Intervention of Smallholder Homegarden Agroforestry Enhanced Soil Fertility status and Soil Organic Carbon stock in Tigray Lowlands, Northern Ethiopia

Abstract

Justification: To reverse the challenges of land degradation, improve soil fertility and access to feed and wood, communities in the lowlands of northern Ethiopia started to establish homegarden agroforestry (HAF) decades ago. However, limited information is available and there was information gap on the effects of homegarden agroforestry systems (HAF) on soil properties and soil organic carbon stock enhancement in the Tigray lowlands, Northern Ethiopia.

Aim: The objective of this was to explore the effect of conversion of mono-cropping systems (MCS) to HAF in Tselemti district, Tigray lowland, Northern Ethiopia.

Materials, Methods and statistical methods used: Two land use types, HAF and MCS fields replicated 15 times were considered. Thus, 30 fields, 15 from HAF & 15 from MCS were used. From each field, 1 composite soil sample for analysis of soil nutrients and 1 undisturbed soil sample for soil bulk density (BD) determination were collected from a depth of 0-30cm. All values were subjected to SPSS version 20 and analyzed using paired samples t-Test statistics at 5% level of significance.

Results: The intervention of HAF resulted in significantly higher ($p<0.05$) and enhance SOC by 76% (1.66 ±0.06 and 0.94 ± 0.05 %); SOC stock by 82% (73± 3 and 40±2); N by 75% (0.14 ±0.02 and 0.08 ± 0.01 %);avP by 37% (6.07 ±0.58 and 4.42 ± 0.21 ppm) and K by 26% (67.05± 4.5 and 53.39± 4.3 mg kg^{-1}) ($p<0.05$) as compared to the MCS.

Conclusion: This study elucidated that home gardening can help for maintaining soil nutrients and soil organic carbon stock. Hence, additional HAF have to be established in the area and in areas with similar bio-physical and socio-economic set up and the government should establish programs and campaigns to disseminate HAF systems and promote the importance of the land use.

Keywords: Homegarden agroforestry, Mono-cropping system, soil fertility, soil organic carbon stock

1. Introduction

Agricultural activities change the soil properties and play the major role of soil degradation mainly due to soil fertility decline as a result of lack of nutrient inputs [1]. Hence, soil fertility depletion is considered as the fundamental biophysical causes for declining per capita food production in sub-Saharan African countries in general and in particular Ethiopia[2]. The problems of land degradation and low agricultural productivity in the country, resulting in food insecurity and poverty, are particularly severe in the Tigray region, northern Ethiopia [3]. The region is one of the regions in north Ethiopia, which is characterized by erratic rainfall, overgrazing, deforestation, soil erosion, soil moisture stress, loss of biodiversity and soil fertility decline[4]. To overcome the problem, establishment of agroforestry systems such as HAF was one, among many interventions [5].

Agroforestry is practiced in temperate, sub-tropical and tropical zones, and includes a wide range of land uses and systems [6]. Of all the land uses analyzed in the fourth assessment report on climate change by the Intergovernmental Panel for Climate Change [7], it was concluded that agroforestry would offer the highest potential of C sequestration in developing countries [8].[9] explained that the land use system has a potential to enhance soil fertility by augmenting organic matter [9, 10, 11]. A number of studies have shown that agroforestry in the tropics has higher C dens ties than field crops or pasture [12, 13]. An additional 12,000 Mg of C per year could be sequest ered, increasing to 17,000 Mg C per year by 2040, simply through improving tree management p ractices. If the current 630 Mha of unproductive crop land and grassland were converted to agroforestry, a further 586,000 Mg C yr-1 could be added by 2040 [8,14]. In addition, many prior studies [15,16,17] have reported that an agroforestry practice enhanced the soil fertility status.

In Ethiopia, the integration of trees and shrubs into agriculture emerged some 7000 years ago [18]. Various agroforestry systems are practiced in different parts of the country. One of the oldest indigenous agroforestry systems is HAF are practiced in different parts of t he country [19, 20, 21]. Despite the fact that Homegardening is an old age practice, studies on Ethiopian homegardens are rather scarce [22] and the research on the land use systems is at its infancy [23]. According to [24]; [25] and [26], there is still lack of knowledge about the effect of land uses managed solely by smallholder farmers on soil properties in Ethiopia. According to

[22], in particular, homegardens in northern part of the country remains largely unexplored since the practice of gardening is well developed in southern part of th e country while the northern part is known for cereal based crop production with the plough and cereal culture that evolved during the long history of agricultural production in the country. Although agroforestry is practiced in the dry land regions including Tigray region of North Ethiopia, studies on its effectiveness for ecological restoration is lacking in the region [5].

Various studies [5,26, 27,2829, 30, 31, 32] have been conducted to quantify the effect of HAF on soil properties in different parts of Ethiopia. However, focus was on the mid to highland areas (elevation greater than 1500 m a.s.l) with less intention to the lowlands (elevation less than 1500 m.a.s.l) and all the studies have been conducted in mid and highlands. Most studies undertaken i n agroforestry systems in Ethiopia have focused on agroforestry designs, component interactions and productivity aspects, and have neglected wider ecological services [33]. Little emphasis has been placed on how agroforestry systems contribute to soil fertility enhanmecement and carbon storage.In contrast to the homegardens' biodiversity and role in food security, soil quality has received little attention[34]. Furthermore, In the Tigray region, knowledge of the grazing lands conversion to exclosures and on soil quality has been well documented .However, limit ed information is available on soil properties dynamics affected by agroforestry practices in the the region and the effect of conversion of open crop fields to HAF on SOC stock and soil fertility status were less studied in Lowlands of Tigray Region, Northern Ethiopia. Moreover, the studies in the region mainly focused on assessing biodiversity in agroforestry systems [5, 32, 35]. On top of that, the effect of land use conversion systems on soil nutrients and SOC stock depends on soil type, land use history, topography [36, 37] and the effect of an agroforestry on soil properties depends on species composition, age, geographical location of the system [38], previous land use [39], climate, soil characteristics, crop-tree mixture, and management practices[40], and agroforestry system [10]. Hence, generalization is difficult unless several and representative studies have conducted. Hence, the present study was thus undertaken to generate information on the potential of HAFs systems to enhance soil properties and SOC stock potential in Tigray lowlands, Northern Ethiopia.

2. Materials and Methods

2.1.Study Area

The study was conducted in Sekota-mariam peasant association (PA) in Tselemti District, North western zone of Tigray, north-Ethiopia which is 380 km far from Mekelle, capital city of Tigray region, towards North West (Figure 1). The study site was selected based on the availability of the land use systems and accessibility of the peasant association (PA) for the study. Geographically, it is located at $13^{0}30'$-$13^{0}39'$ N and $38^{0}15'$-$38^{0}24'$ E at an altitude of 1350 meter above sea level (m a.s.l). Areas characterized by an elevation of less than 1500 but greater than 500 m a.s.l are classified as lowland or locally called ‘Kolla’ [41].

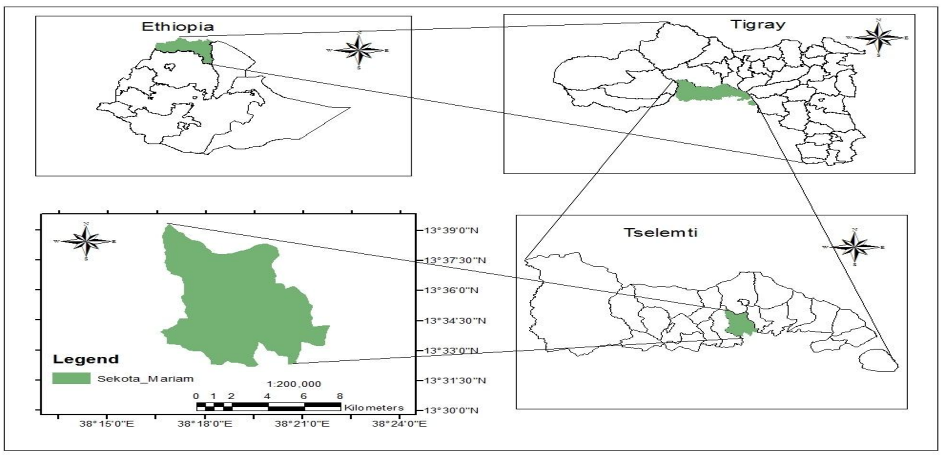

Figure 1 : Map showing study location

Five year (2012-2106) climatic data shows that, the maximum temperature ranges from 26.8°C in August to 38.6°C in April and the minimum temperature is 15.6°C in January to 21.7°C in April. The dry season occurs between November and April while the rainy season occurs between June and September (Fig 2).

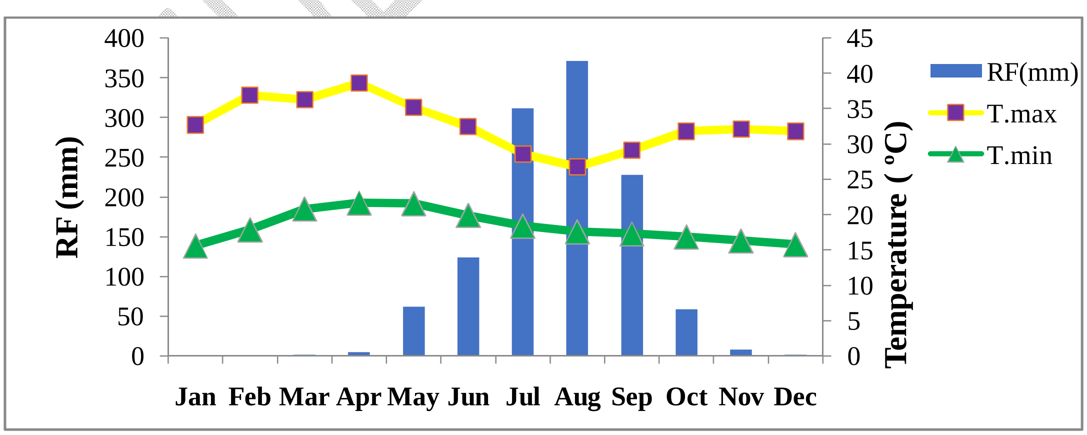

Figure 2. Mean monthly rainfall (mm), maximum and minimum mean monthly temperatures of the study area from 2012-2016 (Tigray meteorological services center).

A diverse soil types are found in the district. However, the dominant soil type of the studied land uses is vertisols [42].

General characteristics and management history of the land uses

HAF in the area refer to tree-crop-animal production systems that are established on small parcels of land surrounding homesteads being intensively managed by family labor. Whereas the MCS is an area where continuous cultivation with less management has been practiced. In this study the adjacent MCS were used and sampled as a reference.

All the HAF in the area have evolved from MCS and had been managed as HAF for at least 20 years at the time of the study means the MCS were converted to HAFs. The reason for the conversion of the land uses was to get additional land for young farmers who don't have residence and the change was as result of settlement by young farmers a subsequently establishment of HAF. As a result of settlement of young farmers in 1997, each land area was sub divided in one half with sole-cropping and the second half with HAF. According the interviews with local farmers, the area under homestead had been used only for crop production prior to 1997.

In the HAF, mainly fruits like *Citrus lemon*, *Carica papaya*, *Mangifera indica¸ Psidium gaujava*, *Citrus aurantifolia* were planted. In addition, species like *cordia africana, Jacaranda mimosifolia, Acacia polyacantha, Ziziphus spina-christi, Croton macrostachyus, Acacia persiciflora, Gardenia lutea, Anogeisus leiocarpus, Acacia albida, Ficus vasta, Acacia seyal, Terminalia brownie, Diospyros mespiliformis, Sterospermum kunthianum, Ficus ingens, Cassia singueanea, Ziziphus jujube, Ficussycomorus, Grewia ferruginea, Commiphora Africana, Dichrostachyscinearea and Vangueria edulis* were also naturally regenerated species and managed by the family members.

The farmers have not been applied irrigation and the ploughing frequency is twice and sowing in the third ploughing in both the land uses. The main crops grown for consumption are sorghum (*Sorghum bicolor*),finger millet (*Eleusinecoracana*) and maize (*Zea mays*). Besides, no soil and water conservation physical structures were observed in both the land uses. Soil erosion was in the MCS were observed to be relatively more common compared to the HAF. In addition, it was characterized by low sediment deposits and higher proportions of bare soil than the HAF.

The area size of the HAF ranges from 640 m^2 to 1510 m^2 and that of MCS ranges from 710 ha to 1220 m^2 ha and Farms elevated from 1339 to 1371 m.a.s.l in the HAF and 1300 to 1401 in the MCs(Table 1). Each pair of sampling plots was within a distance of 10-20m.

Table 1.General descriptions of the 30 farms assessed. Min.= Minimum, Max.= Maximum, SEM= standard error of mean

Land use	**Area (m^2)**			**Slope (%)**			**Elevation(m.a.s.l)**			**stems ha^{-1}**	**Pre-vious la nd use**	**Converted since**
	Min	Max.	Mean ±SEM	Min.	Max.	Mean ±SEM	Min.	Max.	Mean ±SEM			
HAF(*n*=15)	640	1510	973.4±37	2	7	4.1±0.4	1339	1371	1356±2	201	MCS	1997
MCS(*n*=15)	710	1220	955±64	3	7	4±0.3	1300	1401	1354±7	No trees	MCS	Not converted

2.2. Experimental design and data collection

Information on farm history such as previous land use and year of conversion were collected from the elderly key informants, farmers who are the owners of the farms and cross checked with the information given by office of agriculture and rural development of the district in December 2017.

Fifteen households were purposely selected for having HAF and MCS as well as proximity of the land use types on the highest possible biophysical similarity such as slope, elevation, soil types and land size (Figure 3) except their differences in the land management practices. . Hence, a total of 30 sample plots (in this case farms), from the selected 15 farming households (one HAF farm and one mono-cropping farm from each household) were used. For the purpose of this study, the fifteen households were considered as replications, whereas the two land use types were considered as treatments. Thus, 30 plots (2 land use types * 15 replications) were used to compare the two land use types. The plots of the MCS were adjacent to the plots in the HAF at a distance of 10m-20m from the edge of the HAF.

2.3.Soil sampling

In each HAF and mono-crop field one 10m*10m ($100m^2$) sample plot was purposefully laid at the center of each of the farms for soil sampling. Soil was sampled in January 2018 after annual crops harvest .The thirty plots, 15 for HAF and 15 for MCS, were considered for soil sampling. In each plot, five soil pits (from four corners and at the center), following the recommendation of [43] and [44] were dug in an 'X' design. From each pit, soil samples from a depth of 0-30 cm were collected and mixed in a large bucket to form one composite soil sample representing the plot. A total of 30 composite soil samples were taken for analysis of N, P, K, SOC%, EC, CEC and soil pH. In one of the five pits [45], an undisturbed soil samples using core sampler of height 5cm and diameter of 5cm (5cm*5cm) were collected for BD determination and there by SOC stock. Hence, for this purpose, a total of 30 disturbed soil samples and 30 core samples were taken. The core samples were oven dried at 105^oC for 24 hours [46]. The disturbed soil samples were also air dried, grounded and passed through a 2 mm sieve prior to analysis.

Figure 3. Photo showing HAF and MCS

2.5. Soil properties laboratory analysis

The soil analysis was conducted at Shire and Mekelle Soil Research Center laboratories following standard laboratory procedures and methods. TN was analyzed using the Kjeldahl method [47] , av.P was analyzed using the Olsen-P method [48] , bulk density was measured using the core method [49] , SOC content was analyzed using Walkley-Black method [50],Soil pH and EC were measured in the supernatant suspension of a 1: 2.5 soil to water ratio using a pH meter and EC meter respectively [51] ,flame photometry was used to determine Av. K content [52] (Black et al., 1965). CEC using ammonium acetate method [53].

2.6. Soil organic carbon stock estimation

To determine the SOC stock, the dried, 2mm sieved soil was weighed and the volume of coarse fragments was recorded for coarse fragments correction. Then, it was calculated using the following formula:-

$$SOC\left(\text{Mg C ha}^{-1}\right) = [\text{WBC}(\%) * \text{BD}\left(\text{g cm}^{-3}\right) * \text{D} * (1 - \frac{\text{CF}}{100}] * 100 \text{ ....Eq (9)}$$

Where *WBC*(%) = Walkley-Black carbon content of the fine fraction (< 2 mm), D= soil depth (cm), BD= soil bulk density (g cm^{-3}); CF= volumetric content of coarse fraction (%). The volumetric content of the coarse fragments (>2mm material) was calculated from a density of rock fragments value of 2.65 g cm^{-3} [54].

2.7. Statistical analysis

Data were first checked for normality. Whenever data were not normally distributed, they were log transformed. All values were subjected to SPSS version 20 and analyzed using paired samples t-Test statistics at 5% level of significance.

3. Results

SOC% at the depth of 30 cm in the HAF with 1.66 ± 0.06% was significantly higher than that of the MCS with 0.94 ± 0.05% (Table 2) which indicates that the land use change enhanced the SOC% by 76% and brought an additional 0.72 % SOC. SOC stock followed a similar trend to that of SOC%. Accordingly, SOC stock in the HAF with 73 ± 3Mg ha^{-1} was found to be significantly higher than the MCS with 40 ± 2 at the depth of 0-30 cm (Table 2) which shows that the conversion of the MCS to HAF increased the SOC stock by 82%.

Table 2. Mean (±SE) comparison of SOC % and SOC stocks (Mg/ha) between HAF and MCS across different depths. HAF=Homegarden agroforestry, MCS = Mono-cropping systems. Standard error (±SE) mean is shown in parenthesis.

Soil parameters	**Depth(cm)**	**Land use types**		***P-value***
		HAF	**MCS**	
SOC %	0-30	1.66 (0.06)	0.94 (0.05)	$p \leq 0.001$
SOC stock (Mg ha^{-1})	0-30	73 (3)	40 (2)	$p \leq 0.001$

The level of nitrogen content ranged from 0.07-0.36% in the HAF and from 0.02-0.21% in the MCS. The mean value was significantly higher in the HAF (0.14 ± 0.02%) as compared to the MCS (0.08 ± 0.01%) (Table 3), which indicated an enhancement by 75%.

Table 3. Mean values (± SE) of some soil chemical properties at 0-30cm soil depth of HAF and MCS. Standard error (± SE) is shown in parenthesis. HAF= Homegarden agroforestry, MCS= mono-cropping system.

Land use	**Soil parameters**					
	pH	**EC (ds/m)**	**CEC (cmol (+)/ kg)**	**N (%)**	**P (ppm)**	**K (mg kg^{-1})**
HAF	6.64 (0.07)	0.16 (0.03)	31.08 (0.82)	0.14 (0.02)	6.07 (0.58)	67.05 (4.5)
MCS	6.74 (0.05)	0.18 (0.02)	29.41 (0.49)	0.08 (0.01)	4.42 (0.21)	53.39 (4.3)
P-value	0.303	0.621	0.081	0.045	0.028	0.04

The values of P exhibited significant difference between HAF and MCS, with higher concentration in the HAF with 6.07 ± 0.58 ppm than the MCS with 4.42 ± 0.21 ppm (Table 3). This indicated that HAF enhanced the P level by 37 %.

There was a significant difference in K content between the HAF (67.05 ± 4.5 Mg kg^{-1}) and the MCS (53.39 ± 4.3 Mg kg^{-1}). The results indicated that the agroforestry practice improved soil K by about 26% compared to the MCS (Table 3). The statistical analysis showed that the CEC level was not influenced by the land uses types. Even though HAF had about 6% higher CEC than MCS, the difference was insignificant (p=0.081) (Table 3).

EC was found to be insignificant between HAF and MCS (p=0.621), though the MCS had numerically higher soil EC (0.18 dS/m) than the HAF (0.16 dS/m) (Table 3), showing that the MCS had higher EC level by 12.5 %.

Soil pH did not show significant difference between the land uses. Though not statistically significant (P=0.303), the MCS had numerically higher soil pH (6.74) than the HAF (6.64) (Table 3).

4. Discussions

Our study showed higher SOC% and SOC stock on the HAF as compared to the MCS. This might be due to addition of biomass from the trees grown on the land use [55], lower erosion as a result of reduced exposure of the soil to rain and wind, as well as increased surface roughness and reduced runoff [56]. On the other hand, the loss of SOC% and SOC stock in the MCS is due to the increased soil carbon decomposition rates and soil erosion induced by less vegetation cover[27]. According to [57], Erosion has been a major loss mechanism for SOC from agro-ecosystems, which accounts for an estimated 20-50% of historic C losses. The increase in SOC content and SOC stock on the tree based land use systems compared with treeless crop lands might also be due to increased biomass input to the soil of the HAF by continuous supply of organic matter [5], extensive root system of the trees in the HAF and recovery of nutrients from below the crop rooting zone[58, 59]. While low amount of organic materials added to the soil of the treeless cropland because of complete removal of the biomass from the field and reduced physical protection of SOC may be the reasons for low SOC content and SOC stock in the treeless croplands. Lower value of carbon stocks in the treeless croplands might be also due to higher soil organic matter decomposition rate because of exposure of soil and higher temperature. According to [55], exposure of soil and higher temperature in agricultural lands increases soil organic matter decomposition which in turn decreases soil organic carbon.

The finding of this study is in line with a result reported by[27] from Wondo Genet district, southern Ethiopia, who pointed out that conversion of HAF to monocrop fields reduced SOC% content and SOC stock by 13-20% and 18.3–47.1% respectively. Similarly, different researchers[11, 27, 60, 61] from different parts of Ethiopia proved that HAF have a significant role to enhance SOC content and stock. In addition, the finding in this study corroborates with other prior study by [12]from Rupnagar district, north Indian state of Punjab who pointed out that AFs had 88% Higher SOC than rice-wheat system. The SOC stock in 0–30cm cm soil depth in HAFs of our study area was smaller than values reported by [62]for older-aged HAFs based agroforestry systems in the Gedeo area, Ethiopia, (114.8–121.9 Mg ha- 1). This difference with our study might be due the higher density of the trees in the AFs (383-600 stems ha-1 whereas 201 stems ha -1 in our study area). According to [63], tree density highly affects the SOC stock in a soil. However, our results were higher than estimates for other forms of HAF with diverse species in India, ~60–66 Mg $ha^{-}1$ [63]. In addition, the enhancement (by 76%) in this study is higher than the enhancement of the SOC stock driven by Afforestation (introduction of trees on previously treeless crop lands) of former cropland for tropical regions (26 %)[64].The potential sequestration rates for the HAF in this study (1.7 Mg (Mg C ha^{-1} $year^{-1}$) is above the C sequestration gained from Conversion of cropland to HAF in East Africa (0.5–0.6Mg (Mg C ha^{-1} $year^{-1}$) [65]. In contrast to our finding, lack of significant change was reported by [66], as a result of conversion of croplands to agroforestry due to short establishment time (7 years) of the agroforestry systems in southeastern Loess Plateau of China. This implies that the length of the experimental period is a key factor affecting the observed SOC changes, indicating that in a short time, the potential contributions of agroforestry systems toward soil quality improvement might not have been fully exhibited. [67] sgested that at least 10 years of alley cropping were necessary to detect the change in SOC. In addtion, different climate condtions, soil properties, crop and tree species and management practices used in different studies could contributed to the inconsistent results in terms of SOC accumulation [68].

Soils of the HAF had soil pH ranging between 6.28 - 7.18 with an average of 6.64, whereas that of MCS ranging between 6.49-7.13 with a mean value of 6.74, lower in the HAF and higher in the monocropping land. Although there was relative higher pH in the MCS land compared to the HAF, the difference in their pH level was insignificant and the variations in the pH of soils under the two land-use types were generally small. The insignificant increase in pH in the MCS was related to an increase in soil bulk density which has a direct relationship with soil moisture content [69]. Similar result was reported by [12] from Rupnagar district, north Indian state of Punjab reported an insignificant difference among three land uses namely agroforestry, maize-wheat systems and rice-wheat system in their soil pH and EC level. The insignificant difference in soil pH between the two land uses could be attributed to less leaching of base forming cations [43] and high rainfall in the study area which removes basic cationsas rated by[70], the soils in both the land uses are neutral soils. The result in this study agrees with the findings of [71], who reported an insignificant pH response to distance of *Faidherbiaalbida* based land use system in the highlands of Tigray. In addition, [72] pointed out that soil pH value was not significantly affected by establishing agroforestry systems in semi arid ecosystem of India. Similar result was reported by [73], at Limat and Endakeshe sites, northern Ethiopia. In contrary to the find ing in this study, [34] reported a significantly higher soil pH in HAF than croplands, probably du e to the addition of ash, other household waste and manure.

The results agroforestry practices enhanced soil P by about 37% compared to the MCS. The convsion the MCS to an HAF has significantly ($p < 0.05$) improved the avPlevel from 4.42 ± 0.21 p pm in the MCS to 6.07 ± 0.58 ppm in the HAF (Table 3). This result indicated that conversion of the land uses converted the very low level of P in MCS to low level in HAF. According to[70], avP categorized as very low is low if is <5ppm and low if it is 5-10 ppm. This agrees to finding of[26] for Umbulo catchment (southern Ethiopia) and Pinho et al. (2011), for HAF in Roraima, Brazil. A study of soil nutrients under HAF by [74] found an extra of 36.3 mg kg^{-1} P in old homegardens (40 + years old), 14.1 mg kg^{-1} in established HAF (15 – 35 years old) and 8.8 mg kg^{-1} in new HAF (0 – 10 years) as compared to open Savanna soils. A study of soil nutrients under different land uses in Amelekemicro-Watershed, south Ethiopia, by [75], found an extra of 18.7 mg kg^{-1} P (triple) in an established agroforestry as compared to croplands. Similarly,[76], from central mid-hills of Nepal also pointed that transition from conventional system characterized by mono-cropping to HAF significantly improved the av.P level by 53%. The increase might be due to the presence of organic anion exudation and acid phosphatase activity of tree roots which may increase mobilization of P in the rhizosphere[77]. The reason for higher P in the HAF could also be attributed to the potential of trees to increase P availability through accelerating P cycling by enhancing microbial activity [78] and extensive roots of trees which helps to taking up the nutrient released by rock weathering [67]. Generally, according to the ratting of [79] the available P level of both the land uses was found to be in a deficient rate(<10ppm). It also indicated that majority of Tigray region soils including the study district are soils with deficiency of P.

The significantly higher soil N in the HAF than the MCS might be due to increased addition of organic matter from the HAF, which enhances soil microbial metabolism,nitrogencyclingandreduced soil erosion [80].In addition, leguminous trees in the HAF can fix nitrogen and low rate of decomposition may occur in the HAF due to lower temperature. Several of the tree species found in HAF were leguminous trees which are known to fix substantial amounts of atmospheric nitrogen. While the lower content of N under MCS may be attributed to low biomass returns and lack of vegetation cover which can cause severe soil erosion. Our results were similar to studies conducted in central highlands of Ethiopia by [24], who found low N (1.29 mg g^{-1}) in cereals and high N (2.04 mg g-^{1}) in HAF. In the present study, HAF practice improved N by about 75% compared to the MCS. This result is by far higher than previous findings. For instance, [27], and [81]reported an increase in N by 24–29 %and 38% respectively for southern Ethiopia, and by 47% of global average [16]. The finding in this study also corroborates to a report by [17] who reported that the available N content in soil increased by in different tree species under agroforestry over the Agriculture field which is attributed to the addition of organic matter in soil in the form of litter fall and fine root biomass. [76]from central mid-hills of Nepal also pointed that transition from conventional system characterized by mono-cropping to HAF significantly improved TN content by 30%. The enhancement of TN content in our study (75%) is by far more than that was reported by[82](44%) in tropical dry climate of Sri Lanka. But lower than the one reported by [83] (improvement by 90%), in Damot Gale, and SodoZuria districts, Southern Ethiopia. These differences in enhanmecement of the TN level in different districts might be due to dereferences in soil types, conversion time, and agro ecology.

The significant enhancement of K by 26% is consistent with the findings of [24]for HAF in central highlands of Ethiopia, [74] for HAF in Roraima, Brazil, and [17]for Terai region of the GarhwalHiamalayaswho reported a progressive increase in levels of K as the result of agroforestry implementation. These authors revealed an extra of 0.08 cmol$_c$kg^{-1} K addition in old HAF (40 + years old), 0.03 cmol$_c$kg^{-1} in established HAF (15 – 35 years old) and 0.01 cmol$_c$kg^{-1} in new HAF (0 – 10 years) as compared to the open Savanna soils. [75], from Amelekemicro-Watershed also reported that an agroforestry system had 136% more av.K than its adjacent croplands in a depth of 0-30cm. The decrease in the exchangeable cation in the MCS, in addition to the low organic matter addition, may be due to cation leaching [24], as a result of low level of

CEC. The enhancement of K level in the trees based system could also be due to uptake of K from deeper soil layers and thereby returning through the leaf litter on the surface soil layers [84], and reduced loss of nutrients by erosion and leaching [85].According to [86], the lateral extension of tree roots can be considerable, particularly in semiarid areas .In contradict to our finding,[82]in tropical dry climate of Sri Lanka reported that field without agroforestry had higher K than HAF [83], reported that HAF intervention enhanced the av K level by 86-128%, in Damot Gale, and SodoZuria districts, Southern Ethiopia which is higher than the level of improvement in our study (26%).

The numerically, but not statistically higher CEC level in the HAF could be due to higher organic matter accumulation in the HAF. According to [87], the level of CEC of soils depends mainly on the amount of soil organic matter available in the soil. This agrees with the findings of [24], who reported insignificantly higher CEC (by about 10%) in HAF compared to cereal cropped lands. [73] also reported an insignificant difference among CEC levels of three zones (under canopy, near canopy and far from canopy) of *Balanitesaegyptiaca*in agroforestry systems of Humera district, northern Ethiopia.

The insignificant difference in EC level might be due to the inherent low salinity level of the study area. According to [79], majority of Tigray region soils were found to be free of salt (<2ds/m). Similar result was reported by [88] who pointed out that EC was numerically but not statistically lower by 13% and 21% under the tree canopy of *Oxytenantheraabyssinica* and *Dalbergiamelanoxylon* respectively as compared to the open field in an agroforestry systems of KaftaHumera district, Northern Ethiopia. In addition, [89] reported that EC level was not significantly influenced by the presence of an agroforestry tree species (*Faidherbiaalbida*and *Acacia tortilis*)in an agroforestry system of Dugda district, central rift valley of Ethiopia.

5. Conclusion

The present study elucidated that HAF have the capacity to improve SOC%, SOC stock, soil N, soil K and soil P compared to MCS. This improvement was in great part related to increases in organic matter in the form of surface litter. Therefore, besides their role in above-ground carbon sequestration, agroforestry systems also have a great potential to increase carbon stocks in the soil. This implies that homegardening can help maintain the soils around the homesteads. Hence, governmental and private sectors can play their role for the promotion of HAF systems in the study area, and in areas with similar biophysical and social setup. Additional studies are also required with special focus onthe socio-economic gain and other ecosystem services.

Ethics approval and consent to participate

Not applicable

Availability of data and materials

Upon request, the data and materials used in this article are available from the corresponding author.

Consent for publication

Not applicable

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Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

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