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Assessment on Carbon Stock of Natural and Plantation Forest in Setema District, Jimma Zone, South West Ethiopia

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Abstract

A Carbon Stock of Natural and Plantation Forest in Setema District, Jimma, South West Ethiopia was conducted. Carbon (C) densities of the biomass and soil (0–40 cm) in the natural forest and plantations of E.globulus and C. lusitanica in the Setema forest were determined and compared. In the stratum or forest stand, sample plots of 20 m x 20 m,(square) were randomly laid to measure the biomass of woody plants, a total of 90 (30 in each stratum) sample plots were taken for C stock inventory. Biomass C densities were estimated from total tree height, breast height diameter and wood density using allometric functions developed for tropical species and an assumed C content of 50%. Belowground biomass C densities were estimated using root: shoot biomass ratios. Soil organic C (SOC) densities were calculated from measured organic carbon contents (0–20 and 20–40 cm layers) and modeled bulk density values. Mean total biomass C densities for natural forest were greater than those of the plantations, and mean total SOC densities for plantations were greater than those of the natural forest, and the difference was significant ($p < 0.05$) in the cases of plantation and natural forest, but not significant in SOC in the case of E. globulus plantation species. Natural forests can store more total C stocks than plantations of exotic species, but the difference between natural forest and plantation of exotic was depended on plantation species. Therefore, species selection is vital when establishing tree plantations with the aim of the restoration of degraded soils and biomass carbon stocks. Conservation of the natural forest will have an imperative implication to the total C density and ensuring its viability.

Keywords: biomass; carbon stocks; *C. lusitanica; E. globulus;* natural forest; soil carbon stocks
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1. INTRODUCTION

1.1 Background

Forest ecosystems are the major terrestrial ecosystem comprising 4.1 billion ha (Brown *et al*., 2002) and are significantly important in reducing the increasing rate of carbon dioxide (CO_2) build-up in the atmosphere responsible for climate change (Streck and Scholz, 2006). Forests are playing an important and uncountable role in the terrestrial carbon cycle. Forest ecosystems can sequestrate and store carbon through the photosynthetic process of absorption atmospheric CO_2 and subsequent storage in the form of tree biomass (stem trunks, branches, foliage, roots, etc.), (Malhi *et al.,* 2002; Houghton, 2005) and in the form of litter, woody debris, soil organic matter, forest products (Malhi *et al*., 2002), and hummus or organic carbon in the soil (Houghton, 2005).

Forest vegetation and soils constitute a major terrestrial carbon pool with the potential to absorb, sequestrate, or uptake and store carbon dioxide (CO_2) from the atmosphere. The CO_2 source and sink dynamics as trees grow, die, vegetation type, topographic dynamics, temperature variations, and decay are subject to disturbance and forest management. Evidence of climate change linked to activities of the increase in greenhouse gas (GHG) concentrations is well-documented in international studies (IPCC, 2001; 2007). The recognized and importance's of forests in mitigating climate change has led countries to study their forest carbon budgets and initiate the assessment of enhancing and maintaining carbon sequestration of their forest resources.

The total global potential for afforestation enhancing rehabilitation of degraded natural forest and reforestation activities for the period 1995–2050 is estimated to be between 1.1 and 1.6 Pg C (1 Pg=Peta gram, 10^{15} gram) per year, of which 70%, could occur in the tropics (IPCC, 2000). The vegetation of tropical forests is large and play globally significant role in the storage of C stocks per unit area than any other land cover types (Hairiah *et al*., 2011). Afforestation, reforestation of non-forest land and rehabilitation of degraded forest because and management of forest plantations can enhance SOC stock through C sequestration (Lal, 2005).

Land use and plant species also have a significant influence on SOC estimations. In the tropics, deforestation, and changes in land use land covers are significantly impacting the global carbon cycle by increasing the rate of carbon emissions (Silver *et al*., 2000). Converting of the forest into agricultural ecosystems negatively affects SOC concentration and stock by 20–50% (Solomon *et al*., 2002; Lal, 2005; Lemenih and Itanna, 2004). In tropical forests, which serve as powerful carbon sinks, deforestation accounts for 20% of total anthropogenic activities CO_2 emissions into the atmosphere (Baccini *et al*., 2008).

Establishment of exotic species, the plantation can have several advantages and roles. The relatively fast growth rate of exotic species provides wood to be used for various purposes to human. In further, recent studies on tropical tree plantations indicate that exotic species may facilitate the regeneration of native species under the canopy and catalyzes the subsequent succession processes (Yirdaw, 2002). Trees have beneficial effects that are associated with improved soil structure through root action and inputs of organic matter (Olsson, 2001). They can increase the availability of nutrients through enhanced nutrient cycling and can also improve degraded soils by improving soil nutrient status through increased inputs and reduced outputs, (Jobbágy and Jackson, 2001).

In order to minimize deforestation, the Setema forest has been managed under Oromia Forest and Wildlife Enterprise (OFWE) and receives more attention due to its potential as a carbon sink and storage. Alternative strategies to reduce the pressure on the native forest by alleviating the fuel-wood shortage include fast-growing tree and shrub plantations around homesteads, the establishment of clear farm boundaries and wood lots in nearby rural communities (OFWE Office, 2018). At the same time, carbon assessment above ground and below ground carbon stocks of different selected plantation species and natural forest is generating vital information regarding the importance of the forest for carbon exchange and climate change mitigation at local, regional and international levels.

Climate change, caused by global warming, is a phenomenon partly resulting from an abundance of carbon dioxide in the atmosphere. It is the most pressing environmental problem in the world today. Forests provide materials particularly the moist southwestern natural forests support the production of important spices such as ginger (*Zingiber officinale*), cinnamon (*Cinnamomum zeylanicum*) and cardamom (*Elettaria cardamomum*) in addition to climate change mitigation (Girma, 1998). Forests are also important in watershed management, soil protection and biodiversity conservation. Particularly the mountain forests in Ethiopia are situated for capturing and storing rainfall and moisture, maintaining water quality, regulating river flow and reducing soil erosion (FAO, 2003). The importance of Ethiopian forests in the conservation of forest genetic resources has also been rated as one of the highest in Africa (De Vletter, 1991).

Plantation systems as land use can reduce the atmospheric concentration of carbon dioxide. Carbon sequestration through forestry plantations has a huge potential to improve global environmental problems such as atmospheric accumulation of carbon dioxide and related climate change. In Ethiopia *Eucalyptus globulus,* and *Cupressus lusitanica*, and are among common exotic plantation species (Gebrekidan Teklu, 2003). They grow fast, a characteristic that makes them remove more carbon dioxide (CO_2) from the atmosphere than they would release. Meta-analysis studies have shown that replacing native forest with agricultural crops or plantations (at least when less than 40 years of age) generally reduces soil carbon stocks (Guo and Gifford, 2002; Liao *et al*., 2010) and conversely, the establishment of forest on agricultural land use generally increases soil carbon stocks (Lemma *et al*., 2006). However, according to Glenday (2006) that tree biomass and soil C densities in the natural forest was not consistently greater than in plantations of exotics, but depending on plantation age and species diversities.

The Setema natural forest is one of the remaining forests in South Western parts of Ethiopia. More than 300 hectors of natural forest was replaced by exotic species plantation. However, the area of natural forest has declined, and become fragmented and degraded as a result of deforestation and planting exotic tree species. While the tree biodiversity of the natural forests has existed, there is no information known about their biomass and soil C densities, how they compare with those of plantations and, level of impact within natural forest and different plantation species concerning the importance of the forest for carbon stocks and climate change mitigation and ensure the sustainability of the forest of Setema district.

This study therefore aimed to generate data on the comparative assessment of natural and different tree plantation species of forest carbon stocks in setema district so the major aim of this study is to assess carbon stocks of plantations forest and compare it to its adjacent natural forest in Setema woreda South West Ethiopia, To assess biomass carbon stocks of selected tree plantations and compare it to its adjacent natural forest. To assess soil organic carbon stock of land under selected tree plantations and compare it to its adjacent natural forest. To assess ecosystem carbon stocks of selected tree plantations and compare it to its adjacent natural forest.

3. MATERIALS AND METHODS

3.1. Study area description

The study was conducted in Setema district of Oromia region in the southwestern Ethiopia. Geographically, it is located between 8° 2'to 8° 4' North latitude and 30° 20' to 30° 28' East longitude. The study area is located at about 450 kilometers away from Addis Ababa, the capital city of Ethiopia and 100 km in North West of Jimma town. Setema is bordered on the south by Gera, on the west by Sigmo, on the north by the Illubabor Zone, and on the Southeast by Gomma. The administrative center of the woreda is Gatira. The highest points are in the Damu Siga mountain range. Perennial rivers include the Onja, Salako, Gidache and Gebba. A survey of the land in this woreda shows that from 153,273 hectares total woreda area, 27.2% is arable or cultivable (20.8% was under annual crops), 13.1% pasture, 55.1% forest, and the remaining 4.6% are considered degraded, built up or otherwise unusable. The majority of the Sigmo-Geba State Forest, about 100 square kilometers (39 sq mi) in size, is located in Setema. Teff, Corn, and sheep are important cash crops. Although coffee is also an important cash crop in this woreda, less than 20 square kilometers (7.7 sq mi) are planted with this coffee production. The altitude of this woreda ranges from 1,500 to 3,000 meters above sea level.

3.1.1. Vegetation

The forest is classified under moist Afromontane forest consisting high diversity of endemic tree species and a variety of wildlife. Setema forest covers about 16,300 hectares (ha) of land comprising of species-rich natural and various tree plantations including *E. globulus* and *C. lusitanica* and other exotic species. In the Setema woreda Oromia Forestry and Wildlife Enterprise (OFWE) planted different exotic species including *E. globulus* (>250 ha) and *C. lusitanica* (>300 ha) on the most of natural forest boundaries. These exotic species are mainly planted on land that had been cleared of natural forest. The purposes of the plantations are for timber production, to serve as buffers to protect the remaining natural forest, and to mitigation against soil erosion (OFWE, 2018). The plantations have not been utilized by local communities. The location of the area is shown in Fig. 1.

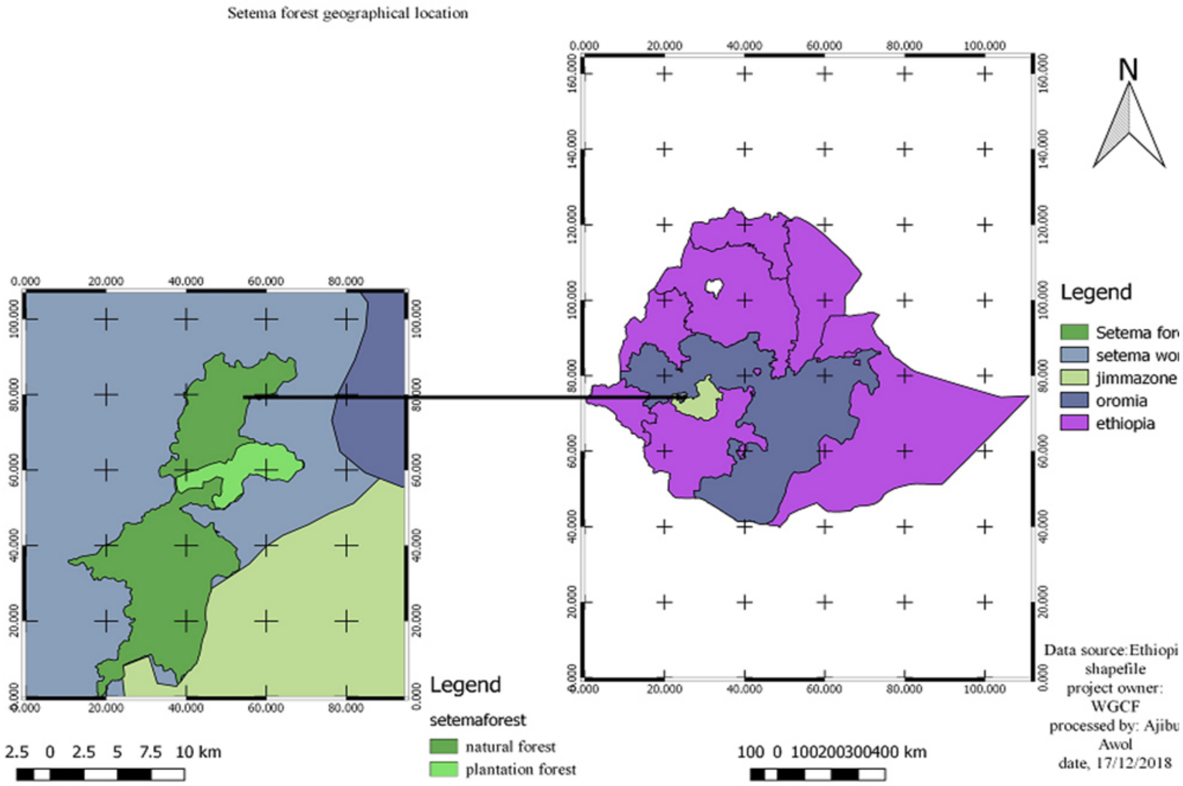

Figure 1: map of study area, it is located between 8° 2'to 8° 4' N and 30° 20' to 30° 28' E.

3.1.2. Climate conditions

The mean annual rainfall in the study area is 1665 mm/year. Western and southwestern parts of the country experience a unimodal rainfall pattern. October to January (Birra) denotes the time when the long rainfall season comes to an end to be followed by a medium to the short dry season during the same period. February to May (Bona) is the start of the long rainy season. Over the western parts of the country in the region also the rainy season starts during March/April. June to September (Main season) is a long and heavy summer rain, normally called the big rain or Gannaa, which falls from June to September. The study area annual average maximum temperature is 27.9°c and the minimum temperature is 11.9°c. Change in time/quantity of seasonal and annual rainfall is an important factor in the agriculture activities of the study areas. In general 80% of the woreda is semi-arid (wayina dega) and 20% is high land (dega) there is no desert (kolla) in the area.

3.1.3. Soil

The soil type of the study area is dominated and characterized as black to red soils; those are sandy soil, loamy soil, and clay soil.

3.1.4. Demographics

The 2018 woreda health office reported total populations for this woreda of 142,635, of whom 7763 are urban dwellers and 134872 are woreda rural population 67909 are children less than 15 ages. The majority of the inhabitants are Muslim religion followers, with 96.91% of the population reporting they observed this belief, while 2.67% of the population said they practiced Ethiopian Orthodox Christianity. The three largest ethnic groups reported in Setema were the Oromo (96.48%), the Amhara (2.22%), and the Tigre (1.0%); all other ethnic groups made up 0.3% of the population. Afaan Oromo was spoken as a first language by 97.17%, 1.75% spoke Amharic and 0.97% spoke Tigringa; the remaining 0.11% spoke all other primary languages reported.

3.1.5. Economic activities

Agriculture is the main economic activities and is dominated by small-scale and mixed crop and livestock farmers.

More than 90% of woreda population are depends on agricultural activities. Crop production is mainly rainfed. Coffee plays a major role in income generation in the areas. Maize, Teff (*Eragrostis teff*) and sorghum (*Sorghum bicolor*) are the major crops grown in the area. Pulses crops, such as, beans and pea are grown to a lesser extent in the area (Dechassa, 2000).

3.2. Conceptual frame work

The conceptual model that was used in this study shows how to determine the biomass and soil organic carbon stock in the study sites, to achieve the idea of study objectives.

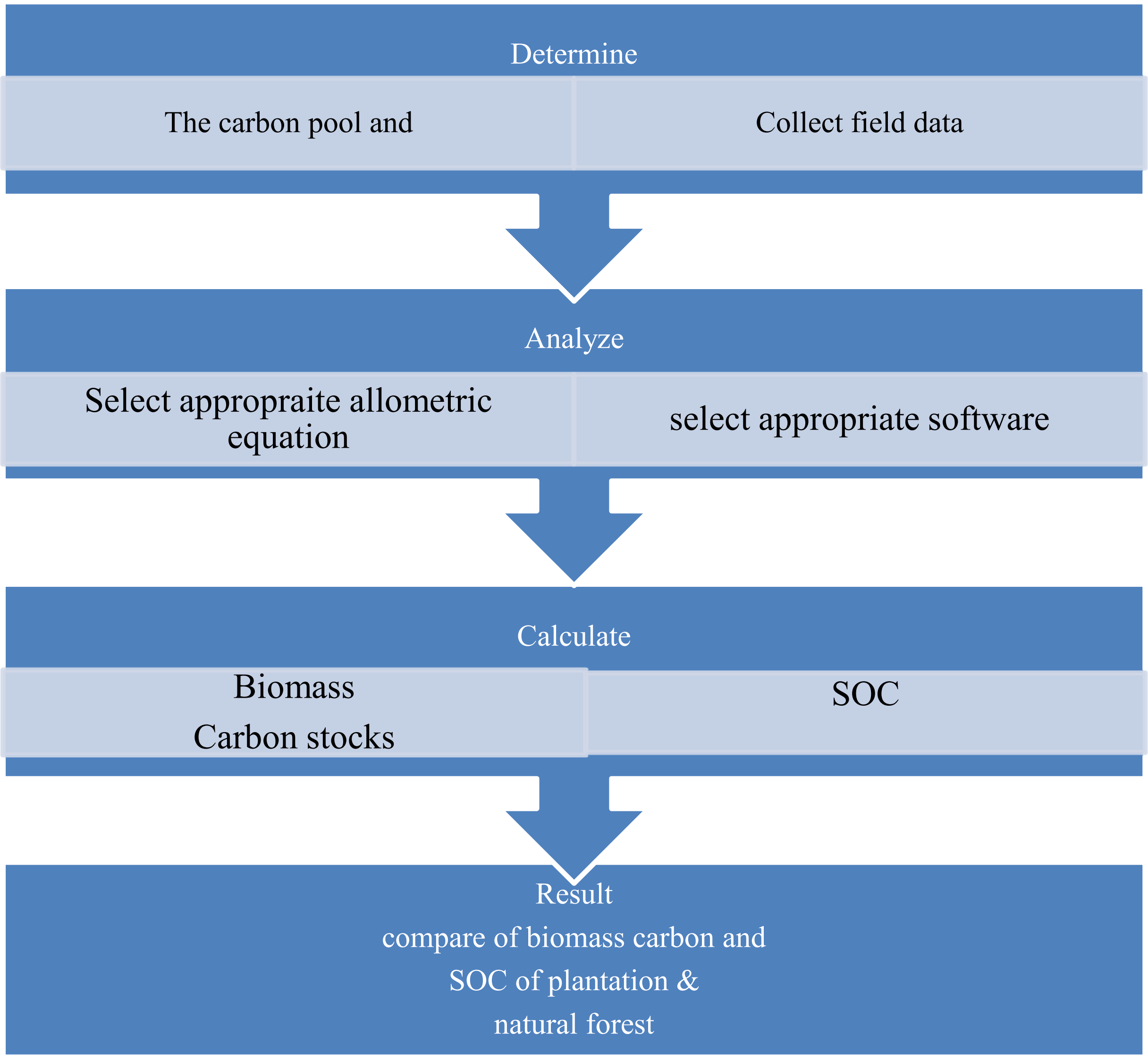

Figure 2: conceptual frame work

This conceptual model that was used to shows how determines the biomass and soil organic carbon stock and ecosystem carbon in the site, to achieve the idea of study objectives.

3.3. Delineation of forest boundary

The study forest area boundaries were delineated to facilitate measurement and accounting of forest carbon stocks (Bhishma et al., 2010), by using QGIS. Global positioning system (GPS) was used for navigation of the sample point of the study area by taking the coordinates of each turning sample point.

3.4. Stratification of the study area

Stratification helps in the forest to get accurate data, to save time and energy in addition, to maintain the homogeneity of the area (Kassahun, 2015). Forest and species types are the major parameters to classify the study area. The strata are defined at each forest and species types, stratified into the natural forest and plantation forest, then similar age plantation which were previously natural forest were stratified based on species into *E. globulus* and *C. lusitania* plantation.

3.5. Sampling design and techniques

Stratified simple random sampling method was used to take samples. Sample points distributed randomly by QGIS. In the stratum or forest stand, sample plots of 20 m x 20 m, were randomly laid to measure the biomass of woody plants, a total of 90 sample plots were taken for C stock inventory. Sample plots in the same stratum, namely E. *globulus*, *C. lusitanica,* and natural forest were computed to give average biomass and C stock for each stand type and other square plots of 1m x 1m square plots were set up within 20m x 20m sample plots for soil sampling. The soil samples were taken for the bulk density and soil carbon stock analysis. Soil samples were collected from quadrants (1 m^2) allocated in the four directions (at four corners of square sample plots) and one in the center as shown in figure 3.

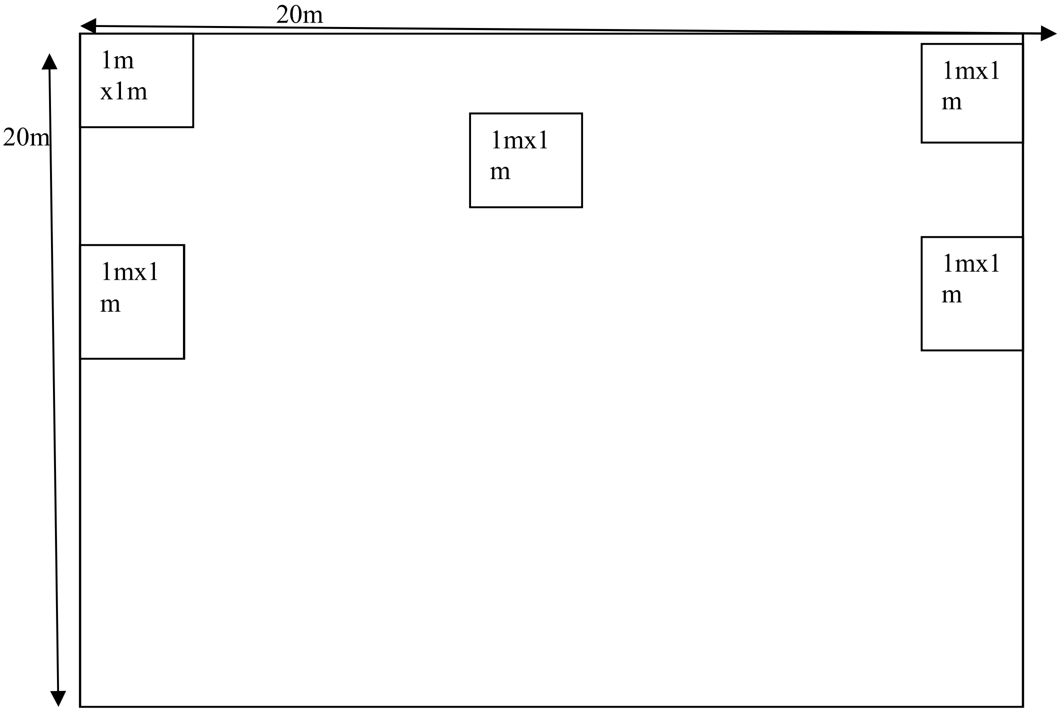

Figure 3: Sample plot design, at the four corners and at the center (1m x 1m) for soil sampling.

3.6. Sample size (sample plot numbers)

To estimate forest biomass and carbon stock potential that is statistically and practically efficient, enough sampling units should be measured to obtain the desired standard of precision no more, no less (Thomas *et a*l., 2015). The number of sample plots for biomass estimation (in other terms, the sample size) is generally selected empirically, based on rules established by experience. A general principle is that, for any given precision, the more variable the material, the larger the sample size: smaller sample sizes are required for a plantation. When the cost of selecting an item is equal for each stratum, there is no difference in within stratum variances, and the purpose of sampling happens to be to estimate the population value of some characteristics. In case, the purpose happens to be to compare the differences among strata, then equal samples election from each stratum would be more efficient even if strata differ in sizes (Picard *et al.,* 2012). Thirty (30) sample plots for single, homogeneous plantation site was recommended by Picard *et al.,* (2012). Based on this experience a total of 90 samples (30 samples for each stratum) were taken for estimation of natural forest and selected tree plantation biomass carbon stock. Vegetation sample points were distributed as shown on the following figure 4.

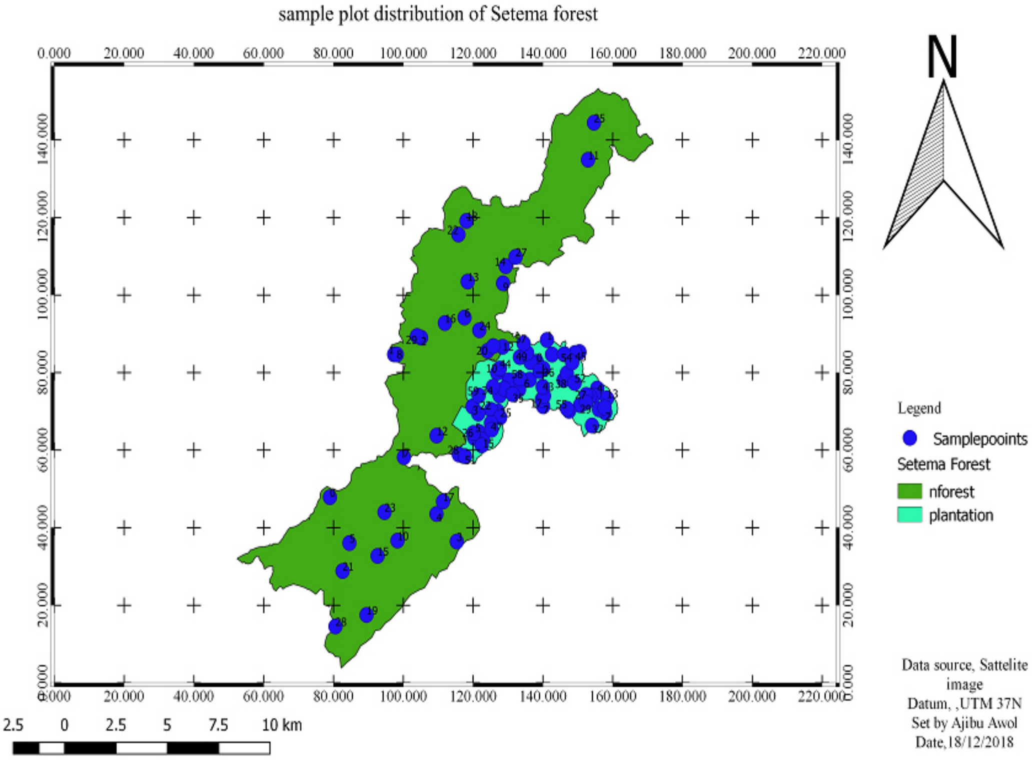

Figure 4: map of Setema forest area and sample plot distribution

3.7. Vegetation survey

Biomass data were collected at two different selected tree plantation species and adjacent natural forest. At each species selected of tree plantation and natural forest, a number of sample plots were distributed to the forest areas. A square sample plots were established randomly in all study sites. Diameter at breast height (DBH) of each tree (≥ 5 cm) within a 20 m x 20m sample plot was measured by using the caliper and height of each tree were measured by using a hypsometer. Trees with multiple stems, ambiguous and forked above DBH are treated as a single tree. A canker, gall or branched trees at DBH have measured of the smallest point below it where the stem assumes near cylindrical shape. Trees with multiple stems or fork below DBH are treated as a single individual stem (Pearson *et al*., 2005). To estimate the above-ground biomass of all trees within the selected site having DBH > 5 cm were recorded. These inventory data were used to calculate stocking (stems ha^{-1}), basal area (m^2 ha^{-1}).

3.8. Soil sampling

Soil samples were collected at two depths (0-20 cm and 20-40 cm) from ten (10) plots in each stratum. From each plot, five samples were taken from the topsoil (0-20 cm) and five from the 20-40 cm depth. Within 1 x 1 m quadrant five soil samples were taken by digging a pit to a depth of 40 cm, and the five soil samples were composited according to their layer (Roshetko *et al.,* 2002; Takimoto *et al*., 2008). The soil sample was mixed homogeneously, and 100 g sub-sample was taken from each sample for laboratory analysis. In addition, from the same quadrants, soil samples from two (0-20and 20-40 cm) depths for soil bulk density determination were collected from the surface soil using 20 cm length and 5cm diameter core sampler carefully driven into the soil to avoid compaction (Roshetko *et al*., 2002).

3.9. Data analysis

3.9.1. Carbon stock estimation

3.9.2. Aboveground biomass of natural forest

As usual methods for determining of the aboveground biomass (AGB) of forests are the combination of forest inventories with allometric tree biomass regression models (Houghton *et al.,* 2001; Brown, 2002; Houghton, 2005). This estimation of AGB in the forest ecosystem is based on plot inventories that involve the following three steps (Houghton *et al.,* 2001; Chave *et al*., 2005).

1. Selection and application appropriate allometric biomass equation for the estimation of individual tree biomass

based on the forest type.

2. Summation of all individual tree AGB to estimate plot AGB, and
3. Calculation of an across-plot average to hectare bases.

To the estimate below and aboveground biomass, all tree/shrub species with DBH ≥ 5 cm were measured in each sample point using Caliper and Diameter Tape. In addition, the total tree heights (to the top of the crown) were measured using Hypsometer (Brown, 2002; Pearson *et al*, 2007). Tree diameter was measured at breast height (DBH) of individual trees standing at 1.3 m which are greater or equal to 5cm DBH in each square sample plots of 400m^2 in area. Tree (DBH) was measured by diameter tape and caliper. Diameter tape was used to measure tree diameter which is very big and not suitable to measure by using a caliper. Each tree was recorded individually with its species, in the plot, local names of trees were records and later scientific names were identified from "Useful Trees and Shrubs for Ethiopia" (Bekele, 2007). In this study, the allometric equation given by Chave *et al*., (2014) was used to estimate AGB. The equation was used since the general criteria described by the author are similar to the study area. Ethiopia also used the same equation to submit its FREL to the UNFCCC (FERL, 2016; 2017). The inclusion of country-specific wood density in the equation significantly improves biomass estimation (Chave *et al*., 2014). For this reason, the following parameters are needed to express aboveground biomass in carbon stock: diameter at breast height (DBH), tree height, a wood density factor. While DBH and height parameters are directly measured in the field, the basic wood density of species was obtained from other studies and databases. Wood basic density of species was used following Ethiopian Forest level submission to UNFCCC (RREL, 2016; 2017).

$AGB = 0.0673 * (\rho * (DBH)^2 * H)^{\wedge}0.976$ …………………………………………..equation (1)

Where,

AGB = above ground biomass (in kg dry matter)
ρ = wood density (g/cm3)
DBH = diameter at breast height (in cm),
H = total height of the tree (in m).

Aboveground carbon stock of each tree biomass is converted to carbon stock based on the equation below (Brown, 2002)

$AGCS = AGB * 0.5$ ……………………………………………………………equation (2)

Where,

AGCS = Above Ground Carbon Stock,
AGB = Above Ground Biomass (kg/tree)

3.9.3 *E. globulus* biomass

Species specific allometric models developed For *E. globulus* of Ethiopia which directly determined on the biomass measurements (Tesfaye Debela , 2017) was used to estimate above ground biomass of *E. globulus*.

$AGB = 0.479 * (DBH)^{2.2578} * (H)\text{-}^{0.374}$……………………………………………equation(3)

3.9.4 *C. lusitanica* biomass

Five linear and non-linear biomass and carbon models of *C. lusitanica* were compared and evaluated for estimation of the overall aboveground carbon, carbon by age groups, and carbon by diameter at breast height (DBH) classes using performance indicator statistics (Berhe *et al.*, 2013). Among the models compared, a carbon model described by $Y = b_0 D^2 H + \epsilon$ (p-value < 0.001), where D = DBH (in cm), H = total height of the tree (in m), ϵ = error, and b_0 (b_0 =0.0319) is a parameter was found to be the best model for estimation of carbon sequestered in *C. lusitanica* plantation stands of the study area (Berhe *et al.*, 2013). This equation was used to calculate above ground biomass of *C. lusitanica*.

$AGB=0.0319 * DBH^2 *H + E$…………………………………….equation (4)

The corresponding carbon content in biomass was estimated assuming 50% of carbon in the biomass as per IPCC (2003).

3.9.5. Belowground biomass

Belowground biomass (BGB), commonly called as root biomass estimation is not easy as AGB calculation, BGB estimation is much more difficult and time-consuming than estimating aboveground biomass (Geider et *al*., 2001). Roots contribute an important role in the carbon cycle as they transfer considerable amounts of carbon to the ground, where it might be stored for a relatively long period of time. The plant uses part of the carbon in the roots to increase the total tree biomass through photosynthesis, although, carbon is also lost through respiration, and decomposition of the roots. Some roots can penetrate to great depths, but the greatest proportion of the total root mass is within the first 30 cm of the soil surface. Carbon loss or accumulation and storage in the ground are intense in the top layer of soil profiles (0-30 cm).Sampling should concentrate on this section of the soil depth (Kassahun *et al*., 2015). The belowground biomass (BGB) was calculated by multiplying above-ground biomass taking 0.26 as the root to shoot ratio (Ravindranath *et al*., 2008)

Belowground biomass (tha^{-1}) = 0.26 × above-ground biomass (tha^{-1})……………equation (5)

Finally, the carbon content in the belowground biomass was estimated by multiplying of BGB by 0.5 IPCC (2003).

3.9.6. Estimation of soil organic carbon

Soil samples for the determination of soil carbon were collected from a sample quadrates laid for soil sampling mean that from four directions and at the center of each sample points to a depth of 40 cm within each quadrate by digging a pit to a depth of 40 cm, and the five soil samples of each layer was composited (Roshetko *et al*, 2002; Takimoto *et al.,* 2008). Five equal weights of soil samples from each layer were taken and mixed homogeneously while a 100 g composite sample was taken from each sample quadrate for determination of organic carbon in the laboratory using Walkley and Black, (1934) method. The soil samples were air-dried, well mixed and sieved through a 2 mm mesh size sieve for soil carbon analysis following the right technique (Walkley and Black, 1934). In addition, from the same quadrats, soil samples for soil bulk density determination were collected from the surface soil (from 0-20 cm and 20-40 cm depths) using 20 cm length and 5 cm diameter core sampler carefully driven into the soil to avoid compaction (Roshetko *et al.*, 2002). The carbon stock density of soil organic was calculated as recommended by (Pearson *et al.*, 2005) from the volume and bulk density of the soil.

$V = h\ X\ \pi\ r^2$ ……………………………………………...……………………….equation (6)

Where,

V =is a volume of the soil in the core sampler augur in cm3,

h =is the height of core sampler augur in cm, and

r =is the radius of core sampler augur in cm.

Moreover, the bulk density of a soil sample was calculated as follows (pearson *et al.*, 2005):

$BD = \frac{\mathrm{Wa,dry}}{\mathrm{V}}$……………………………………………………………….equation (7)

Where,

BD is the bulk density of the soil sample,

Wav, dry is an average oven dry weight of soil sample

V is a volume of the soil sample in the core sampler in cm^3. Then, the soil organic carbon stock pool was calculated using the formula (pearson *et al.*, 2005)

$SOC{=}BD{*}d{*}\%C$……………….…………………………………………………….equation (8)

Where,

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

BD = soil bulk density (g/cm3),

D = the total depth at which the sample was taken (0-20 cm and 21-40 cm), and

%C = Carbon concentration (%) determined in the laboratory.

3.9.7. Estimation of total carbon stock of the area

Total carbon stock of the area was calculated by summing the carbon stocks densities of the individual carbon pools of the stratum. In this study, the total carbon stocks of stratum were determined by nondestructive methods which include, field survey, laboratory analysis, and allometric equations. In Setema forest dead wood and litter carbon pools are not included, because the forest area is near to village those carbon pools are intensively collected for fuel-wood purpose. Dead and broken pones are usually withdrawn from plantation stands after several years (Yamaguchi *et al.*, 1963). Saplings which are < 5cm DBH also excluded, since there is no regeneration in the plantation forest. Measuring might not be required if the understory is dominated by herbaceous material as this likely would account for negligible changes over the duration of the activity (less than 3 percent) (Pearson and Brown *et al.*, 2007). 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, 2010). Carbon stock density of a study area:

C stock=CAGB + CBGB + SOC……………………………………………equation (9)

Where:

C stock = Carbon stock density for all pools (ton ha^{-1})

CAGB = Carbon in above -ground biomass (t C ha^{-1})

CBGB = Carbon in below-ground biomass (t C ha^{-1})

SOC = Soil Organic Carbon

3.10. Statistical analyses

Descriptive statistics were calculated to describe the plot biomass and soil C stocks by forest and species type, and forest area. Differences in biomass and soil C stocks between species and forest types across forest areas were determined using a one-way analysis of variance (ANOVA). The difference between biomass C and SOC densities and its significant effect within each selected plantation species and the related natural forest was tested by using the one way ANOVA. Relations plantation species and the related natural forest were calculated to describe the dependence of C densities on species and forest types. The statistical analyses were performed using MINITAB version 17.

4. RESULT

4.1. Stand characteristics

The range in characteristics of the natural forests and plantations of exotic species are different as shown in Table 1. Those having the largest diameter trees and stand basal area were associated with the natural forest. The natural forest stem densities in Setema were considerably higher than in the plantation forest types. Stem densities were also compared in terms of the plantations of two different species that are *E. globulus* and *C. lusitanica*. There was a higher difference in the mean diameter of the trees in the natural forest among forest types.

Table 1: Stand of study plot (stand by forest type) for different forest types in Setema forest.

Forest type	Characteristics	Mean	Min	Max
Natural forest	DBH(cm)	28.41	5	143
	BA(m^2/ha)	37.36	13.30	44.84
	Stem density(#/ha)	587	175	1025
E. globulus	DBH(cm)	25.54	5	55
	BA(m^2/ha)	36.32	28	38.23
	Stem density(#/ha)	380	150	600
C. lusitanica	DBH(cm)	19.45	5	63
	BA(m^2/ha)	30	23.74	43.59
	Stem density(#/ha)	525	350	750

dbh= diameter at breast height; BA= basal area.

4.2. Aboveground biomass carbon

The aboveground biomass carbon was found to be significantly higher in natural forest (210.8 C t/ha) followed by *E. globulus* plantation (133.7 C t/ha) and *C. lusitanica* plantation (99.8 C t/ha). The difference was significant at (p =0.000 and F=24.91) only in the case of the natural forest and plantations, but not significant between plantation species. Larger biomass carbon in the natural forest might be attributed to DBH, species diversity and allometric equation used.

Table 2: Aboveground carbon content of different forest types in t/ha in Setema, forest Southwestern Ethiopia

Forest categories	Mean	St Dev	95% CI
Natural Forest	210.8	89.1	(188.0, 233.5)
E. globulus	133.7	55.6	(111.0, 156.4)
C. lusitanica	99.8	27.41	(76.54, 122.01)
p-value		0.000	

4.3. Belowground biomass carbon

According to this study, there was significant difference in belowground carbon content of different forest types (at p=0.000 and F=22.93) as indicated (Table 3). Natural forest and *E. globulus* sequestered higher and comparable belowground carbon (53.50 and 34.76 t/ha) respectively. The belowground carbon content of *C. lusitanica* (25.81t/ha) was lower than that of others.

Table 3: Belowground biomass carbon stock of different forest types in t/ha in Setema forest Southwestern Ethiopia.

Forest categories	Mean	St Dev	95% CI
Natural Forest	53.50	22.88	(47.63, 59.36)
E. globulus	34.76	14.45	(28.90, 40.62)
C. lusitanica	25.81	7.13	(19.95,31.68)
P- value		0.000	

4.4. Soil organic carbon

The SOC density ranged from 74.40 to 162.12 t C ha^{-1} in the 0–40 cm layer for the natural forest (Table 4). Under E. *globulus* plantation it ranged from 89.47 to 111.92 t C ha^{-1} in top the 0–40 cm layer. SOC densities were generally higher in the *C. lusitanica* plantation than in the natural forest and *E. globulus* in 0-40 cm layer. It ranged from 103.94 to 165.91 t C ha^{-1} in the 0–40 cm layers respectively under *C. lusitanica*. The differences were positively significant only in the case of the *C. lusitanica* and not significant in the case of *E. globulus* plantations. But in the second layer (20-40 cm), only E. *globulus* was negatively significant at (p-value=0.005).

Table 4: Soil organic carbon of natural forest and two different species plantations in Setema forest Southwestern Ethiopia

Depths	(0-20 cm)	(20-40 cm)	(0-40 cm)
Natural Forest	62.96±15.56	42.76±10.94	105.73±24.11
E. globulus	63.26±6.07	35.34±5.10	98.60±7.01
C. lusitanica	78.55±6.16	54.41±17.75	132.96±17.58
p-value	0.003	0.007	0.000

4.5. Ecosystem carbon stocks

Total C (AGBC +BGBC + SOC) in the natural forest, *Eucalyptus globulus,* and *Cupressus lusitanica* were 370.03, 267.06, and 258.04 C ton ha^{-1} respectively. There were significantly higher total C in the natural forest than the plantations. *E. globulus* plantation had the second largest total C stock (table, 5), because of higher biomass than *C. lusitanica* and though it is not statistically significantly higher than that the total C of the *C. lusitanica.*

Table 5: Average C storage potential in the different pools by major forest stands in study area.

	C storage capacity (t/ha) in different pools			
Forest stands	AGC	BGC	SOC	Total
Natural forest	210.8	53.50	105.73	370.03
E. globulus	133.7	34.76	98.60	267.06
C. lusitanica	99.8	25.81	132.96	258.57
p-value	0.000	0.000	0.000	0.000

AGC: aboveground carbon; BGC: belowground carbon; and SOC: soil organic carbon.

Calculated in all forest types, the natural forest had higher biomass C densities than the plantations. SOC densities were generally higher in the *C. lusitanica* than in the natural forest and *E. globulus.*

5. Discussion

5.1 Biomass C density

The observed differences in C stocks between forests types are primarily due to the replacement of natural forest with exotics through lose of biomass carbon in forest ecosystem. As there were no such comparative studies, there is no baseline biomass or soil carbon data available against which to compare our current carbon density values of the study area. However, from local knowledge, observation, and secondary data, it is known that most of the plantations in the Setema forest are on land that had been cleared of natural forest and the plantations, with the same management, have been protected and largely remained unutilized. The total biomass carbon in Setema natural forest (264.3 ton/ha) was lower than values reported by Dibaba *et al* (2019) which was 288.82.t/ha for Carbon stock of Gerba-Dima moist Afromontane forest, South-western Ethiopia. According to the study by Mohammed Abaoli and Bekele Lemma (2014) on the Belete-gera forest, moist montane forest in South Western Ethiopia, a mean biomass C densities of 135.00±36.63 Mg C ha^{-1} was reported for the natural forest. The result of this study natural forest biomass carbon stocks in line with Gera Afromontane Rain forest biomass carbon stock (260.81 t/ha) (Nesru Hassen, 2015).

Table: 6 Comparison of biomass carbon stocks (t/ha) of the present result of natural forest with other studies

Study Place	AGBC	BGBC	TBC
Setema natural forest (this study)	210.8	53.50	264.3
Arba Minch Ground Water Forest (Belay Melese *et al.*, 2014)	414.70	83.48	498.18
Egdu Forest (Adugna Feyissa *et al.*, 2013)	278.08	55.62	333.7
Menagasha Suba State Forest (Mesfin Sahile, 2011)	133.00	26.99	159.99
Ades forest (Kassahun *et al.*, 2015)	259.165	52.19	311.35
Moist Afromontane (MEFCC, 2018)			96-243
Natural high forest carbon stock of Ethiopia (Temam, 2010).			200

AGBC = Aboveground Biomass Carbon; BGBC = Belowground Biomass Carbon; TBC = Total Biomass Carbon.

Moreover, the variation of carbon stock in biomass depends on many factors such as the stand structure and composition, topography, altitude, disturbance, forest fire and fuelwood collection, microclimate. The difference in biomass C densities amongst these cited studies may partly be related to the use of different allometric biomass functions, wood density values used, tree size included in the calculations, and sampling methods and designs (Mulugeta Zewdie *et al.*, 2009).

The biomass C density of natural forest was significantly higher than that of the *C. lusitanica* and *E. globulus* plantations. The result indicated that average aboveground C in the tree plantations was better in *Eucalyptus* species (133.7 t/ha) than in C. *lusitanica* (99.8 t/ha). According to Birhanu Iticha (2017), in Chato Afromontane Forest, Western Ethiopia biomass carbon for *E .globulus* and *C. lusitanica* was reported to be 254.29, 223.37 t/ha respectively. Patula and Oeba, (2016) also estimated of aboveground and belowground carbon sequestration of *Eucalyptus* and *C. lusitanica* plantation species in Kenya as 247.9 and 98.4 t/ha respectively.

The C densities of the *C. lusitanica* in Setema forests were lower than the *Eucalyptus* plantation, as indicated by the lower dbh and basal area values (Table1). The biomass C density of the *Eucalyptus* plantations was not similar to that of the natural forest, but this can be attributed to a relatively high proportion of *C. lusitanica* plantation. The aboveground biomass C densities of the *E. globulus* plantations were higher next to those of the natural forest (table 2).

The establishment of plantations on either the disturbed or previously forest land had reduced the tree and total biomass carbon compared to the reference adjacent natural forest. This may be due to the difference in the species composition and higher age of trees and higher average DBH under the natural forest relative to the younger age and pure stands of plantations. Diversity of trees and the stand structural variables such as basal area and percentage of large trees (higher DBH range) were found to explain a high variability of the estimated biomass and carbon density of natural forest than plantations (Mensah *et al*., 2016).

The significant difference in the amount of aboveground and belowground carbon sequestered between species may be explained by the nature of tree species, age, and site conditions such as soil. *E. globulus* is generally known to grow fast and accumulate more biomass than *C. lusitanica* resulting in a high amount of carbon sequestration within the same period. *Eucalyptus* is also known to be self-pruning thus demanding less silvicultural management as compared *C. lusitanica* which requires such operations at a specific time of growth to improve on their stem quality and total biomass. Delays of such operational management are more likely to affect the diameter growth, which is a key parameter on tree volume that has a direct relationship on the estimation of the total biomass from the stem density (Patula and Oeba, 2016).

5.2. SOC density

The results showed that the amount of C stored in the top 20 cm soil layer has the order: C. *lusitanica* > *E. globulus*> natural forest. The amount of C stored in the second (20-40 cm) soil layer and total depth (0-40 cm) has the order: *C. lusitanica* > natural forest> *E. globulus*. Compared in terms of the soil organic carbon subject to natural forest, *E. globulus* and *C. lusitanica* plantations stored more organic carbon. This means that soil organic carbon under *C. lusitanica* was higher than the soil organic carbon under the adjacent natural forest.

Table: 7 Comparison of soil organic carbon (t/ha) of the present result of different forest stand with other studies

	Forest categories			Study Place (reference)
	N. forest	*E. globulus*	*C. lusitanica*	
SOC t/ha	105.73	98.60	132.96	Setema forest (this study)
SOC kg/ha	93	87	86.1	Munessa Forest, (Abate, 2004),
SOC t/ha	71.04	41.70	53.16	Chato forest(Birhanu Iticha, 2017)
SOC t/ha	305	209	252	Kenya (Omoro *et al (2013)*

In this study with respect to the total SOC stock under the natural forest and two exotic species plantation in the 0-20 cm soil depth, the natural forest had a lower SOC compared to the *C. lusitanica* plantations. This is due to might be the low input of fresh litter as is indicated by the low C low amount of C found under the natural forest in the 0-20 cm soil depth, compared to plantations.

According to the study by Anatoli (2012) conducted at Munessa-Shashemene natural forest, the SOC of the natural forest in the 10-20 layer cm remained low over the decade and a possible explanation for this might be the low input of fresh carbon as is indicated by the low C in the 0-20 cm layer under natural forest.

Result indicated that the SOC under natural forest and plantations were higher in the top 0- to 20-cm soil depth and decreased in the second layer (20- 40 cm). It is conformity with those reported for South Central Ethiopia (Lemenih *et al*., 2005) and Demessie *et al*., (2011) reported for Gambo district Southern Ethiopia. They reported that the larger portion of C was confined to the 0- to 10- and 10- to 20-cm depths. Similarly, as described by Russell *et al* (2007) the larger portion of SOC was accumulated in the upper 0- to 15-cm soil layer following the planting of trees in an abandoned pasture at La Selva Biological Station, Costa Rica.

The higher SOC in the upper layers relative to the lower depth is attributed to the continuous supply of litter, reduced rate of disturbance little erosion impact and lower temperature under the canopy of the closed forest that may reduce decomposition favoring an increase in residence time of soil organic matter (Erskine *et al*., 2002).

In this study, at its maturity age (40 years old), *C. lusitanica* was found to store significantly higher amount of C than E. *globulus* of equal age (Setema district OFWE Office, 2018) and slightly higher than a natural forest in top 40 cm soil layer. The study showed that converting of natural with *C. lusitanica* and *E. globulus plantations* net accumulation of SOC depends on plantation species. At 0-40 cm soil depth C. *lusitanica* and *E. globulus* plantations had 25.75 % higher and 6.76 % lower SOC storage respectively compared to adjacent natural forest.

Accordingly, SOC under plantations was higher (10.05 t/ha) 9.5% in the top 0- 40cm soil depth. Might be because of plantations were established on previously natural forest not loosed soil organic carbon, and might be restored in 40 years, even if it was loosed.

According to Wainkwa Chia *et al* (2017) study conducted at Wondo Genet, Southern Ethiopia, restoration of SOC to the level of original natural forest through afforestation in agricultural lands may be a rather complicated matter and degree of restoration of SOC following afforestation may depend on the integration of various factors including: vegetation type of afforestation (e.g., composition and diversity), climate factors, soil properties (e.g., soil type and pH), time after conversion, and the degree of soil C loss due to cultivation before afforestation

According to Anatoli (2012) a total SOC increased by 25 % under *C. lusitanica* and 20 % under *Eucalyptus* within a decade. This is also in agreement with Abate (2004) who reported greater amounts of SOC under *C. lusitanica* compared to natural forest and *E. globulus*. In the study conducted at Wondo Genet College of Forestry and Natural Resources, Southern Ethiopia, depending on species type, SOC can restore or even increase above the original level through plantation and it may be attributed to a greater input of organic matter including SOC than a loss of organic matter in plantation (input>loss of organic matter) (Wainkwa Chia *et al*., 2017). The SOC content of any land use was governed by the level of biomass, species diversity, quantity of litter fall and management condition (Mulugeta *et al*., 2005).

The higher amount of SOC stored under C. *lusitanica* can be explained by the larger amount of litter biomass of C. *lusitanica* than *Eucalyptus*. What possibly could have made the difference in SOC between *C.lusitanica* and *Eucalyptus* was the larger quantity of branches and coarse root litter produced under *Cupressus* plantations (Abate, 2004; Lemma *et al*., 2007). The lower amount of litter produced under *Eucalyptus* plantations in combination with the slow decomposition rate resulted in a lower amount of SOC. The *E. globulus* site in this study is located close to the village which probably results in an intensive collection of litter for fuelwood purposes.

Generally, converting natural forest to *E.globulus* and *C. lusitanica* plantations was loosed 27.82% (102.97 t/ha) and 30.12% (111.46 t/ha) carbon stock of the ecosystem in the study area respectively. This finding has shown that forest land conversion to exotic species plantations would actually lose total C, but it was depending on species types. The carbon stock in the natural forest was found to be significantly higher than the carbon stock in the plantation forests. It is demonstrated that ecosystem C pools, including those in above- and belowground biomass, were lower in plantations than in natural forests but, soil carbon was lower in natural forest. Ecosystem C pools discussed above were statistically different between plantations and natural forests, such differences were affected by various factors. High variabilities were observed between the two different groups in relation to these factors in this study, indicating that watchfulness is needed in predicting the differences on the basis of mean effects. Many of these factors are well known to affect ecosystem C pools (Guo and Gifford, 2002) For example, stand age of plantations and site preparation for plantation establishment might have an impact on the accumulation of aboveground biomass and litter and then affect ecosystem C sequestration. Additionally, improper silvicultural activities in plantations might have accelerated ecosystem C loss in plantations (Berthrong *et al*., 2009) Site preparation with burnt treatment, for example, increased soil C loss, compared with unburnt one. To avoid ecosystem degradation associated with plantations, restoration measures need to be implemented to persuade ecosystems toward their natural potentials.

6. CONCLUSIONS AND RECOMMENDATION

6.1. Conclusions

The results of this finding indicated that conversion of natural forest to plantation mainly affects the carbon stocks either in their biomass or soil organic matter. This study showed that natural forest cleared for exotic species plantation areas lose high organic carbon in biomass and it was not significant soil organic carbon within more than 40 years old *E. globulus* plantations. The natural forest of the Setema generally had higher biomass C densities than plantations of exotic species.

The average aboveground C in the tree plantations were more in *Eucalyptus* plantation (133.7 t/ha) and SOC was higher in *C. lusitanica* (132.96 t/ha) than natural forest and *E. globulus.* Generally, natural forest has better carbon stock than plantation; because the natural forest has higher biomass carbon.

The plantation of *C. lusitanica* was more suitable to sequester SOC than E. *globulus* plantation and natural forest. However, *Eucalyptus* plantations also had positive effects on SOC (0-20cm) which is higher than SOC under natural forest, but statistically non-significant. It was concluded that Setema natural forests sequestered more C trough biomass than plantations and C. *lusitanica* plantation sequestered more soil C than E. *globulus* plantations and natural forest. In general, replacing natural forest with exotic plantation attributed to the loose of 28.16% (104.215 t/ha) C from the ecosystem. So it’s better to conserve natural forest instead of replacing by plantation from the perspective of maintaining carbon stocks.

6.2. Recommendation

- Replacing natural forest with plantation has a significant effect in reducing carbon sequestrations, particularly when they remove long-lived natural forest that stores more carbon than exotic species plantation.

- It is important to note the growth of planted forests is increasing in the future, thus plantations should not be used to replace natural forests. There is a need for taking into account the contribution of species in total carbon sinks. These demands for more awareness of different potentials each tree species has in carbon sequestration.
- The species difference in influencing on soils carbon stocks of natural forest was apparently strong.
- Therefore, species selection is imperative when establishing tree plantations with the aim of restoration of degraded soils and biomass carbon. It suggests that SOC can be sequestered, restored or maintained through the plantation and through careful selection of species such as *C. lusitanica* for plantation establishment as the increases in SOC seen, when compared to that of the reference natural forest.
- Conservation of the natural forest will have an imperative implication to the total C density and ensuring its viability.

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