer	For kicking core samplers
12	Sacks	For collecting soil and litter samples
13	Machete	For clearing herbaceous vegetation
14	Digging Hoe	For Digging the soil to remove core samplers
15	Measuring Stick	For measuring the actual height of DBH

Appendix 8: field data collection format for Tree inventory

Date:________Location (GPS): E______m, N_____m Altitude M.A.S.L_________,

Name of strata: ___________ Plot number: ____________

Tree Inventory format

Tree No	Local name	Scientific name	DBH (cm)	Ht (m)	Remark
1					
2					
3					
4					

BIOGRAPHICAL SKETCH

Kurabachew Tenaw was born on June 27, 1986 in Gojjam, Ethiopia. He attended his elementary and junior secondary school education at Geter Fana from 1993 to 1998. He pursued his high school education at Amanuel Senior Secondary School from 1999 to 2001. He joined at Mertulemariam ATVET College from 2002-2004, and he pursued his higher education by joining Bahir Dar University from 2007-2011.

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