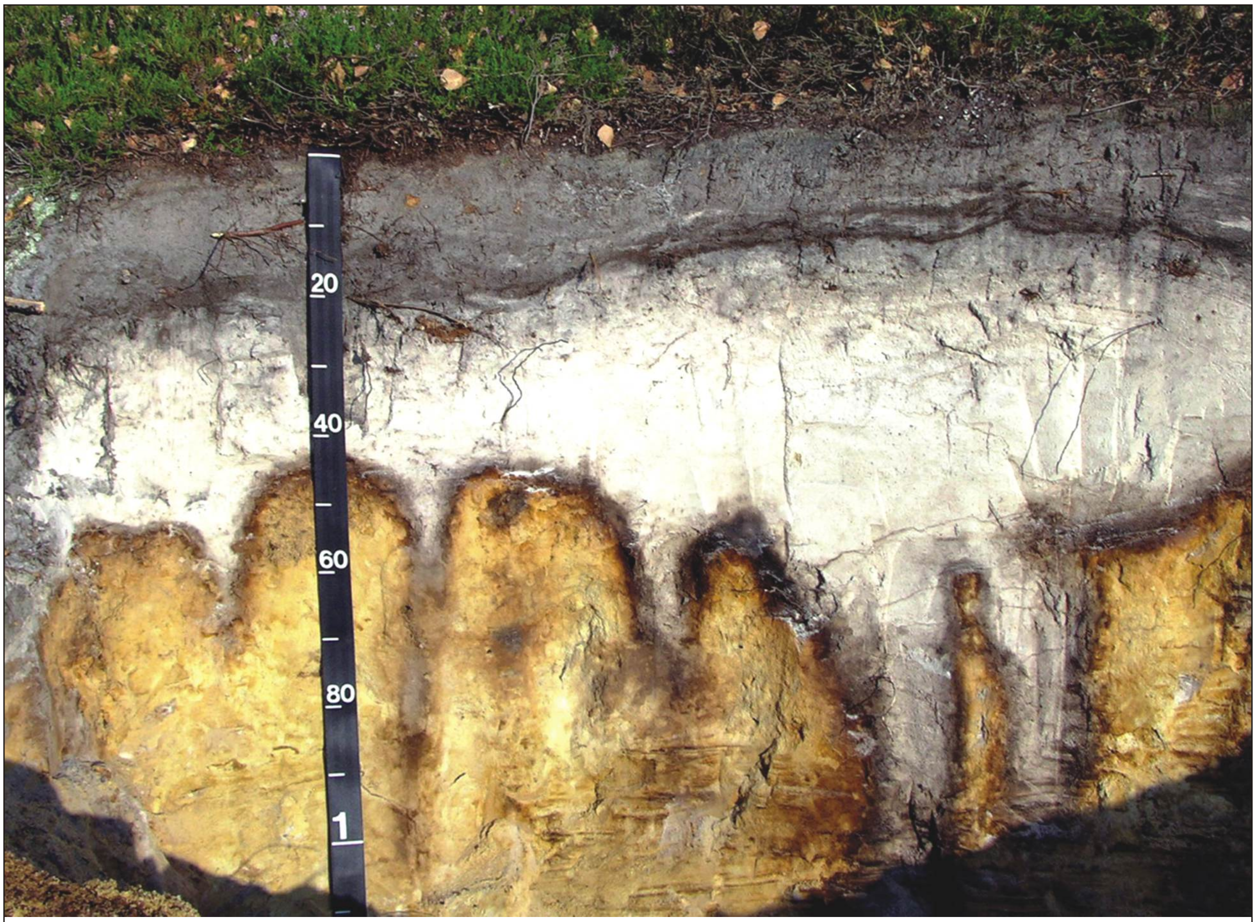

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Research Article

Biomass and Soil Organic Carbon Stocks of Woody Species at Ades Dry Afromontane Forest, South-Eastern Ethiopia

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Abstract

Background and Objectives: There is lack of information on biomass and soil carbon stocks in dry Afromontanes forests of Ethiopia. This study was therefore aimed to determine the biomass and soil carbon stocks of woody species in Ades dry afromontane forest of south-eastern Ethiopia. **Materials and Methods:** Three different forest types (Indigenous forest plantations of *Cuprecess lusitanica* and *Eucalyptus globules*) have been investigated for biomass and soil sampling. The sampling plot design was based on a US Forest Service model for the indigenous forests. In each plot, all woody species $\geq$5 cm Diameter at Breast Height (DBH) were sampled for biomass carbon stock and Soils were sampled at two depths (0-15 and 15-30 cm). **Results:** Total biomass C densities were generally higher for the indigenous forest and lower for the exotic plantations. The mean above ground carbon stock of the study area for the three forest types was 317.55 MgC ha^{-1} with average CO_2 sequestration potential of 1165.41 Mg CO_2 ha^{-1} and the mean value for below ground carbon stock was 86.2 MgC ha^{-1} with the average CO_2 sequestration potential of 316.35 Mg CO_2 ha^{-1}. **Conclusion:** The study concluded that among the three different forest types studied, the indigenous forest is highly valued for its biomass and carbon stock potential. There was positive relation between the SOC and depth of the soil in all forest types.

Key words: Biomass, carbon stocks, Ades, indigenous forest, soil carbon, dry afromontane forest, Southeasten Ethiopia, woody species

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The continuous deforestation and degradation of forest ecosystems in the tropics is of major concern due to the negative impacts this has on many of the ecosystem services that the forest provides[1]. Likewise, it is observable phenomena that the forest cover in Ethiopia is declining from time to time as a result of deforestation, in spite of the disagreement on the original forest cover of the country[2].

This phenomenon is making the Ethiopian Afromontane forest fragments to be continuously shrinking[3] which were ones known to be dense and intact forests in the country[4]. Studies from pollen analysis provide evidence of decline in forests in response to human impact[5,6]. Historical evidences from vegetation maps in the country also shows the increase in magnitude of deforestation from time to time[7]. The continued total deforestation of some areas is causing significant damage preventing the forest from achieving its natural climax state[8].

Against this, the Ades dry Afromontane forest, which is characterized by a variety of tree species have gained its cover during the last 10 years due to the concern from the Regional Government of Oromia. The forest comprised both indigenous and exotic species[9,10]. The protection of the Ades forests results in increasing plant species composition and the floristic diversity. Increase in plant species composition and diversity of the forest increase the capacity of the forests to effectively militate against climate change and again mitigates the biomass and carbon estimates of the woody species in the forests[11].

In Ethiopia, studies on biomass and soil carbon stock are inadequate and this is, especially, true for the dry Afromontane forests of south-eastern Ethiopia in general and Ades forest in particular. Above all, such studies have been very important issues for ecological explanations and for effective conservation design. Furthermore, the studies can provide information needed for carbon marketing and the value of forests in carbon sequestration. Given this lack of information, studies that provide woody species biomass and soil carbon stocks in the Ades dry Afromontane forest have become one of the most important issues. This study was therefore aimed to determine the biomass and soil carbon stocks of woody species of the indigenous and exotic species in Ades dry afromontane forest, south-eastern Ethiopia.

MATERIALS AND METHODS

Location of the study area: The study was carried out in Ades dry afromontane forest about 407 km south-east of Addis Ababa, from May 2018 to April 2019. It is located between 1029419 m E-1030017 m E and 746685 m N-746986 m N (Fig. 1). The altitudinal gradients of study area ranges from

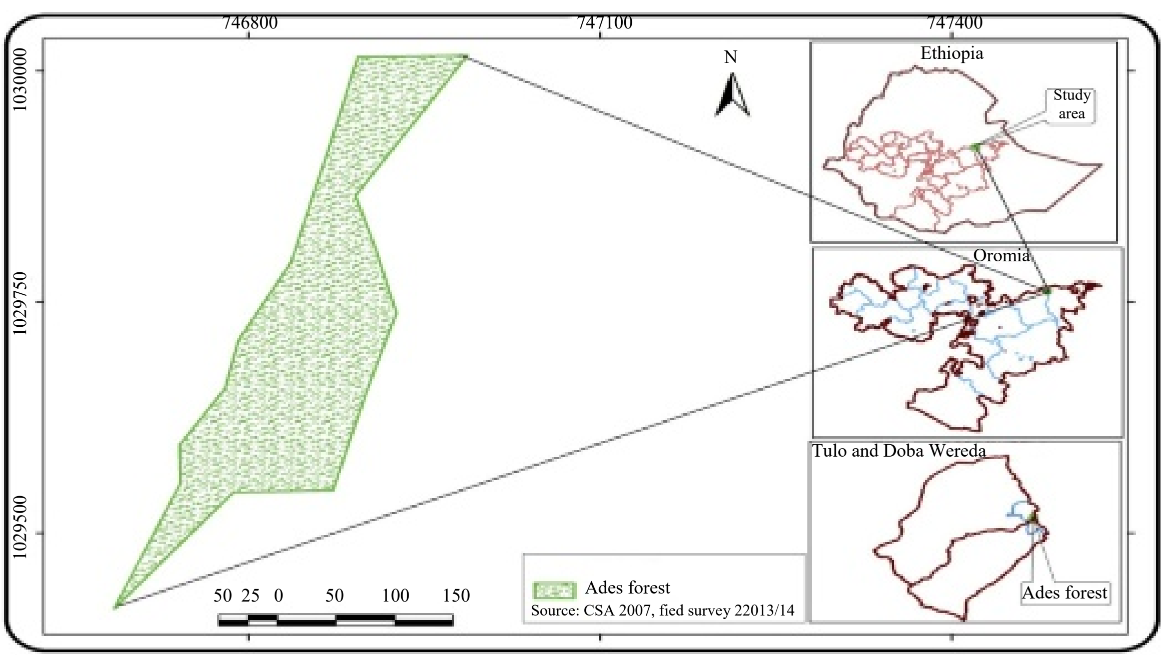

Fig. 1: Map of the study area
Source: CSA[12], field survey 22013/14

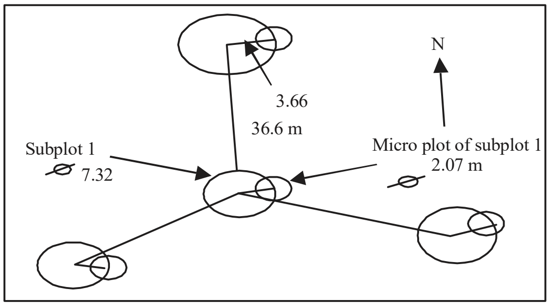

Fig. 2: Layout of plots and sub-plots

2517-2743 m above sea level. The forest coverage of the study site is 618 ha and it contains various species of plants and animals.

Methods of data collection

Plot layout and sampling: The Forest Inventory and Analysis Programme (FIA) developed by USDA[13] had been applied for the collection of biomass and soil organic carbon stocks. Circular plots of 0.017 ha were arranged in groups of four in which the central plot was surrounded by three plots forming an equilateral triangle at a distance of 36.6 m out from the central plot (Fig. 2).

A random selection of groups of plots was made and pair of plots was again selected randomly from each group of plots and established for each forest types. The allocation of the total number of plots varies depending on the area of each forest type.

Vegetation measurement: Sampling of the woody vegetation and soils were made from each of the plots selected at random. All woody plants with diameter at breast height (dbh) >5 cm were identified and recorded. The indigenous species were identified using a guide book Flora of Ethiopia and Eritrea, with the assistance of a local Para-taxonomist. For those species difficult to identify in the field, fresh specimens were collected and then pressed properly for identification at the National Herbarium of Addis Ababa University.

Soil sampling: Soil sampling was accomplished by using two soil augers of lengths of 15 and 30 cm, for taking disturbed soil samples at two layers 0-15 and 15-30 cm. The sampled soils were placed separately in each plot and layer in polythene bags which were then tied with cotton strings and taken to the laboratory. Undisturbed soil samples for bulk density analyses were taken using a cylindrical metallic core ring with 5 cm height and 2.5 cm radius. The core ring was driven into the soil surface using a hand sledge and a block of wood. It was then removed by carefully lifting after removal of excess soil around the edges using a flat-bladed knife. The soil samples were pretreated by oven drying at 105°C for 24 h, then crushed and sieved through a 2 mm sieve.

Data analyses

Soil analyses: The soil samples were analyzed for organic carbon content using a Walkley and Black method[14] at the Haramaya University Soil laboratory.

Biomass carbon stocks and density analysis: The estimation of Above Ground Biomass (AGB) was done using an allometric function that integrates the DBH and wood density of each species[15]. Above ground biomass have been shown to be better predicted through the use of diameter[15,16]. In this study, the allometric function developed for the above ground biomass of dry forests[15] has been used estimate the Above Ground Biomass (AGB):

$$AGB = WD*\exp(-0.667+1.784*\log(DBH) + 0.207*(\log(DBH)^2 - 0.0281*(\log(DBH))^3 \quad (1)$$

where, WD is global wood density, DBH is diameter at breast height, ln is natural logarithm.

The specific wood densities of the different species in the study site were taken from Wood density tables and Global wood density database[17,18]. In some cases, when the wood density values for some indigenous species were not found in the two tables a value of 0.5 recommended for tropical areas was used[15]. For those trees of cypress species their wood densities were adapted from FAO[19]. A shoot: root ratio approach has been applied for the estimation of Below Ground Biomass (BGB)[20]. In this case, a ratio of 0.25, 0.24 and 0.33 were used for indigenous trees[21], Conifers[22] and Eucalyptus[15] respectively. The root biomass will be then converted in to root carbon stock by taking 50% of the root biomass. The Carbon (C) content of each tree in the plots was calculated as the product of the dry weight biomass and an assumed C content of 50%[23] and The tree carbon contents were then summed and divided by the area of the plot to give above ground and below ground C density values for each plot expressed in Mg C ha^{-1} ignoring the analysis of carbon stocks in deadwood and litter[15].

Soil Organic Carbon (SOC) density: The Carbon stock of the soil was done using the volume and bulk density of the soil[24] as:

$$V = h \times \Pi r^2 \quad (2)$$

where, V is the volume of the soil in the core sampler (cm^3), h is the height of the core sampler (cm) and r is the radius of the core sampler (cm)[24]:

$$\text{Bulk density (BD)} = \frac{W_{av.dry}}{V} \quad (3)$$

where, BD is the bulk density of the soil sample per, $W_{av,\,dry}$ is average air dry weight of soil per the quadrant and V is the volume soil in the soil sampler auger (m^3):

$$SOC = Bd \times D \times C\ (\%) \quad (4)$$

where, SOC is the soil organic carbon per unit area ($t\ ha^{-1}$), BD is the soil bulk density ($g\ cm^{-3}$), D is the total depth at which the soil was taken (30 cm) and C (%) is the carbon concentration (%). Descriptive statistics were calculated for mean biomass and soil organic carbon densities by forest types. Differences between carbon densities in biomass and soil for each forest type was tested by a two-way ANOVA and Tukey's multiple comparison using SPSS version 16[25].

Estimation of total carbon stock density and its carbon sequestration potential: The total carbon stock density was calculated by summing all the carbon pool stock densities[15] using the following Eq:

$$CT = AGC + BGC + SOC \quad (5)$$

where, CT is the total carbon stock for all pools ($mg\ ha^{-1}$).

The total carbon stock was converted to Mg of CO_2- equivalent (CO_2-e), multiplying it by 44/12, or 3.67 which is the ratio of molecular weights between carbon dioxide and carbon[26].

RESULTS AND DISCUSSION

Above ground and below ground biomass carbon densities: A greater amount of carbon stock has been observed in a species which has counted long lived in the study site and also species which are densely populated in the pool. As a result the current study of the site indicates unbalanced tendency of carbon stock input in the above ground. The high biomass rate has been held by species such as *Podocarpus falcatus*, *Juniperus procera*, *Croton machrostachys* and *Hagenia abyssinica*, on the other hand species such as *Rytigynia neglecta*, *Rhamnus prenoids*, *Rhus glutinosa* and *Phytolacca dedocandra* had less contribution. There was a significant difference among the mean biomass carbon stocks among the forest types (Table 1). The above ground carbon stock's potential of the forest ranged from 63.11-5507.73 MgC ha^{-1} with the overall mean above ground carbon stock of 317.55 MgC ha^{-1} for the three forest types was (Table 1).

A two-way analysis of variance revealed significant differences in biomass carbon (C) densities between the three forest types. A significantly higher biomass carbon stock were recorded in the in indigenous forest than the plantation forests.

The minimum (63.11 MgC ha^{-1}) and maximum (5507.73 MgC ha^{-1}) AGBC from this forest have carbon dioxide (CO_2) sequestration potential of 231.61 and 20,213.4 Mg CO_2 ha^{-1}, respectively. The overall mean AGBC (317 MgC ha^{-1}) of the study area sequestered the amount of carbon dioxide equivalent to 1163.39 Mg CO_2 ha^{-1}. There was variation in terms of AGBC among species of different types in which *Podocarpus falcatus*, an indigenous species which was dominant in the forest had the highest value of carbon stock of 604 MgC ha^{-1} (Table 2) and this can have the potential to sequester the amount of CO_2 equivalent to 2216.68 Mg CO_2 ha^{-1} followed by *Juniperus procera* 403 Mg C ha^{-1} which has potential to sequester CO_2 equivalent to 1479 Mg CO_2 ha^{-1}, *Croton macrostachys* with 169.16 Mg C ha^{-1} equivalent to CO_2 sequestration value of 620.8 Mg CO_2 ha^{-1} and *Hagenia abyssinica* with 143 Mg C ha^{-1} equivalent to sequester 525 Mg CO_2 ha^{-1} while the species of *Rytigynia neglecta* had the lowest mean carbon density of 1.61 Mg C ha^{-1} equivalent to sequester 5.91 Mg CO_2 ha^{-1} (Table 2).

It has been reported in some studies, that the carbon stock potential of the forest in given environment can be affected by several factors such as: type of species, age and density of the forest vegetation[27]. The occurrence species that

Table 1: Mean±standard deviation) carbon stocks (MgC ha^{-1}) in tree biomass of the three forest types at Ades dry afromontane forest, south-eastern Ethiopia

Stock	Indigenous (n = 16)	*C. lusitanica* (n = 11)	Eucalyptus (n = 11)	Min-Max	Overall mean
AGBC	548 ± 153^{a}	166.00 ± 72.40^{b}	238.07 ± 131.7^{c}	63.11-5507.73	317.00 ± 75^{aa}
BGBC	137 ± 67^{a}	39.84 ± 17.6^{b}	78.56 ± 28.3^{c}	12.62-1-101.55	86.20 ± 34^{bb}
Total biomass carbon	685±220	206.00±90	316.63±160.07	73.73-6,609.28	402.54 ± 104^{abc}

AGBC: Aboveground biomass carbon, BGBC: Belowground biomass carbon, NB: Means with different letters are significantly different (Tukey's test, p<0.05)

Table 2: Above-ground carbon (Mg ha^{-1}) density of different species at Ades dry afromontane montane forest, south-eastern Ethiopia

Species	AG B carbon	BGB carbon	Species	AG B carbon	BGB carbon
Aningeria altissima	45.91	11.48	*Lepidotrichilia volkensis*	23.68	5.92
Apodytes dimidiata	12.97	3.24	*Macaranga kilimandscharica*	18.14	4.53
Balanytus aegyptica	6.81	1.70	*Maesa lanceolata*	30.34	7.58
Bersama abyssinica	37.45	9.36	*Maytenus obtusifolia*	20.58	5.15
Brucea antidysenterica	5.96	1.49	*Maytenus obscura*	26.58	6.65
Calpunia subdecandra	7.47	1.87	*Myrsine africana*	23.94	5.98
Carrisa edulis	10.28	2.57	*Ocimum lamifolium*	13.21	3.30
Cuprecess lusitanica	10.90	2.72	*Ocotea kenyensis*	15.27	3.82
Calpurina aura	13.70	3.43	*Olea europaea*	83.65	20.91
Celtis africana	52.11	13.03	*Olea capensis*	42.47	10.62
Chata edulis	15.85	3.96	*Olinia rochetiana*	13.70	3.43
Clerodendron myricoides	16.64	4.16	*Phytolacca dedocandra*	2.49	0.62
Croton macrostachys	169.16	42.29	*Pittosporum abyssinicum*	12.81	3.20
Cordia africana	81.15	20.29	*Podocarpus falcatus*	604.0	150.90
Discopodium penninervium	35.92	8.98	*Polyscias fulva*	9.23	2.31
Dodonaea angustifolia	12.23	3.06	*Prunus africana*	42.09	10.52
Dombeya torrida	43.81	10.95	*Premna schimperi*	18.67	4.67
Dovyalis caffra	19.85	4.96	*Rapanea simensis*	3.49	0.87
Dovyalis abyssinica	10.93	2.73	*Rhamnus prenoids*	2.01	0.50
Dovyalis vericosa	8.32	2.08	*Rhus glutinosa*	2.41	0.60
Erythrina brucei	37.15	9.29	*Rosa abyssinica*	4.47	1.12
Ehretia cymosa	40.55	10.14	*Rosmarinus offinalis*	7.27	1.82
Ekebergia capensis	61.58	15.40	*Rubus apetalus*	4.15	1.04
Embelia schimpri	61.04	15.26	*Rubus studneri*	9.98	2.49
Ficus sur	135.56	33.89	*Rumex abyssinicus*	2.94	0.73
Gardenia lutea	16.96	4.24	*Rumex nurvosus*	15.09	3.77
Gravelea robusta	9.62	2.41	*Rytigynia neglecta*	1.61	0.40
Hagenia abyssinica	142.88	35.72	*Schfflera abyssinica*	20.15	5.04
Hypercum revolutum	10.28	2.57	*Sizygeem guineense*	6.53	1.63
Ilex mitis	27.01	6.75	*Vernonia amygdalina*	5.40	1.35
Jasminum abyssinicum	7.83	1.96	*Vernonia auriculifera*	28.76	7.19
Juniperus procera	403.06	115.76	*Vernonia leopoldii*	8.22	2.06

AGB: Aboveground biomass, BGB: Belowground biomass

are characterized by their large number of individuals could have an effect on AGB carbon stock[28]. This has been observed in the Ades dry afromontane forest where some tree species like *Podocarpus falcatus* and *Juniperus procera* with larger number of individuals in addition to their bigger DBH were dominant in the area.

The mean above ground carbon estimates in Ades forest of 317$\pm$75 Mg C ha^{-1} was higher than the above ground carbon densities ranging between 30-46 Mg C ha^{-1} reported from other dry forests[28]. The values obtained in the Ades dry afromontane forest are an indication of good conservation and management of the forests with resultant gain in carbon stocks. The values of the above ground carbon density in this study are in line with some other results reported from elsewhere[29-31]. But this value is lower than the mean above ground carbon density of 517 Mg C ha^{-1} reported from Tanzania that ranged between 252 and 581 tC ha^{-1} [31]. This may be due to differences in geographical variations and the types of the species together with varying degree of exposure to human degradation. It had been reported by various studies that different ecosystems have different biomass and carbon stock densities[32].

The biomass of below ground helps to determine the carbon stock of the study area. The minimum and maximum BGC stock's potential of Ades forest was 12.62 Mg ha^{-1} and 1,101.55, respectively (Table 1). The mean value of BGC stock was 86.2 Mg ha^{-1}. The average carbon dioxide sequestration potential of BGBC was found to be about 316.35 Mg CO_2 ha^{-1}. The total biomass carbon of the three forest types in this study ranged from a minimum of 73.73 Mg ha^{-1} to a maximum of 6,609.28 Mg ha^{-1} with the overall mean total biomass carbon of 402.54 MgC ha^{-1} that can sequester the amount of carbondioxide equivalent to 1,477.32 Mg CO_2 ha^{-1}.

Carbon stock in soil (SOC): The bulk density of the soil profile found in the study site ranged from a minimum of 0.61 g cm^{-3} to maximum of 1.42 g cm^{-3} with the average value of 0.83 g cm^{-3}. The soil organic carbon stocks also showed a

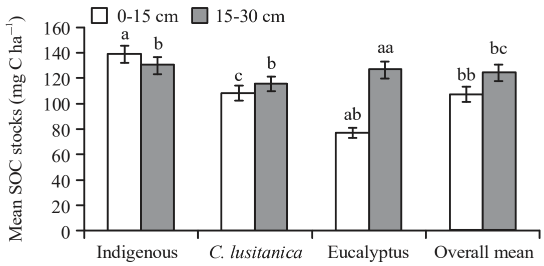

Fig. 3: Mean SOC stocks (Mg C ha^{-1}) of the three forest types (0-15 and 15-30 cm) at Ades dry afromontane forest South-eastern Ethiopia

NB: Means with different letters are significantly different (Tukey's test, $p<0.05$)

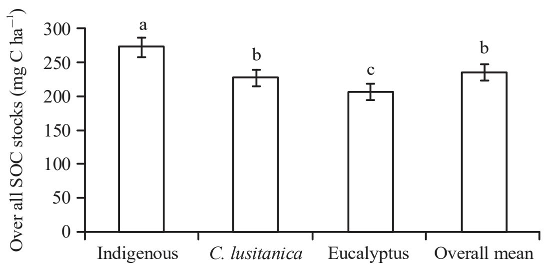

Fig. 4: Over all SOC stocks (Mg C ha^{-1}) of the three forest types (0-30 cm) at Ades dry afromontane forest, South-eastern Ethiopia

NB: Means with different letters are significantly different (Tukey's test, $p<0.05$)

similar trend in which the indigenous forest had significantly higher SOC stocks than the exotic plantations of *C. lusitanica* and Eucalyptus (Fig. 3).

The mean SOC density in the different forest types ranged from 77.52-140.02 Mg C ha^{-1} in the 0-15 cm layer, from 116.57-130.91 Mg C ha^{-1} in the 15-30 cm layer (Fig. 3) and from 205.22-270.93 Mg C ha^{-1} in the total 0-30 cm layer (Fig. 4). In the case of the 0-15 cm layer, the mean SOC density in the indigenous forest was significantly higher than that of the *C. lusitanica* and Eucalyptus forests. The overall SOC was found to be 234 Mg ha^{-1} that sequestered 858.78 MgCO$_2$ ha^{-1}.

A two-way analysis of variance revealed significant differences in Soil Organic Carbon (SOC) densities between the three forests types ($p<0.05$). The *C. lusitanica* plantations had higher soil carbon stocks than eucalyptus unlike the biomass carbon stocks which showed higher values in eucalyptus.

The mean soil carbon densities estimates of 234 Mg C ha^{-1} in all three soil depths in this study were higher than some other values for soils in South African savannas[32] and Mexican dry forests[33]. It is also higher than mean soil carbon densities of 6-18 MgC ha^{-1} reported for agricultural soils in Bukoba district[34]. The value of the SOC from Ades dry forest is in line with soil carbon pools reported from Eastern Arc Afromontane forests that have been observed to be slightly lower than the above ground biomass carbon pools[31].

However, the C storage in the soil component in this study is lower than the above ground biomass carbon which is contradictory to the findings reported from Tanzania[31] indicating the being there of higher C pools in the soil than the above ground vegetation. The difference is likely to be due to the depth of the soil studied in two forest types. This study used a soil depth of 30 cm for soil analysis while the other studies used soil analysis down to 100 cm depth. There can be considerable amount of soil organic carbon down to up to 200 cm, even though it is usually concentrated in the top 30 cm. The minimum and maximum CO_2 sequestration potential of soil carbon in this study was 265.34 and 2005.66 Mg CO_2 ha^{-1}, respectively.

The total carbon stock of Ades forest was obtained by adding all carbon value of the three pools which revealed (above ground carbon, below ground carbon and soil organic carbon) for the entire sample plots of the study site. As a result of these, the total carbon stock of Ades forest ranged from the minimum value of 146.03 MgC ha^{-1} to the maximum 7155.78 MgC ha^{-1} with the overall mean carbon mass of 637.54 Mg ha^{-1}. The difference in Carbon storage between the three forest types can obviously be attributed to the difference in disturbance level, type of forests and its structure. Forests can alter soil carbon sequestration capacity, other soil characteristics. The results showed that the types of forests can impact soil carbon concentration and stock across soil depth and that the Carbon concentrations and stock under indigenous natural forest were higher than plantation forest. The study suggested that using indigenous tree species could have a positive impact on Carbon storage. The increase CO_2 in the atmosphere is becoming of global and local concern. The amount of CO_2 sequestered in the forests depends on forest type, forest status; dominant tree species and forest stand age[31]. This therefore requires mapping of carbon distribution in different cover types among others, as a means to establish baseline for Reduction of Emission from Deforestation and Forest Degradation(REDD+).

CONCLUSION

The greater variation in carbon densities by components in this study clearly show the potential to increase carbon storage within the forest areas by forest management and promoting protection of the Ades forest. It is suggestive that the on-going forest management has increased carbon stocks potential of the forest. There was significant difference among the mean biomass carbon stocks in the three forest types. There was positive relation between the SOC and depth of the soil in all forest types. It was again observed that indigenous forests were found to sequester more CO_2 than those of exotic plantations.

SIGNIFICANCE STATEMENT

The study provides insights into the role of forests in carbon stocks potential income generation from carbon trading that would assist in developing sustainable forest management towards building climate resilient livelihoods in forest areas. It also provides a reliable baseline carbon stocks and sequestration potential of forests. The information will assist managers, planners and policy makers in determining the REDD+ potential of these forests through its sustainable management.

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