Print : ISSN 0970-7662
Online : ISSN 2455-7129

Journal of Tree Sciences
online available at www.ists.in

Volume 36 No. 1 June, 2017

Role of Agroforestry and Plantation on Climate Change Mitigation and Carbon Sequestration in Ethiopia

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DOI: 10.5958/2455-7129.2017.00001.2

ABSTRACT

Agriculture adversely affects the earth's climate (e.g., CO_2 emissions in connection to agricultural expansion). Conversely, agriculture and plantation could also be a solution for climate change by widespread adoption of mitigation and adaptation actions. This happens with the help of well managed agroforestry practices. Agroforestry is a tree-based farming system that has been practiced in Ethiopia for long period of time. Thus, growing of trees and crops together provide several ecosystem services including carbon sequestration and nutrient availability in soil. However, the potential to store carbon depends on types of species composition and ecological management systems. In conclusion, properly managed agroforestry systems can deliver countless outcomes in ecological, economic and social services, which need further research in Ethiopia.

Key words:

Agroforestry, Climate, Ethiopia, Mitigation, Sequestration, Plantation

INTRODUCTION

Global climate change caused by rising levels of carbon dioxide (CO_2) and other greenhouse gases (GHG) is recognized as a serious environmental issue of the 21st century (Heimann and Reichstein 2008; Schroth et al. 2011). This climate change has strong relationship with agriculture; typically in developing countries where their livelihood directly associates to farming activities (IPCC 2006; Lasco et al. 2011). About 4.1 billion ha of forest and 1.5 million ha of agricultural land has been estimated in the world (FRA 2010). However, forests have been cleared over time and now global estimates suggest that 30 % of original forest cover has been converted for various uses and another 20 % has been degraded (Rizvi et al. 2015). The average annual net loss of forest has reached about 5.2 million ha in the past 15 years. A historical perspective reveals the conflict between sustainable forest management and agricultural practices. In most populous and agrarian societies (e.g., Sub-Saharan Africa) such dilemma is extremely challenging (FAO 2012). Thus, for assuring adequate food supplies in harmonized ecosystem carbon stocks, a green revolution with a special emphasis on agroforestry systems (AFS) is needed. AFS are distinct from other forms of agriculture in their ability to store higher amounts of carbon in total biomass and soils (Mbow et al. 2014; Schroth et al. 2011). Despite these facts, more than half of global species diversity is still subject to increasing human pressure, leading to the replacement of natural vegetation by monocultures (FOA 2012).

To maintain balance between environmental protection and human needs, agroforestry is thus win-win strategy to combine the two. Especially after the Kyoto Protocol (KP), stabilizing the CO2 levels has attracted substantial scientific attention (Berhe and Retta 2015; Guillozet 2011; Mohammed and Bekele 2014). Agroforestry is now receiving increasing attention as a sustainable land-management option over the world because of its ecological, economic, and social values (Bajigo et al. 2015; Berhe and Retta 2015; Mowo et al. 2013; Schroth et al. 2011). While the number of scientific publications on various aspects of agroforestry is being expanded at a rapid rate, there is scarcity of quick reference for researchers at national level in Ethiopia. Thus, in order to raise up multi-dimensional aspects of scientific knowledge of agroforestry, quick accessible information consist of both the challenge and opportunity of agroforestry on carbon sequestration and climate change mitigation is needed. The main objectives of this paper were to: (1) Give comprehensive information on the role of agroforestry and plantation on carbon sequestration in Ethiopian context; (2) Assess the main agroforestry practices on mitigating climate change; (3) Compile scattered research results in long-term carbon sequestration and improving yields of crop production.

MATERIALS AND METHODS

All the data herein were compiled from documents available in wide relevant sources (such as, published articles, books, dissertations and conference proceedings) including Google Scholars were browsed by putting some important key words. Among the few online searching terms/strings are agroforestry, climate change, carbon sequestration, soil organic carbon, and plantation and so on. The present paper was organized from the following major topics: effects of forest management actions on ecosystem carbon stocks, important services of agroforestry practices and understanding of challenges and opportunities in climate change adaptation and mitigation options in the context of Ethiopian farming systems. Furthermore, the study incorporated some case studies that depicted solutions in multiple AFS. The final section concludes the implication of previous case studies and puts some future directions.

AGROFORESTRY MANAGEMENT - ACTIONS ON ECOSYSTEM CARBON STOCK

Effects of Forest Plantation on Long-term Soil Carbon Pools

The degradation and conversion of several forest areas to other land use types are typically associated with high population growth rate and agricultural expansion (FOA, 12; Gizachew et al. 2017; Rizvi et al. 2015). Natural forests and woodlands were reduced from 15.1 to 12.3 million ha of Ethiopia's land in 1990. Currently, the remaining closed natural forests get to 3.37% (4.12 million ha) (Bekele 2011). Many authors argued that unless appropriate forest plantation and soil management activities are adopted, deforestation and land use changes (LUCs) have been posed a serious threat to the long-term carbon sequestration, economic viability and national food security (Jandl et al. 2007; Johnson, 1992; Shete 2015). Community based promoting forest plantation is one of the strategies adopted by many projects which are working in several countries. For examples, FARM-Africa; SOS Sahel, GTZ and JICA are some of the NGOs and international institutions that have been most active in promoting and supporting the development of participatory forest management (PFM) in Ethiopia (Gizachew et al. 2017; Lemenih and Woldemariam 2010; Winberg 2011). Plantations of trees play a positive role in global carbon cycle. Ethiopia has also started large scale industrial plantations in the early 1970s with supported from the Swedish government (Bekele 2011; Mohammed and Bekele 2014). Despite the promotion of plantation for the economic purposes, there is still not given much attention about the effects of selective tree species plantation on long-term carbon sequestration and establishing environmental friendly agro-ecosystems.

The role of selection of tree species

Currently, the importance of the plantation sector gets more recognition for environmental remediation (Winberg 2011). In Ethiopia, the forest plantation areas have been increased from an estimated 190, 000 ha in 1990 to 9,72, 000 ha (Bekele 2011; Lemenih and Woldemariam 2010). However, there is only little room for expansion of plantations on public land due to the high competition for land. In addition, plantations in Ethiopia are mainly made up of exotic tree species with few indigenous trees in some of the national forest priority areas. The main species in these plantations are *Eucalyptus spp* that accounts for 56% of the total area, followed by *Cupressus lusitanica* (32 %), *Juniperus procera* (2%), *Pinus patula* (1.8 %), and other species (8 %) (Table 1).

Table 1: Commercial forest plantation area in ha by species and region

Regions	Eucalyptus	Cypress	Juniper	Pines	Grevillea	Others	Total area
Oromia	29700	32100	4400	3500	1300	7800	78800
Amhara	18000	23400	300	100	-	2800	44600
SNNPR*	20300	7000	-	-	-	-	27300
Tigray	39700	-	-	-	-	-	39700
Total	107700	62500	4700	3600	1300	10600	190400

*** Southern Nations and Nationalities Peoples Regional State.**

Source: Bekele 2011

Several findings revealed that planting of multipurpose tree species in non-forest land categories serves a dual purpose with supplying economic and ecological benefits (Gebreegziabher et al. 2010; Meragiaw et al. 2016; Murthy et al. 2013). Many rural households in Ethiopia are dependent on such resources for food consumption, medical care, income generation, and cultural values. Photo 1 illustrates a nursery site for the propagation of *Dobera glabra* (Forssk.) Poir. in the Aba'ala district, which is well known famine wild edible plant species in Afar (Meragiaw 2016).

Photo 1 : *Dobera glabra* tree and nursery site in Aba'ala district, northern Afar

The impact of a given tree species on carbon and nitrogen stocks varies according to previous land use history, crop management, local climate and spatial variability of soil property. According to Berthrong et al. (2009), afforestation caused a 6.7 % and 15% (P, 0.05) decrease in soil carbon and nitrogen content respectively, but Pinus plantations took the highest percents (15% and 20% decrease, P 0.05). The results indicate that trees take up considerable amounts of nutrients from soils so that harvesting this biomass repeatedly could negatively affect long-term carbon sequestration, soil fertility and productivity. For the permanence of carbon sequestration it is more relevant to use the right tree species for the right ecosystems that increase stabilization of carbon pool in both cropland and forested soils (Jandl 2007; Mbow et al. 2014). Some descriptions on Eucalyptus plantation, fertilizer trees, and perennial crops are given in the following paragraphs.

Effects of Eucalyptus plantation on native tree species

Native tree species play a central role in conserving biodiversity, mitigating environmental problems, and maintaining many ecosystem services in forests. Unfortunately, many native forests have been destroyed or replaced by large-scale and continuous planting of fast-growing exotic tree species such as Eucalyptus species (Gebreegziabher et al. 2010; Li et al. 2015). Eucalyptus species have been planted (about 20 million ha) in many countries throughout the world because of their high productivity, wide adaptability, and rapid economic returns (Du et al. 2015). Similar studies in East Africa and elsewhere confirmed that Eucalyptus is among the most widely planted tree in both rural and urban landscapes (Du et al. 2015; FOA 2009; Lemenih and Woldemariam 2010; Li et al. 2015). Zhang et al. (2016) carried out their research in Eucalyptus plantations in South China and the report indicated that poor establishment of native trees mainly results from Eucalyptus roots rather than litter. Although economic factors over weight for local people, Eucalyptus plantations may have deleterious ecological effects (Mohammed and Bekele 2014; Scherr 1995; Tefera et al. 2014)). Ethiopia is one of the pioneer countries that introduced the species and at present it holds the largest Eucalyptus (e.g., E. globulus) plantation that covers 477,000 to 506,000 ha in East Africa (FAO 2009; Gebreegziabher et al. 2010). A community-based program for sustainable integration of indigenous trees and crops would require support from national and local government agencies as well as NGOs.

Some researchers found that soil organic carbon (SOC) and N were decreased more significantly in Pinus plantation than Eucalyptus this could be due to differences in the distribution and decomposability of plantation biomass. Typically, Du et al. (2015) concluded that Eucalyptus plantations *(E. urophylla and E. grandis)* have considerable biomass carbon sequestration potential during stand development in total biomass. However, they may deplete soil nutrients more than slower growing species. The development of mixed forest communities may improve the carbon pool changes and ecological function (Brethrong et al. 2009; Guo and Gifford 2002; Li et al. 2015; Post and Kwon 2000). A sound agroforestry strategy is thus required to achieve the best combination of high wood diversity and carbon stock potential.

Nitrogen fixing tree plantation

Many leguminous agroforestry tree species improve the soil through biological nitrogen fixation whereby recycled nutrients are deposited and finally incorporated into the soil (Mowo et al. 2013). For instance, a Sesbania sesban tree fallow in eastern Zambia was one of the most important agroforestry options to restore soil fertility. The first and second year fallows typically generated 78% and 92% of maize (Zea mays) more wealth respectively, than the control with continuous unfertilized one (Kwesiga et al. 1999). Likewise, these improved fallow systems will need to assess in Ethiopia. In field trials, only 10 to 20% of the nitrogen released is taken up by annual crops and a large portion is stored in the long-term in the soil organic matter. This presumes that nutrient release patterns will assist in the selection of species for harmonizing with crop demand and improve nutrient use-efficiency (Palm 1995). Leguminous trees such as *Faidherbia albida*, is another ideal agroforestry tree commonly intercropped with annual crops such as, millet and maize in the dry and densely populated areas of Africa. Typically, it is widely distributed in agroforestry lands of Ethiopia associated with *Acacia tortilis, A. sieberiana, A. etbaica, A. seyal,* and *Balanites aegyptiaca* (Photo 2).

Figure : 2 Traditional agroforestry in the rift valley and south Wollo with *Faidherbia albida* and other leguminous trees integrated with cereal crops

It has been proved by different researchers in many countries including Ethiopian that F. albida improves the yield of crops grown under its canopy and biomass of ecosystems (Laike 1992). Higher biomass of ecosystems is associated with diversity, and higher species diversity leads to greater carbon sequestration (Murthy et al. 2013). However, most farmers of the central region of Ethiopia do not give much attention to the role of F. albida trees in cropping systems rather they over-use for fuel-wood that foreshadows the gradual disappearance of the species (Mokgolodi 2011). In one of research work which was carried out at Danbatta (Nigeria), a soil under F. albida canopy was compared with the same way for the canopy, shows that organic carbon (OC), nitrogen, total phosphorus and potassium were all significantly higher than the site not covered by *F. albida* tree canopy with the values of 0.3433 (4 m away from the trunk), 0.463, 19.9983, 0.4645 and 0.152 (6 m away from the trunk), 0.1833, 5.7523, 0.1625 respectively (Sanda and Atiku 2013). With these results, it is possible to conclude that *F. albida* significantly increases the availability of SOC content depends on proximity to the trunk. Species rooting patterns and nitrogen fixation prop up SOC in the majority of cases, and represent an opportunity for carbon sequestration and causing long-term improvements in soil fertility (Johnson 1992). Thus, leguminous trees especially F. albida both wild and planted are very promising trees to improve the productivity of degraded soils in the semi-arid region of our country if governmental inputs are added in its protection and plantation activities.

Perennial tree crops in fields and homegarden

Agroforestry is an ecologically based traditional farming practice, which integrates perennial tree crops into the farming systems to increase agricultural productivity and improve soil fertility, control erosion, conserve biodiversity, and diversify income in most Africa countries (Mowo et al. 2013). One of the research findings in South-west Ethiopia (Gera) showed that biomass carbon (BC) stocks significantly varied with each land use types. Their study indicated that the total carbon stock in the native forest is greater than coffee based agroforestry which shows much greater than annual crop field (Table 2). This may depict that, conversion of annual crop field to coffee based agroforestry can increases carbon stock in the study area (Mohammed and Bekele 2014). There are many perennial crops in different agro-ecological zones of Ethiopia, such as, enset (Enset ventricosum (Welw.) Cheesman) is Ethiopia's most important root crop in populous southern parts of Ethiopia (Photo 3). According to Rosell and Olvmo (2013), the comparison results showed that SOC are much higher in the perennial enset fields (3.98%) than annual crop rotation (2.46%). Therefore, agroforestry for the perennial cropland needs to have a top priority for soil fertility management systems in Ethiopia.

Photo : 3 *Enset and coffee based homegardens in southern Ethiopia*

Agroforestry practices are vital to climate change mitigation through rotational woodlot, buffer planting and homegarden activities (Uisso 2015). Homegarden agroforestry has been known for its biodiversity, carbon sequestration, and food security by growing many perennial fruit crops (such as, *Coffea arabica* L., *Mangifera indica* L., *Persea Americana* Mill., *Annona squamosa* L., *Citrus sinensis* (L.) Osb., *C. limon* (L.) Burnm.f., *Psidium guajava* L., *Carica papaya* L., *Casimiroa edulis Llave* et Lex., *Musa x. paradisiacal* L. and others) in many parts of Ethiopia. According to Schroth et al. (2011), in Mexico, Indonesia and Brazil Amazon, carbon trading with shade coffee (Coffea sp.) production is used to conserve and increase tree cover on farmland. This approach will benefit Ethiopia where it has known by coffee origin from a better integration of agricultural and forest policies (Mohammed and Bekele 2014).

Estimations of Carbon Store in Various Agroforestry Systems

Vegetation controls the magnitude and composition of SOC stocks. However, conversion of vegetations (such as, subtropical native broadleaved evergreen forest) into monoculture causes to release stored carbon into the atmosphere as CO_2 that would have a serious impact on global climate change (Heimann and Reichstein 2008) and alteration of the chemical composition of SOC (e.g., Guo et al. 2016). Thus, changes in the chemical composition of SOC might strongly affect the global carbon cycle as it controls the SOC decomposition rate. The effect of carbon storage in soil pools is very controversial and varied in coniferous tree vs deep root deciduous tree, and mixed vs pure species stands depend on soil fertility and environment variables (Jandl et al. 2007). An integrated farming approach can bring about change in carbon accumulation in living biomass and soil (Kwesiga et al. 1999; Murthy et al. 2013).

AFS differ from other forms of agriculture in that AFS often conserve more biodiversity and store higher amounts of BC on landscape (Schroth et al. 2011). This implies that agroforestry can make land use more sustainable and viable in both ecological and economical situations (Mowo et al.

2013; Neufeldt et al. 2012). There are diverse agroforestry practices in Ethiopia, which provide multiple products and services. According to several authors, the total carbon stock was significantly different in relation to various agroforestry practices and land use types (Table 2). One of the case studies of agroforestry practices in Wolayitta showed the variation in SOC among agroforestry practices and relatively highest value in homegarden can be linked with high litter accumulation and species diversity in homegarden (Bajigo et al. 2015).

Table 2: *Carbon stock variation among agroforestry practices in various study sites*

Agroforestry practices	AGC/ha (Mg/ha)	TBC/ha (Mg/ha)	SOC/ha (Mg/ha)	TC (Mg/ha)	References
Homegraden	6.63±2.2b	8.29±2.8b	61.57±11a	86.4±20b	Bajigo et al. 2015
Parkland	0.57±0.13c	0.7±0.1c	49.05±2.1a	51±0.7b	Bajigo et al. 2015
Woodlot	106.47±8.5a	133.09±10.6a	48.57±0.3a	44.48±43a	Bajigo et al. 2015
Cropland (in 2 villages)	-	51.72	25.85	6754.77	Murthy et al. 2013
Annual crop fields	1890 m 2100 m	0.05±0.03a* 0.02±0.02a*	63.34±2.95b* 66.99±2.21b*	65.4	Mohammed and Bekele 2014
Coffee based farm	1890 m 2100 m	54.46±7.45a* 62.23±17.14a*	90.65±8.89b* 94.30±5.14b*	150.73	Mohammed and Bekele 2014

*Mean values of BC & SOC

The role of agroforestry systems in soil biological activities

It has been known recently that biological processes can control the Earth system in a globally significant way. By definition, the carbon balance of an ecosystem at any point in time is the difference between its carbon gains through photosynthesis and losses in the form of CO_2 through respiration (Heimann and Reichstein, 2008). The need for transforming some of the lower biomass arable croplands to carbon-rich tree-based land use systems have relatively high capacities for storing atmospheric CO_2 in vegetation and soils. AFS spread over one billion ha in diverse eco-regions around the world have a special relevance in soil microbial biomass comprises about 1-5% of total SOC (Schroth et al. 2011; Yadav et al. 2010). AFS at farmers' field under various legume tree plantations enhance soil biological activity (Yadav et al. 2010). According to these authors, soil microbial biomass varied between 262-320 (carbon), 32.1-42.4 (nitrogen) and 11.6-15.6 (phosphorus) $\mu g\ g^{-1}$ soil under agroforestry, with corresponding microbial biomass of carbon (186), nitrogen (23.2) and phosphorus (8.4 $\mu g\ g^{-1}$) of soils under a no tree control site. Fluxes of these nutrients through microbial biomass were also significantly higher in legume species site in comparison to a control one.

IMPORTANCE OF AGROFORESTRY SYSTEMS FOR MULTIPLE SERVICES

Interaction between Climate Change and Agriculture

The post-KP (Kyoto Protocol) discussions on climate change are heavily oriented towards an agenda on mitigating high atmospheric CO_2 concentration (IPCC 2006). The KP under article 3.4 particularly recognizes the role of afforestation, reforestation, and natural regeneration of forests in increasing the carbon storage capacity of terrestrial ecosystems (Jandl et al. 2007; Schroth et al. 2011). Agriculture provides the livelihoods of the majority (83%) of the population in Ethiopia (Mowo et al. 2013; Guillozet 2011). Its activity could be a source of GHGs as well as a sink, notably through the storage of carbon in the soil organic matter and in biomass (Yohannes 2016). The relation between climate change and agriculture is clearly point out in article 2 of KP which states the promotion of sustainable forms of agriculture with a special emphasis on climate change. Global adoption of sustainable AFS and organic agriculture (OA) systems can reduce agricultural GHG emissions approximately by 32%. OA is a production system that sustains the health of soils, ecosystems and people mainly through farm internal inputs (organic manures, legume production, wide crop rotations etc) with less or no use of fossil fuel (Bishaw et al. 2013). In relation to LUC, improved cropland agroforestry, feeding and grazing land management and restoration of degraded lands to increase soil carbon sinks could also be main climate change mitigation measures in agriculture sector (Lasco et al. 2011). Therefore, the agricultural management activities are relatively affordable form of mitigation option.

Adoption of agroforestry for economic and ecological services

A study in Siaya and South Nyanza districts showed that agroforestry adoption is dependable on economic incentives of LUC, household-levels and costs and risks associated with new agroforestry practices (Scherr 1995). It is obvious that agroforestry serves as a counter balance to the adverse impacts of climate change. Trees on farms enhance the coping capacity of small farmers to climate risks through income diversification, efficient nutrient cycling, soil and water conservation (Mowo et al. 2013). Different researches on agroforestry in most central Africa countries reported that significant crop yield increases for maize, sorghum, millet, cotton and groundnut when grown in proximity to F. albida tree (Lasco et al. 2011). Research done by Mowo et al. (2013) has demonstrated that there are many ways agroforestry can reduce poverty, and addressing climate change in Ethiopia. Sustainable agricultural development strategy in Ethiopia was launched in 2011 to build a climate resilient green economy initiative that promotes agroforestry among other environment conservation activities. It has planned to reforest 15 ha of land and engaged in the regeneration of tree cover on communal and croplands on a large scale to improve food security and environmental resilience in Ethiopia.

According to Mbow et al. (2014), the agricultural dilemma can be resolved by socio-ecological links. Perennial evergreen agriculture is now encompassing many ecosystem services that are very promising for the future food security and the build-up of social capital. At the Durban climate change convention in December 2011, the Ethiopian government declared to plant 100 million F. albida trees on smallholder cereal croplands across the country in order to improve food production even in drought years. Similar trends are noted in thousands of farmers now have excess grain in Niger, Mali and Senegal. Many studies testified that association of trees have complementary ecological and social functions (Berhe and Retta 2015; Mohammed and Bekele 2014). Farming practices and land management are key tools to maintain these complex outcomes. Agroforestry is known in West Africa for increased soil fertility using nitrogen fixing trees; water availability; maintained wood biodiversity and ecosystem health through management of natural regeneration and animal husbandry using fodder trees such as F. albida and S. sesban (Mbow et al. 2014).

CHALLENGES AND OPPORTUNITIES OF AGROFORESTRY SYSTEMS IN CLIMATE CHANGE MITIGATION

Barriers to adapt and mitigate climate change in agroforestry systems

It is important to recognize that crop cultivation typically involves much more soil carbon losses and prolonged disturbance than harvesting and reforestation, even with intensive site preparation (Johnson 1992). On the other hand, climate change mitigation needs long time (15-60 years) to obtain maximum carbon sequestration in soils or terrestrial biomass, depending on management practices being modified (Li et al. 2015). According to Luedeling et al. (2014), predicting future trends for AFS while considering complex and interlinked environmental and socio-economic factors. Although there is a huge potential for agroforestry in Ethiopia, improper land use policy implementation is the main barrier to climate change adaptation (Mowo et al. 2013). Findings revealed that policy barrier such as lack of local context and limited capacity to implement the policy, hinder farmers to practice different adaptation activities (Bajigo 2015). Awareness creation and education on the linkage between climate change and agroforestry is therefore needed to encourage farmers (Tolentino et al. 2011). By the help of the right farming practice, agroforestry could be the main solution for climate change by mitigation and adaptation response (Uisso 2015).

How agroforestry interventions are suitable for climate change mitigation?

Climate change is one of the greatest global challenges in recent time that needs to be addressed due to its adverse induced changes. The stabilization of CO2 and other GHG emissions is thus the most important approach to mitigate climate change (Du et al. 2015). A study of agroforestry adoption in Kenya suggests three opportunities related to historical increases in tree domestication and management intensity; high variability in individual farmers' tree-growing strategies; and reduction of costs and risks associated with new agroforestry practices (Scherr 1995). Both top-down and bottom-up interactions on climate change adaptation strategies are needed in Ethiopia. Agriculture and forestry should work jointly in AFS that are complex assemblages of tree-based ecosystem which respond positively to climate change (Luedeling et al. 2014; Tolentino et al. 2011). Some of the challenges and opportunities were discussed by Uisso (2015) in improved fallows and homegardens of Sukuma agro-pastoralists. Researchers have been working in the existing knowledge on climate change adaptation via agroforestry, which are synthesized as a basis for decision making for future adaptation strategies.

Agroforestry refers to the integration of tree species with crops and/or pastures on the same land unit resulting in economical and ecological benefits (Mbow et al. 2014; Verchot et al. 2007). There are many types of AFS that are practiced at different levels to increase the SOC stock, productivity, and mitigate climate change (Mowo et al. 2013; Uisso 2015). It has been reported that accelerated carbon depletion in Ethiopia occurs on an estimated 0.2 million ha of forest land and on 8 million ha of croplands in two cropping seasons (Shete 2015). AFS involve careful selection of tree crops to optimize the production and positive effects of climate change. The history of forest and agricultural management practices at various levels, however, have not yet given adequate attention either to the traditional AFS or to the rights of local communities in the formulation of policies to combat climate change (Parrotta and Agnoletti 2012).

Agroforestry practice use in climate change mitigation and adaptation strategies

Mitigation and adaptation are the two main strategies that are used effectively to address climate change (Rizvi et al. 2015). Mitigation is an intervention to reduce the sources of emissions or enhance the GHG sinks whereas adaptation is an adjustment in natural or human systems in response to actual or expected climatic stimuli, which moderates harm or exploits beneficial opportunities (IPCC 2006). AFS can contribute toward "climate-smart agriculture" that can increase sustainable productivity, carbon sequestration and strengthen food security. Various agroforestry practices had been shown in four agro-ecosystems (two highlands and two lowlands case studies) in Ethiopia and Kenya

(Mowo et al. 2013). The following agroforestry practices were forwarded by these authors:

a). Leaving land fallow is a means of allowing depleted soil to recover some of the fertility lost through continuous cropping with limited or no fertilizer application. Apart from natural fallow, improved fallow is used by farmers as a strategy that consists of planting legume tree species, in order to enrich the soil nitrogen within a shorter time period (Kwesiga et al. 1999).

b). Rotational woodlot is an agroforestry option that attempts to simulate the traditional fallow system in shifting cultivation, where trees contribute to maintain soil fertility through nutrient cycling.

c). Alley farming is the planting of trees or woody shrubs in two or more sets of single or multiple rows, with agronomic crops cultivated in the alleys between the rows. This agroforestry practice is used to diversify farm products; reduce surface water runoff and erosion; improve use of nutrients; modify the microclimate for improved crop production, and enhance the aesthetics of the area.

d). Live fencing can serve as productive and ecologically valuable components of AFS.

e). Windbreaks are strips of trees and/or shrubs planted to alter wind flow and improve microclimate, thereby protecting a specific area. Like other agroforestry practices, windbreaks store substantial amounts of carbon and can provide nitrogen for crops, and fodder for livestock.

f). Riparian forest buffers are natural or re-established streamside forests made of tree, shrub, and grass plantings. They shield non-point source pollution of waterways from adjacent land, reduce stream bank erosion, protect aquatic environments, and enhance wildlife.

g). Forest farming practice has high value specialty trees and shrubs crops, e.g., coffee is grown under the protection of a managed forest canopy that has been modified to provide the correct shade level.

h). Homegardens are integrated tree crop-animal production systems that have been established on small portion of land surrounding homesteads. It comprises numerous indigenous and introduced woody species in close, multi-storied association with herbs, perennial tree- and enset-based crops, and livestock all managed in traditional farming system (Photo 4).

Photo 4 : Wonchi (left) and Bonga-Kefecho (right) homegardens in Southern Ethiopia

I). Fodder banks are concentrated units of forage legumes established and managed by pastoralists near their homesteads as a means of providing additional protein for cattle during the dry season. Agroforestry practices such as the planting of fodder trees and shrubs, or fruit trees along the contours and edges of bench terraces will retain the soil protection structures in steep land and cropping systems. According to Yohannes (2016), terracing and different water harvesting practice are widely used in Konso (southern Ethiopia), where it has been registered as UNESCO World Heritage Monuments.

j). Silvopasture is an agroforestry practice that integrates livestock, forage production, and forestry on the same land-management unit. Silvopasture systems are deliberately designed and managed to produce a high-value timber product in the long term, while providing a short-term annual economic benefit from a livestock or from an annual crop component.

Other agroforestry practices that serve as adaptation means of climate change were noted by Yohannes (2016). These are: change crop variety involves altering from one crop variety to another in response to climatic changes (for example, introducing Avena species (Gench) as fodder crop in some Ethiopian highlands). Change in cropping pattern and calendars are the applications of changes in how crops are cycled within a season. This helps greatly for the farmers live in East Gojam (Choke Mountain) and East Hararghe in Ethiopia. Change farm management practices include OA practice focus on maintaining diverse farming systems and source of incomes.

Agroforestry as a Solution for Addressing Future Challenges

Agroforestry can contribute variety of climate change mitigation directly to effective, efficient and equitable REDD+ as a part of complementary landscape-level actions (Gizachew et al. 2017). Indeed, the environmental services provided by agroforestry mean that its adaptation potential extends well above the farm level such as addressing some of the drivers of deforestation related to energy demand (Mbow et al. 2014). Agroforestry practitioners need to be linked to carbon credits that farmers can get financial assistance to increase their adaptive capacity to climate change (Uisso 2015). Moreover, Mowo et al. (2013) reported that further research is required in the following areas:

- Better understanding of the contribution agroforestry practices to adapt and mitigate climate change and how climate change affects AFS
- Adoption and adaptation of agroforestry practices by farmers
- Development of methods and approaches scaling agroforestry technologies to attain landscape level impacts
- Identification of agroforestry tree species for different agroecological and farming systems that meet both production and ecological objectives in general and for the domestication and promotion of trees species suitable for agroforestry in drylands
- Development of appropriate policies and institutional infrastructure to promote adoption of agroforestry.

CONCLUSIONS

Several reviewed literatures in the present paper indicated that the knowledge of both traditional agroforestry practices and science-based approaches has dual purposes to increase crop production and carbon sequestration. Mitigation GHG emissions mainly relies on appropriate agroforestry activities. In Ethiopia, AFS are more complex and very important backbone of country's economy. Integrated tree based and soil-crop management system is a feasible solution for increasing agricultural productivity, biotic carbon sinks and several ecosystem services. It has been proved by different researchers in many countries that many legume trees (such as, *F. albida* and *S. seban*) can improve the yield of crops grown under their canopy.

Generally, plantation and agroforestry management practices are the most useful options for offsetting CO_2 emissions.

Improving co-operation between nations' farming, forestry sectors and stakeholder consultations will help to reduce deforestation; engage farmers in agroforestry practices; improve food security and carbon markets in Ethiopia. Future researches on these areas may also improve the effectiveness of agroforestry management systems through improved fallows with legume trees, perennial crops and indigenous tree plantations. The implementation of international agreements and convention about climate change and agriculture could alleviate the pressure on the environment and still need more focus on this scenario.

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