Soil Carbon Stock and Soil Physico-Chemical Properties under *Acacia saligna* Plantation in Northern Ethiopia

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Abstract

Afforestation of degraded lands using both exotic and indigenous species is used to reduce land degradation and to reforest degraded areas. Acacia saligna is one of the common exotic plantation species planted in Ethiopia. This study analyzed the existing carbon stock and some soil physico-chemical properties of A. saligna plantation at two districts in Tigray, northern Ethiopia. Soil samples were collected from 204 samples at three soil depths from plantation site and adjacent grazing lands. Paired t-test was used to analyze data. Soil organic carbon (SOC) stock was higher at lower depth (40-60cm) than middle and upper depths at plantation sites while the second depth (20-40cm) was found higher SOC at grazing lands. Furthermore, in Mai-Brazio, soil properties except Total nitrogen(TN) and Available Phosphorus (Av,P), Cation Exchange Capacity (CEC), Available Potassium (Av,K) and soil pH were significantly (P<0.05) higher than adjacent grazing lands While CEC and Av.K were non-significant in Barka-Adisbha site (p>0.05). Area converted to plantation site showed lower soil bulk density than the open grazing land. Further, CEC is negatively correlated (P < 0.001) with soil pH, this may shows that CEC is affected by the variation of soil pH.

Key words; *SOC, Soil physico-chemical property, A.saligna, bulk density, TN, Climate change*

Introduction

The northern Ethiopian highlands are suffering from the cumulative effect of land degradation, deforestation and the inevitable consequences of soil erosion, making agricultural productivity to decline (Descheemaeker *et al*., 2005; Edward et al., 2010; Girmay *et al.*, 2007). Besides, Tigray region is the most degraded part of the country (Girmay *et al.*, 2007). This in turn causes low agricultural production challenging smallholder farmers and making environmental degradation to its irreversible consequence while the plantation of fast growing exotic species such as Acacia species make rehabilitations of degraded lands promising (Birhane *et al*., 2002; Descheemaeker*et al*., 2005).

Land rehabilitation is the process of Afforestation and reforestation of degraded lands using indigenous and exotic species and have been practiced in Ethiopia (Birhane *et al*., 2002). Indigenous forest species with poor performance are being replaced by fast growing exotic species such as *Acacia saligna* and Eucalyptus in Tigray region northern Ethiopia (Girmay *et al.*, 2007; Descheemaeker*et al*., 2005). Tree play substantial role in reducing atmospheric concentration of CO_2 by storing carbon in above and belowground biomass and in soil. (Global Invasive Species Database, 2015; PCC, 2003 and IPCC, 2006; Mekuria etal., 2018, Getnet et al., 2019; Gebregerges et al., 2017; Geberegrgs et al., 2018; Kass et al., 2017). According to the study by (Birhane, 2002; Birhane et al., 2017; Geberegerges et al., 2017; Geberegergs et al; 2018; Getnet et al., 2019; Mekuria et al., 2018) the exclusions of open grazing lands results in to rejuvenations of lost species, soil fertility enhancement and erosion control.

Acacia saligna is a species with a wide diversity of plant forms and functions and grows in a wide geographical range and serves as livestock feed in dry land part of the region (Getachew, 2005 and John *et al*., 2002). *Acacia saligna* has a long history of multipurpose use in Australia and some countries of the world such as Cyprus, Eritrea, Ethiopia, Greece, Iran, Iraq, Israel, Jordan, Libyan Arab Jamahiriya, Mauritius, Mexico, Namibia, South Africa, Syrian Arab Republic, Tanzania, Tunisia and Uruguay (Reid and Murphy, 2008).

A.saligna has been used for mine site rehabilitation, re-vegetation, in agro-forestry, as a tree for climate change mitigation through carbon sequestration, amenity plantings and as a fodder plant for livestock (Lal, 2004). It is identified as one of three priority multipurpose species with more than 300 000 ha plantation globally in arid and semi-arid zones (Midgley& Turnbull, 2003). There is globally growing concern and recommendations of research findings that shows that soil carbon sequestration plays a vital role to manage global climate change (IPCC, 2003; FAO and ITPS, 2015). This carbon pool exists between five interconnected pools, which includes oceanic pool, geological pool, soil, terrestrial biomass pool, and atmospheric pool. Soils better serve as carbon sink instead of releasing it into the atmosphere, (Center for International Climate and Environmental Research Organization, 1997, Mekuria et al., 2018; Kassa et al., 2017, Getnet et al., 2019; Geberegeres et al., 2017; Geberegergs et al., 2018).

On the other hand, due to its interaction with the earth's climate system carbon storage is considered as one of the critical soils ecosystem function that has gained increasing attention in recent years (FAO and ITPS, 2015). Soil stores much larger amount of carbon than the amount stored by combination of both atmospheric and terrestrial vegetation (IPCC, 2003; FAO and ITPS, 2015). Accordingly, soil organic matter (SOM) contains 55-60% C by mass (FAO and ITPS, 2015). According to FAO and ITPS, (2015), the top soil with a depth of up to 30cm is with the highest carbon concentration than lower depths. Soil organic carbon and soil nitrogen (N) are considered as the most important components of soil fertility and affects productivity and climate change (FAO, 2003; FAO and ITPS, 2015; FAO, 2006; IPCC, 2003; Mekuria et al., 2018; Getenet et a., 2019; Kassa et al., 2017). In the dry lands, land degradation caused by soil erosion and loss of vegetation cover is the major factor for loss of soil organic carbon (FAO and ITPS, 2015;UNEP, 2008; Girmay et al., 2008; Mekuria et al., 2018).

According to the study by Negash and Starr (2015), have found soil organic carbon in the range of 109 and 253 Mg ha^{-1} in soil of 0-60 cm in smallholding agro forestry practices in southern Ethiopia. In this practice, soil carbon stock was highest in the enset system (186 Mg ha^{-1}) followed by the lowest in the enset coffee system (178 Mg ha^{-1}).

Besides, the study conducted by Yimer *et al* (2007), in South-Eastern highlands of Ethiopia revealed that, despite of the non-variability in the SOC and TN between forest and grazing lands, the mean SOC and TN in soil depth of 0-20cm were significantly different in native forest and grazing lands, from crop lands of the same soil depth.

Little is known about the effects of *Acacia saligna* plantation on soil physico chemical property and soil organic carbon stock in the region. Hence, this paper is aimed at estimating existing soil carbon stock under *Acacia saligna* plantation, investigating effect of conversions of grazing lands into Acacia *saligna* plantation on some soil physical and chemical properties and examining the relationships between SOC, soil N and selected soil properties. Ensuring reliable, accurate and site specific data base information could strengthen global C trading of the country (Araya, 2016;Shimelse, 2014; Gebregerges et al., 2017; Solomon et al., 2017; Mekuria et al., 2018). This study focuses on three related question: (1) is there any significant variation in soil carbon stock of *Acacia saligna* plantations and the adjacent grazing land (2) Does the conversion of open grazing land into *A. saligna* plantation affect soil physico-chemical properties (3) Is there any significant variation in soil bulk density between Acacia *saligna* plantation and adjacent grazing land

Methodology

Study areas

Geographically, Tahtay Mychew and Atsbi-Wemberta districts lies between 13^0 52' and 14^0 19' N and 38^0 29' and $38^0$42' E and 13º 36" N and 39 º 36"E, respectively (Shumbahri, 2012; Meaza, 2010). The districts covers total area of 18,618 Km^2 and 1420.96 Km^2, respectively (OARD, 2018). Tahtay Mychew and Atsbi-wemberta districts are located in the altitudinal ranges of 1473 m.a.s.l.to 2493 m.a.s.l. and 988 m.a.s.l. to 3063 m.a.s.l. , respectively (OoARD, 2018). The specific study areas , Mai-Brazio and BarkaAdisbha (Figure 1), are geographically situated between 44º 47' 25" -46º 60' 74" E and 15º 35' 97" to 15º 77 09" N, and 39° 39'30" to 39°45'30"E and 13° 45' 0"- 13° 51' 0" N.

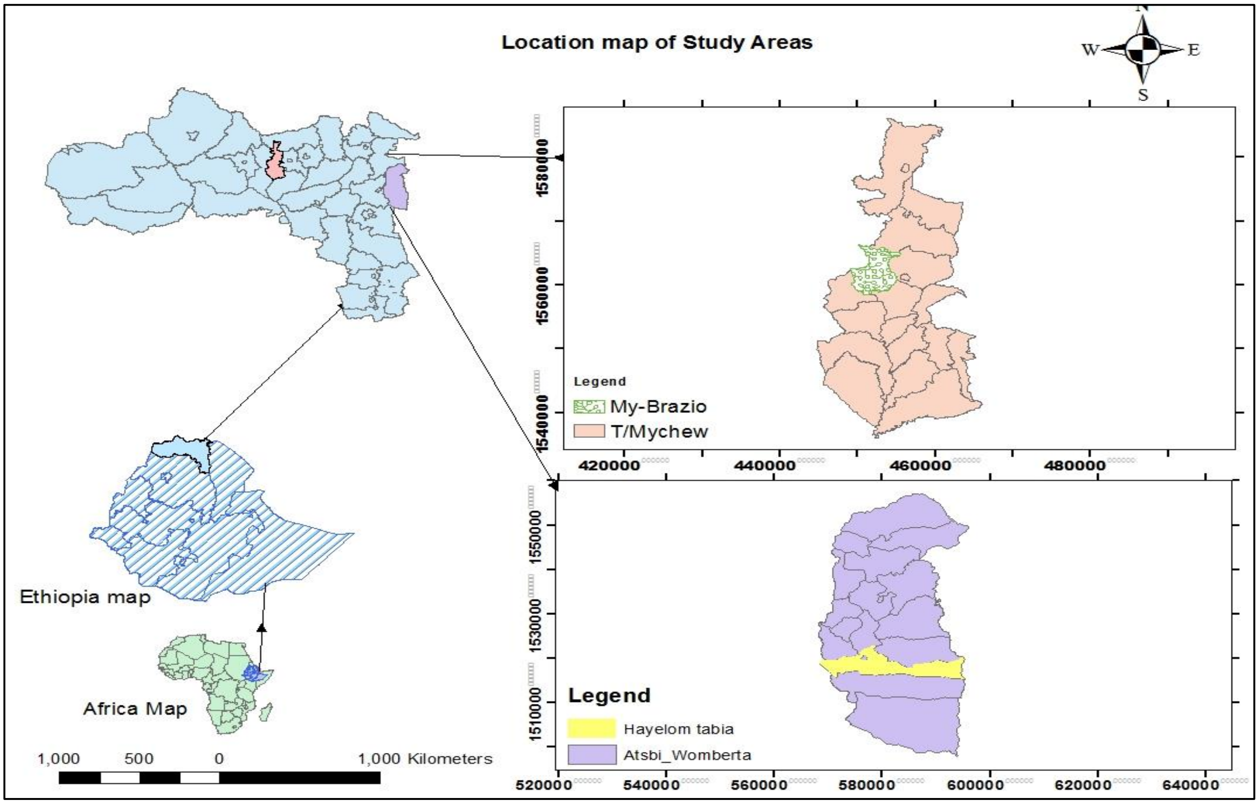

Figure 1 Location Map of the study areas

The two districts are characterized arid and semi-arid agro-ecological zone with erratic rail fall and rugged terrain (Taha *et al*., 2006). The mean annual rainfall of the districts ranges between 650-750mm and 332.2- 972.8mm per year with mean minimum and maximum air temperatures of 14^{0}c and 26^{o}c for Tahtay Mychew and 9.4^{0}cand 20.4^{0}c for Atsbi-womberta districts, respectively (TMSC, 2018). The district has 89,880 hectare (ha) of state forest, 96,861 ha of plantation site, 6946 ha of communal land and 13,059.45 ha cultivated land (OARD, 2018). The existing native tree species are *E.schempri, Olea.africana*, *Acacia abyssinica*, *Maytenus senegalensis*, *Dodonae aangustifolia*, *Milletia ferruginea* and *Rhusnat alensis* while in the Acacia *saligna* plantation, there are some native tree species which are grown with combination of the trees such as *Olea europea C.africana*, *Dodonae aangustifolia,* and *Acacia abyssinica.* The study area is dominated by plateau (OARD, 2018). The geological formation of the study area is characterized by sandstones, Paleozoic sedimentary rocks, Tillite, and recent alluvial sediments (Nata and Bheemalingeswara, 2010) and the dominant soil types are Leptosols, Regosols, Cambisols and Fluvisols (Gessesse, 2017). The total population of Tahtay Maichew and Atsbi-wemberta district is 116,824 and130, 575 (Shumbahri, 2012).

The total area coverage of T/Maychew district is 142,096 hectare of which 13,059.45 ha is cultivated land (11,301.45 ha is rain fed and 1758 ha is irrigated) (OoARD, 2018). The major annual crops grown in the district includes; wheat, barley, teff, maize and sorghum where as the dominant pulses are beans and field pea and also in irrigated lands different vegetables and fruits such as tomato, pepper, lettuce, onion, banana and *psidiumgaujava* are cultivated. (OoARD, 2018).

Table 1 characteristics of study areas

Site name	Characteristics					
	Farming system	Major soil type	Major crop type	Annual rainfall	Annual temp.	Dominant tree/shrub species
Tahtay Maichew	Mixed	Leptosols, Regosols	Zea maiz and erogrosis teff	650-750mm	14^0c and 26^oc	*Dodonae aangustifolia and E.schempri*
Atsbi-womberta	Mixed	Regosol and Fluvisols	Barley and Wheat	332.2-972.8mm	9.4^0cand 20.4^0c	*Dodonae aangustifolia and Acacia abyssinica*

Soil data collection

Soil sampling

Soil sample were collected from five soil pits per plot with the depth of 0-20cm, 20-40cm and 40-60cm using X pattern based on stratified sampling (Pearson *et al*., 2005; Negash and Starr, 2015) (four from each corners of the 20x20m plot and one from the center) and composited to form one representative soil sample . This was done for both plantation site and the open grazing lands. In addition, from the same quadrants, soil samples for bulk density computation were collected using 10cm length and 3.4cm diameter core sampler carefully driven into the soil to avoid compaction (Gebregergs et al., 2017; 2018; Negash and Starr 2015). Finally, 102 disturbed and 102 undisturbed soil sample were collected for both sites and land uses

Table 2 Sample sizes taken from both (Mai-Brazio and Barka-Adisbha) sites

Site name	Land uses	Plot size	No of plots	No of soil samples		
				Disturbed	Undisturbed	Total
Mai-Brazio	Plant.	20x20m	9	27	27	54
	G. land	20x200m	9	27	27	54
Barka-Adisbha	Plant.	20x20m	8	24	24	48
	G. land	20x20m	8	24	24	48

*: *plant. = Plantation site, G.land = Grazing lands*

From the three soil depths, the soil sample with approximate weight of 100g were submitted to Shire Soil Research Center (SSRC) and Mekelle University Geology Department soil laboratory for TN, SOC stock, av K, av P, Electrical conductivity (EC), CEC and soil pH between sampled plantation site and open grazing lands.

Sample tray was used to mix the disturbed soil samples to form one composite soil sample. Soil from each depth was air-dried, and sieved through a 2-mm sieve, and ground before analysis (Gebregerges *et al.*, 2017 and Shimelse *et al.*, 2018; Mekuria et al., 2018; Geberegergs et al., 2018).

Determinations of soil bulk density

One soil core sample were collected from each soil depth of central plot of each landscape positions separately (Mekuria and Aynekulu, (2011). One hundred and two soil samples (54 from Mai-Brazio and 48 from Barka-Adisbha) sites were collected. The soil core samples were oven dried at 105^{0}c to constant weight (Labata *et al*., 2012). The formula for the calculation were (Walker et al., 2012)

$$BD = \frac{DM}{\text{Vol core} - \left(\frac{Mcoarse\ frag}{Dens\ rock\ frag}\right)} \qquad 1$$

Where, BD = bulk density (g/cm^3) M. coarse frag = mass of coarse fragments (g)

DM = dry mass (g/cm^3) Dens rock frag. = density of rock fragments (g/cm^3)

Vol. core = mineral soil core volume (cm^3)

Data analysis

Estimation of existing soil carbon stock

According to the recommendation by Pearson *et al*. (2005), carbon stock density of SOC was computed using the formula (Pearson et al., 2005)

$$V = h\pi r^2 \qquad 2$$

Where, V = volume of the soil in core sampler, h = height of the core sampler

Table 3 Method and equations of soil analysis

Soil sample analysis	Methods	References
Soil organic carbon	Wet oxidation method	Walkley and Black (1934)
Soil nitrogen	Kjeldhal method	Jackson (1958)
EC	1:2.5 soil to water suspension	
CEC	Ammonium acetate	Thomas (1982)
Av.P	Olsen method	Olsen *et al.*, (1982)
Av.K	flame photometer	-
Soil pH	1:2.5 soil water suspension	-
Bulk density	Core method	Blake and hartge (1986)
Statistical analysis		
Comparison	Variables	Statistical test

Plantation site and grazing land	Paired t-test

Statistical Analysis

Data was checked for normality, and some soil parameters where not normally distributed around the mean. As a result, log transformation was used to meet the assumption of normality and homogeneity of variances.

Soil C content (%) was analyzed using Walkley and Black methods (Walkley and Black, 1934), and bulk density was analyzed through the application of paired t-test using SPSS statistical software version 20. Significant differences were also tested at $P \leq 0.05$ using Tukey's least significant difference test.

Results

Comparison of SOC Content and SOC Stock between land uses at Mai-Brazio

Table 4 Mean comparison of SOC content and SOC stocks between plantation site and grazing land across different depths in Mai-Brazio site Tahtay Maichew

Soil parameters		Land Uses		
	Soil depth(cm)	Plantation site	Grazing Land	P-Value
Soil Organic Carbon (%)	0-20	1.5(0.23)	0.1(0.13)	0.039
	20-40	1.3(0.21)	1.1(0.08)	0.31
	40-60	2.2(0.18)	0.72(0.18)	0.003
Bulk density (g/m-3)	0-20	0.67(0.167)	1.11(0.26)	0.57
	20-40	0.67(0.289)	1.00(0.28)	0.489
	40-60	0.56(0.147)	1.02(0.23)	0.489
SOC (Mg/ha^{-1})	0-20	23.93(7.82)	11.01(1.96)	0.155
	20-40	17.89(4.77)	22.1(4.01)	0.73
	40-60	40.36(9.35)	17.97(5.63)	0.062
Total SOC stock (Mg/ha)	0-60	82.18(15.51)	51.08(7.73)	0.099

Our findings revealed lower OC accumulation in the upper 0-20cm surface (1.5%) (P = 0.039) and higher at lower depth 40-60cm (2.2 %) (P=0.003). However, OC in the second depth of the soil didn't show any significant difference to the adjacent grazing land. Similarly, SOC in the plantation site was found to be (23.93±7.82) much higher than the SOC found in the upper surface of the grazing land (11.01Mg/ha^{-1}±1.96). However, the SOC (Mg/ha^{-1}) found at the middle depth (20-40cm) of the plantation site was found to be (17.89Mg/ha^{-1}±4.77) lower than the adjacent grazing land with the same soil depth 22.1Mg/ha^{-1}±4.01) (P=0.73) (Table 4).

Comparison of SOC Content and SOC Stock between land uses at Barka-Adisbha

According to our soil laboratory result, OC concentration in plantation site and adjacent grazing lands of Mai-Brazio, ranged from maximum value of 5.822% and 3.464% and minimum values of

3.297% and 1.054% while the average value was 4.725% and 2.346%, respectively. Furthermore, minimum and maximum SOC stock in both plantation site and adjacent grazing lands of Barka-Adisbha ranged (35.465 Mg/ha), (6.825Mg/ha), and (113.487Mg/ha), and (82.593Mg/ha), respectively (Table 5).

Table 5 Comparison of SOC content and SOC stocks between plantation site and grazing land across different depths in Barka Adisbha site in Atsbi-Womberta district.

Soil parameters		Land Uses		
	Soil depth(cm)	Plantation site	Grazing Land	P-Value
Soil Organic Carbon (%)	0-20	1.5(0.327)	0.54(0.16)	0.003
	20-40	1.63(0.263)	0.99(0.125)	0.021
	40-60	1.5(0.267)	0.8(0.136)	0.034
Bulk density(g/m-3)	0-20	0.75(0.164)	0.85(0.163)	0.609
	20-40	0.75(0.25)	0.78(0.16)	0.915
	40-60	0.75(0.25)	0.92(0.21)	0.675
SOC(Mg/ha^{-1})	0-20	21.39(4.72)	7.93(3.43)	0.044
	20-40	20.5(3.13)	17.58(4.07)	0.507
	40-60	26.06(9.01)	14.83(4.66)	0.314
Total SOC stock (Mg/ha)	0-60	67.95(8.6)	40.35(8.95)	0.065

This phenomenon is observed for both plantation site and adjacent grazing lands. Moreover, despite of decreasing-increasing trends with soil depth at grazing land, higher SOC was observed at the lower depth (40-60cm) of plantation site (26Mg/ha) and decreasing at the second depth (20.5 Mg/ha) and finally, relatively increased at the surface (21.33Mg/ha) (figure 2). Soil organic carbon stock at the first depth significantly varied with the adjacent grazing land (p = 0.044).

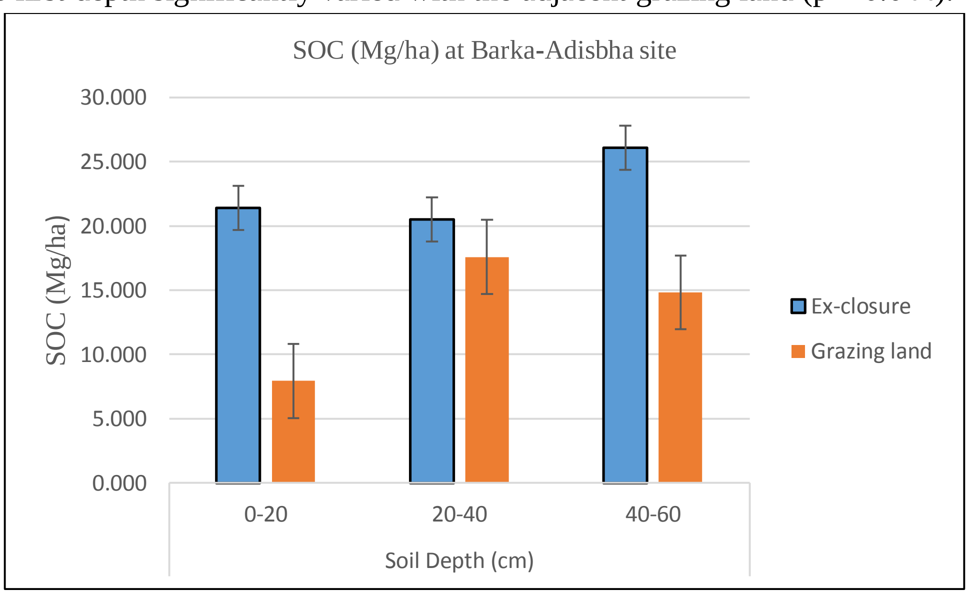

Figure 2. Soil organic carbon variation with land use and soil depths

Unlike the result in Mai-Brazio, OC in Barka-Adisbha site varied significantly in all soil depths, respectively. Additionally, the highest OC accumulation was found at the second soil layer (20-40cm). This is very promising for both plantation site and the adjacent grazing land with 1.63% ± 0.263 and 90.99% ± 0.125 (Table 4). According to Figure 2, SOC of the plantation site was higher at the lower depth (40-60cm) with 26.06 Mg/ha^{-1} but relatively higher SOC (Mg/ha^{-1}) accumulation in the grazing land was observed at the second soil layer (20-40cm) with the amount of 17.58 Mg/ha^{-1}

Moreover, the total SOC of Barka-Adisbha site was higher in plantation site 67.95±8.6) than that of the adjacent grazing land 40.3±8.95) (Table 5 and Figure 2). This result was similar to SOC (Mg/ha^{-1}) found at Mai-Braziowith 82.18±15.51) and 51.08±7.73 with P=0.009. However, the total SOC stock in Barka-Adisbha did not show significant variation with the adjacent grazing land (P = 0.063)

Soil nutrient contents and soil properties in plantation site and adjacent grazing lands

Result of soil analysis revealed that soil pH in both plantation sites (Mai-Brazio and Barka-Adisbha) was significantly higher than the adjacent grazing lands (P = 0.000 and P = 0.005), respectively. This illustrates that, the exclusions of open grazing land into Acacia *saligna* plantation sites results in neutralization of soil pH. On the other hand, the conversion of open grazing land into *Acacia saligna* plantation did not bring statistical significant difference in soil EC at Mai-Brazio (P = 0.357) (Table 6). However, significant difference was found at Barka-Adisbha (P = 0.003) (Table 6). The average pH and EC for both sites with adjacent grazing land ranged 6.62, 6.12 and 0.189 (ds/m), 0.23(ds/m) for Mai-Brazio and 6.96, 6.66 and 0.13 (ds/m), 0.36 (ds/m) for Barka-Adisbha, respectively.

Table 6 Mean values of some soil chemical properties at 0-60cm soil depth of plantation site and grazing land at both Mai-Brazio and Barka-Adisbha

Site name	Land uses	Soil parameters					
		*TN (%)	Av.P (ppm)	CEC (cm[+]kg-1)	Av.K(mg/kg)	EC (ds/m)	pH
Mai-Brazio	Plant.	0.10 (0.03)	5.4 (0.21)	31.9 (0.85)	39.5 (4.4)	0.189(0.18)	6.62 (0.06)
	G. land	0.054(0.02)	4.3 (0.54)	28.9 (0.37)	25.5 (7.3)	0.231 (0.44)	6.12 (0.04)
	P-value	**0.173**	**0.08**	**0.001**	**0.08**	**0.357**	**0.000**
Barka-Adisbha	Plant.	0.197 (0.03)	5.83 (0.240	29.25 (0.60)	16.38(1.17)	0.13 (0.008)	6.96 (0.042)
	G. land	0.035 (0.008)	4.89 (0.37)	27.54 (3.40)	15.25(1.91)	0.36 (0.06)	6.66 (0.077)
	P-value	**0.000**	**0.005**	**0.620**	**0.549**	**0.003**	**0.005**

*: TN = total nitrogen, Av.P = available phosphorus, CEC = cation exchange capacity, Av.K = available potassium, EC = electrical conductivity and pH refers to = soil pH

Furthermore, the available K-of *Acacia saligna* plantation at Mai-Braziosite was higher (39.5 ± 4.4) than the adjacent grazing land (25.5±7.3) (Table s 6). However, the variation is not statistically significant (P = 0.08). Despite higher numeric value (16.38 ± 1.17) at plantation site and lower at

15.25 ± 1.91 of av K, at Barka-Adisbha site, no statistical significant difference was also found (P = 0.549).

The CEC of the examined land use at both Mai-Brazio and Barka-Adisbha sites was found to be 31.9 ± 0.85 and 28.9 ± 0.37 at Mai-Brazio plantation site and open grazing lands, respectively and were statistically significant difference was found between plantation site and open grazing lands at Mai-Brazio (P = 0.001)(Table 6. Unlike the above result, statistically not significant difference was found at Barka-Adisbha site (P = 0.62). Likewise, CEC at Barka-adisbha site ranged between 27.54 ± 3.40 at plantation site and 29.25 ± 0.60 at open grazing land, respectively.

Unlike the above result, the conversions of open grazing land to *Acacia saligna* plantation brought statistical significant difference in av P (P = 0.005) for Barka-Adisbha sites. However, in Mai-Brazio, conversion of open grazing land into *Acacia saligna* plantation site did not bring statistical significant difference in the accumulation of av. P (P = 0.08) (Table 6). Despite TN in plantation site was higher than that of the adjacent grazing lands, this difference is not statistically significance at Mai-Brazio (P = 0.173) (Table 6). On the other hands, TN at Barka-Adisbha site was statistically different from that of grazing land (P = 0.000). In line with this results, the TN for both land uses ranged between (0.197 ± 0.03 and 0.035 ± 0.008) (Table 6).

DISCUSSION

SOC and OC Concentration across plantation sites

SOC sequestration is crucially important to reduce soil degradation, improve SOC stock, increase productivity and mitigate climate changes (Lal, 2001; 2004 and Gebregergs, 2018). The total SOC stock in both plantation sites were higher (82.18 Mg/ha^{-1} and 51.08) at Mai-Brazio) and 67.97 and 40.35 Mg/ha^{-1} at Barka-Adisbha than the open grazing lands (Table s 4 and 5). The higher SOC in plantation site is due higher SOM through tree/shrub litter fall (Mokria 2017; Mekuria and Velkamp, 2009; Araya, 2016; Gebregergs, 2018). Our findings revealed that SOC increased with an increase in soil depth which, might be due to accumulation of root biomass in lower soil depths of plantation sites and redisposition of wind-blown degraded soil due to establishments of plantation sites or translocation of soil particles from the surface (Araya, 2016; Gebrewahid et al., 2018; Gebregergs 2018). In contrary, according to the review by Girmay et al. (2008), little change in SOC was observed in Ethiopia.

On the other hand, area converted to plantation site showed lower soil bulk density than the open grazing land and except the significant variation in the second and third depths of the first site, it didn't show significant variation between land uses. According to Gebregergs et al. (2018), controlling of livestock from degraded area significantly reduced soil compaction. However, in the rangelands of southern Ethiopia, exclusion of grazing lands did not show reduction in bulk density (Aynekulu et al., 2017). Similarly, the presence of high bulk density in grazing land may attribute to soil compaction as a consequences of frequent livestock grazing and decline in organic matter (Gebregergs et al., 2018). The increment in soil compaction and strength could be caused by direct pressures of livestock excreting pressure on the soil through their hoof action (Gebregergs et al., 2018; Getnet et al., 2019 and Kassa et al., 2017).

Our finding is showed that, the plantations of Acacia *saligna* significantly contribu**ted** to the accumulation of large amount of SOC in the soil. However, the plantations of *Acacia tortilis* in arid environment of Northwestern India sequesters 6 .02 Mg $ha^{-1}$and 36.3% to 60.0% more SOC in comparison to the plantations of *Azadirachtaindica*as scattered tree in silvo-pastoral system and 27.1–70.8% more than the sequestration by pasture system (Mangalassery*et al.*, 2014) which is much lower than our findings. On the other hand, SOC stocks of scattered trees in semi-arid environments of Western Tigray, Ethiopia ranges from 2.28 to 40.5Mg C^{-1}(Gebrewahid et al., 2018) which is much lower than our findings. Furthermore, SOC stocks of tropical forests, tropical savannah and tropical agricultural land in the depths of 60 cm have been reported to be121–123 Mg Cha^{-1}, 110–117 Mg C ha^{-1}, and 80–103 Mg C ha^{-1} respectively (Lal, 2004).

Table 7 Comparison of AGB, AGC, OC and SOC stock with previous findings

Land use	Study sites	AGB	AGC	OC %	SOC	References
Ex-closure	GET	-	9.08	1.08	21.24	Araya, (2016)
Range land	GET	-	1.49	1.2	22.03	Araya, (2016)
C. lusitanica	AET	31.27	18.76	-	-	Shimelse et al. (2017)
Ex-closure	TNWT	20.50	10.25	-	141.31	Gebregerges *et al.* (2017)
Grazing land	TNWT	18.13	9.065	-	135.18	Gebregerges *et al.* (2017)
A.saligna	KET	27.00	16.20	-	-	Shimelse et al. (2017)
A.etbaica	KT	-	15.9			Luganga, (2015)
A.saligna plant.	TCT	64.87	32.43	1.66	82.18	Current study
Grazing land	TCT	-	-	0.64	51.08	Current study

**: GET Gergera Eastern Tigray, AET Atsbi-womberta Eastern Tigray TNWT Tselemti North Western Tigray, KET Kilte-Awlaelo Eastern Tigray, KT Kiteto Tanzania TCT Tahtay-Maichew Central Tigray*

Our finding however indicated that SOC stock in *Acacia saligna* plantation site is much lower than the report of Gebregerges*et al*, (2017), while lower results of OC concentration and SOC stock were reported by Araya (2016) in Gergera watershed ET (Table 7).

The presence of higher total SOC in plantation site than the adjacent grazing land (P = 0.09) might be due to high litter input and more biological activities. Some studies in Ethiopia shares this fact (e.g., Mokria, 2017; Mekuria et al., 2018; Gebregerges et al., 2017; Gebregergs et al., 2018; Getnet et al., 2019; Kassa et al., 2017). Additionally, the leaves of *Acacia saligna* might have led to the accumulation of organic matters in the soil surface of plantation sites (Araya, 2016; Mokria, 2017; FAO, 2010; Dixon *et al.*, 1994).

The soil analysis however, indicated that at both plantation sites OC was higher than the adjacent open grazing lands despite the variation is statistically significant ($p<0.05$) at the first and third depth in Mai-Brazio while, significant variation is found in all depths ($p<0.05$) at Barka-Adisbha site. Our result is in line with finding by Abay, (2018) and Gebregerges*et al.,* (2017). However, OC is found higher at the lower depth than the second and the first depths both at Mai-Brazio and Barka-Adisbha, respectively (Table 4 and 5). In this manner our finding is contradicting to the results of Gebregerges*et al*. (2017). On the other hand, the conversions of open grazing lands into *A.saligna* plantation did not brought significant improvement in soil physical property (soil bulk density) at both Mai-brazio and Barka-Adisbha sites P>0.05 (Table 6). Further, our result is lower than the report by Getnet et al. (2019) while, the total mean carbon stock in plantation of Western Ethiopia was found to be 160.1 ± 35.8 t ha^{-1} lower than the mean carbon stock of natural forests (195.3 ± 58.3 t ha^{-1}).

Soil nutrient variation in *Acacia saligna* plantation sites

According to our soil laboratory analysis in Barka-Adisbha except CEC and Av.K, all analyzed soil nutrients (TN, Av.P, EC and pH) were significantly varied with the adjacent open grazing lands while in Mai-Brazio only CEC and pH are significantly different between plantation and open grazing lands (Table s 3 and 4). Inline, with our results in semi-arid environments of north western Tigray Ethiopia, Gebregergs et al. (2018) founds higher CEC in ex-closure than in open grazing lands. Similar result was reported by Mekuria and Aynekulu (2013) and Mekuria (2013) in Northern Ethiopia.
As a result, soils at the examined land uses are categorized under pH neutral. Similar results were reported at Gergera watershed (Araya, 2016). It is stated that land use type significantly affects soil pH (Yimer*et al.*, 2008; Gebregergs et al., 2018; Lal, 2004; Kassa et al., 2017; Getnet et al., 2019; Mekuria et al., 2018).

Furthermore, this result is in line with the finding of Abay (2018). On the other hand, higher CEC in ex-closure than adjacent grazing lands was reported by Mekuria and Aynekulu (2011) Mekuria and Aynekulu (2013) and Mekuria (2013).

However, numerically at Mai-Brazio TN, Av.P, EC and Av,K were higher in plantation sites than in open grazing lands (Tables 3and 4). Similar results were reported by Gebregerges*et al.,* (2017). SOM in both plantation sites were found significantly ($p<0.05$) higher than open grazing lands. The higher soil nutrient content in plantation sites indicated that *Acacia saligna* plantation brought significant positive effect on the restoration of degraded grazing lands (Table 6). This result is in agreement with the work of Mekuria and Aynekulu (2011) where, ex-closure brought significant positive impact over the restoration of degraded lands. The pH of both plantation sites were significantly different from the adjacent grazing lands. This result was in line with the report of Kassa et al. (2016), while soil pH in agroforestry of White Nile basin Western Ethiopia was reportedly statistically significant different from crop lands. However, pH in grazing land was reported higher than in Ex-closures in North Western Ethiopia (Mekuria et al., 2018).

Generally, based on the analyzed macro-nutrients, soil pH is categorized slightly acidic to neutral (5.95 to 6.78 (Table 6). This result is in agreement with the work of Demelash and Stahr (2010).

According to Norton et al. (1999), the removal of basic cat-ion is a major process causing soil acidification naturally and the presence of low base saturation is additional indicator of soil acidity.

Relationships among soil properties

Our analysis shows that the concentrations of organic carbon (OC %) positively ($P < 0.01$) affects SOC stock (Tables 4 and 5). However, BD negatively ($P < 0.01$) affects SOC stock. This result is in line with the report of Welemariam et al. (2018), while strong positive and significant correlation was found between SOC stocks and OC in Northern highlands of Ethiopia. The negative correlation between SOC stock and BD implies that soil compaction disallows soil organic carbon accumulation. According to the study by Demelash and Stahr (2010), soil BD negatively and significantly affects

SOC stock of conserved lands in North Western Ethiopia.

Table 8 correlation coefficient between soil properties (n = 102)

Soil parameters	SOC	OC	BD	N	CEC	PH	Av.P
SOC	1	-	-	-	-	-	-
OC	0.625**	1	-	-	-	-	-
BD	-0.33**	-0.114^{ns}	1	-	-	-	-
N	0.048^{ns}	0.212**	-0.076^{ns}	1	-	-	-
CEC	0.132^{ns}	0.115^{ns}	0.092^{ns}	0.027^{ns}	1	-	-
PH	0.009^{ns}	-0.031^{ns}	0.092^{ns}	0.083*	-0.241**	1	-
Av.P	0.012^{ns}	0.019^{ns}	-0.109*	0.022^{ns}	0.069^{ns}	0.019^{ns}	1

Note: ns indicate correlation is not significant

**Correlation is significant at p < 0.05*
*** Correlation is significant at p <0.001 confidence interval*

CEC is negatively correlated ($P < 0.001$) (Table 8), with soil pH, this may shows that CEC is affected by the variation of soil pH (Yimer et al., 2008; Demelash and Stahr, (2010). In contrast, unlike to the result reported by Demelash and Stahr, (2010), soil pH is negatively ($P < 0.05$) correlated with CEC. It is possible to note that, the chemical and biological soil reaction are directly influenced by soil pH and as outlined by Demelash and Stahr, (2010) and Yimer et al., (2018), low production soil are associated with low level of exchangeable bases and soil pH.

Conclusion

The findings indicated that *Acacia saligna* plantation sites are able to sequester essential amount of carbon and playing key role in climate change mitigation. Generally, it is possible to note that soil of the study area are categorized under pH neutral and moderately fertile than the adjacent open grazing lands. Furthermore, the establishment of *Acacia saligna* plantation site at Tahtay Maichew CT and

Atsbi-womberta ET were found crucially important to enhance some soil physical and chemical properties and SOC stock. Further, climate change mitigation measures should consider expanding and conservations of plantation sites. Hence, plantation sites are improving SOC stock, OC content and other soil nutrients, promotion of such land uses over degraded grazing lands should be enhanced. This study was limited only on estimation of *Acacia saligna* soil carbon stock, further study is needed to investigate effects of environmental variables on soil carbon stock of *A.saligna* and *A.saligna* plantation sites.

Declarations

Author contribution statement

Mulat Kebede: Conceived and designed the survey; performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. E. Birhane F. Fisseha, G. Girmay and N. Hagazi, advised the manuscript.

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Data Availability

Based on the requirement of data accessibility statement all excel files containing SOC and other soil properties will be submitted to public repository (dryad).

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