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Agroforestry: A Supplementary Tool for Biodiversity Conservation and Climate Change Mitigation and Adaptation

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Abstract
Biodiversity loss and climate change are the major global problems threating livelihoods in developing countries. Agroforestry as an integrated land use system has been proved to reduce these problems. However, contributions of agroforestry for conservation of flora and fauna biodiversity and reduction climate change impacts faced empirical evidence. This paper aimed to provide empirical information on role of agroforestry for conservation of flora and fauna biodiversity and climate change mitigation and adaptation. The result reveled that agroforestry has played a greater role for conservation of fauna and native flora diversity and mitigation of CO_2 than monocroping and open cereal based agriculture but less than natural forest. The tree components of agroforestry are important for biodiversity conservation, CO_2 sequestration and climate change adaptation. CO_2 sequestration through above and ground biomass, offsetting CO_2 emission from deforestation and microclimate modification are major climate change mitigation effect. Provision of numerous ecosystem services such as food, fodder and fuel wood, income source, enhancing soil productivity, protecting pest and increased resistance to diseases help community to sustain changing climate effects.. Hence, considerable attentions need to be given to agroforestry to contribute considerable benefit in conservation of biodiversity, and climate change mitigation and adaptation next to forest.
Keywords: Agroforestry, flora and fauna diversity, mitigation of CO_2, ecosystem services.
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1. Introduction

Biodiversity and their ecosystems are crucial for human well-beings. Biodiversity forms the foundation for vast array of ecosystem services that critically contribute to human well-being (MEA, 205).They provide ecosystem services such as soil fertility, clean water and food, especially for poor people in developing countries, whose livelihoods are closely linked to natural resources (Olivier et al., 2012). Forests sustain the livelihood of more than 1.6 billion people worldwide (Aerts and Honnay, 2011) and about 55 % of global forest carbon (Pan et al., 2011).

However, current land degradation including biodiversity loss and climate change has seriously challenging the world. Land degradation is increasing in severity and extent in many parts of the world estimated to affect 2.6 billion people in many countries (Adams and Eswaran, 2000). Due to forest fragmentation, nearly 20% of the world's remaining forests are within 100 m of an edge in close proximity to modified environments where impacts on forest ecosystems are most severe. Forest removal and fragmentation, therefore reduces biodiversity up to 75% and impairs key ecosystem functions by decreasing biomass and altering nutrient cycles (Haddad et al., 2015). Repots revealed earths have lost more than 3/4 of its species in the past 540million years and now may under the way to sixth mass extinction (Barnosky *et al*., 2011). The loss of biodiversity and ecosystem integrity due to conventional agriculture approach (Godfray *et al.,* 2010; Pretty and Bharucha, 2014; Maxwell *et al.,* 2016; Waldron *et al.,* 2017) are now increasingly challenging social and environmental system. The impact of climate change greatly threat agriculture productions and food security more in many developing countries (Cotter and Tirado, 2008). Moreover, conflicts of interests between conservationist and agriculture sectors on biodiversity reserve area were intensified in tropical human-dominated landscapes (Mukul and Saha, 2017). The above all indicated that conservation of biodiversity (both flora and fauna) merely in natural reserve is proved to be difficult. Thus, reduction of biodiversity loss, mitigation and adaptation of climate change at the same time safeguarding agriculture productivity and food security through sustainable natural resource use requires new technologies in agriculture and conservation system. From this point of view, different scholars (e.g. Godfray and Garnett, 2014; Pretty and Bharucha, 2014; Seneviratne *et al.,* 2015; Waldron *et al*., 2017) suggested the need to focus more on agriculture practice that can multi-functionally increase food production while simultaneously enhancing social and environmental goals. Recently, role of tree in agriculture has gotten important place in achieving environmental sustainability, food and nutritional insecurities while successfully mitigating impacts of climate change (David and Gailyson, 2013; Getachew and Mesfin, 2014; Seneviratne *et al.*, 2015).

Agroforestry system where trees on farmland form an integral part of the farming system has usually biological, ecological and economical interactions among the components (World Agroforestry Center, 2006) produced positive mixing effects, or complementarity effects in the system (Brockerhoff *et al*., 2017). Agroforestry system provides natural elements of semi-natural vegetation and shelters for many species (Molla and Asfaw, 2014; Hartoyo *et al.,* 2016) and helps preserve germplasm of sensitive species and providing other ecosystem services such as erosion control and water recharge (Molla and Asfaw, 2014). Besides, it play roles in climate change adaptation through its considerable maintenance of intraspecific genetic variation at the landscape level (Dawson *et al.,* 2014) and carbon sequestration in woody biomass (Verchot, 2007) and in the soil (Nair *et al.,* 2009). Agroforestry help people to resist climate change effect through increasing agricultural productivity and environmental resilience (Ofori *et al.,* 2014; Waldron *et al*., 2017). The direct benefits of ecosystem services and other indirect benefits such as global climate change mitigation through carbon sequestration and microclimate modification (Seneviratne *et al*., 2015) are crucial in increasing resilience of crops and farm livelihoods (Dawson *et al.,* 2014; Mbow *et al.*, 2014; Waldron *et al*., 2017). Through its diverse use, agroforestry has served to bridge the conflict and the divide that often exists between the need for conservation of biodiversity and provision of needs of human society (McNeely and Scherr, 2003) and enhancing carbon sinks (Nair *et al*, 2010; Jose and Bardhan, 2012).

Although the potential contribution of agroforestry systems for conservation of biodiversity is still in argument (Harvey *et al.,* 2007) and undeveloped and remains largely unexplored (Seta and Demissew, 2017). Furthermore, empirical evidence about the links between agroforestry and livelihood resilience of households (Lin 2011; Nair and Garrity, 2012) especially related to climate change mitigation is scarce. These all are due to lack of comprehensive empirical information. Therefore, the objective of this paper is to provide empirical evidence on specific role of agroforestry in conservation of floral and faunal diversity and climate change mitigation and adaptation and some of the aspects determining its role in conservation.

2. Role of agroforestry for biodiversity conservation and climate change mitigation and adaptation

2.1 Potential of agroforestry for conservation of floral diversity

Agroforestry practices have often been shown to increase levels of wild biodiversity on farm land, and able to play a supporting role in the conservation of biodiversity in remnants of natural habitat that are interspersed with farm land in tropical land use mosaics (Jeffrey *et al*., 2006). The role agroforestry in conservation vary across the world with type (Table 1) and management of agroforestry so that different investigators recorded different number and composition of plant species including exotic and native species.

Table 1. Biodiversity dimensions in traditional agroforestry systems in the tropics.

Agroforestry system	Biodiversity issues
Shifting cultivation or slash-and-burn	Fallows consist of multiple species; and biological diversity, in both inter- and intra-species, is intense. Long fallow periods of 15 to 20 years preserve wild species diversity
Homegardens and compound farms	High inter- and intra-species diversity involving a number of fruit, fodder and timber trees and shrubs, food crops, medicinal and other plants of economic value
Forest gardens / agroforests	Maintain high species diversity similar to natural forests but dominated by a few carefully managed economically valuable tree species
Parkland systems	A variety of crops grown in association with naturally propagated trees ensure wide species diversity. Parks range from monospecific to multispecific with up to 20 tree species.
Trees on farmlands (boundary plantings, scattered trees)	Diversity is more at the landscape level rather than at field level in terms of both inter- and intra-species.

Source: Atta Krah et al. (2004)

Study in Ethiopia (e.g. Worku and Bantihun, 2017) showed agroforestry has potential to conserve economically and environmentally important species of indigenous tree such as *Acacia tortilis*, *Acacia nilotica*, *Balanites aegyptiaca*, *Tamarindus indica*, *Tamarix* spp., and Z*iziphus* spp., which are used as source of fodder, food, medicine, fuel wood, farm tools and wood for utensils. Talemos *et al.* (2013), reported communities practices in agroecosystem for maintain annual and perennial herbs and woody perennials of diverse species and useful plant categories fulfilling the subsistence and cash needs of households in Ethiopia. They also reported about 159 species in homegarden of which 112 are categorized as useful to the community and 23 species are medicinal valued plants. Molla and Kawessa (2015) also identified 50 woody species (of which 85% were indigenous) belonging to 31 families in traditional agroforestry practices in Ethiopia. Kassie (2015) also described 43 woody plants belonging to 25 families. Framers, for instance in Bako, Ethiopia has practiced intercropping of maize under endangered tree species such as *Cordia africana* for long time help conservation such species (Hoekstra *et al*., 1990). Bachi(2017) also reported 60 woody species with multipurpose including *Cordia Africana* in different agroforestry system. Study carried out in Atlantic Nicaragua showed small, diversified agroforestry systems have the potential to maintain comparable species richness and phylodiversity to uncultivated secondary forests plant diversity and greater biomass than lower diversity crop or pasture systems (Sistla *et al.,* 2016). Some studies in this area and elsewhere (e.g. Jose, 2009; Cadotte *et al.,* 2011) indicated that allowing agroforestry systems to develop alongside secondary forests and reserve areas may be a viable strategy to promote biodiversity conservation.

Besides, agroforestry maintaining a quite a very good number of native plants spices that are deteriorating or facing a risk of disappearance in the natural habitat (Figure 1&Table 1). For instance Tadesse *et al.* (2014) reported about 19 native woody species including rare/threatened species such as of *Baphia nitida, Cordia africana, Manilkara hexandra,* and *Prunus africana* in smallholder coffee farm agroforestry.

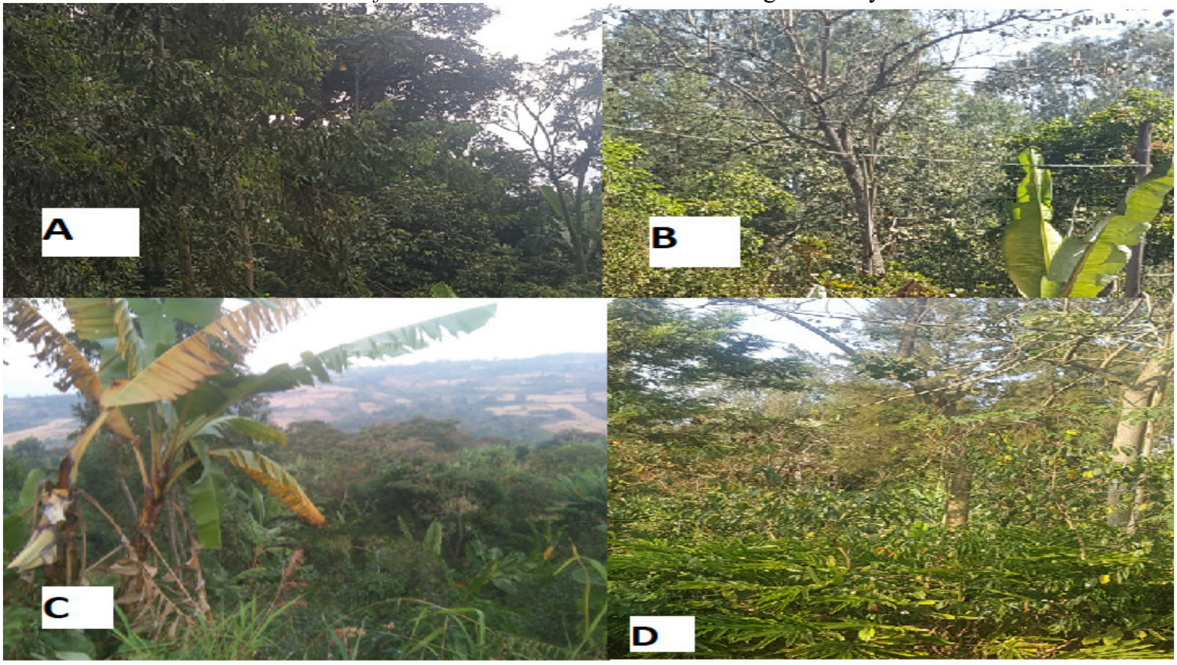

Figure 1. Diversity of species in homegarden agroforestry consists of *Cordia african*(A, B, C &D), *Aframomum corrorima(D, Enset ventricosum*(A&B), *Musa paradisiaca* (C)(Photos taken from Bench-Maji zone (A&C) and Jimma zone(B&D) by Mulatu, 2019).

The study also revealed 22 native woody species were recorded as of interest for conservation to IUCN Red lists and local criteria. Among these, *Pygeum africanum* and *Rhus glutinosa* were categorized as vulnerable in the wild, and in need of conservation priority. Negash *et al.*(2012), also reported total of 58 woody species, belonging to 30 families from three agroforestry practices (enset-AF, enset-coffee-AF and fruit-coffee-AF) of which enset-AF maintain the highest (92%) proportion of native woody species followed by enset-coffee-AF (89%). Kassa *et al*. (2018) also revealed that agroforestry are conserving endemic plant species that are listed in the endangered category of IUCN. They also indicated that agroforestry consist of more common species 30% higher than evergreen forest and 36% higher than in cropland. Tadese(2013) also found that over 60% of woody species and associated biodiversity can be conserved in shade coffee based systems.

Furthermore, de Souza *et al.* (2012) identified a total of 231 tree species from eight different agroforestry and found that 78% of tree species were native species. Some report (e.g., Lopez-Gomez *et al.,* 2008; Negawo and Beyene, 2017) also showed that coffee agroforestry contains higher number of tree and shrub species than that of the forest reserve. Similarly, Bandeira *et al*. (2005) in Mexico reported higher (45) wild plant species recorded in coffee agroforestry than in forest (34). Guyassa and Antony Raj (2013) reported that agricultural landscape play a major role in the conservation of native woody species in which 39 woody species were recorded compared to only 23 woody species recorded in enclosures indicating highest species richness on agricultural land uses than in forests. This showed proper management of agroecosystem taking into account the crucial role of plant biodiversity in ecosystem services are vital for sustainable diversity conservation,

Table 2. Role of agroforestry practice for conservation of native species

Agroforestry practice	Number of species		Sources
	Total No of spp. count	% native spp.	
Coffee agroforestry	63	73	Negawo and Beyene, 2016
Enset-AF, Enset-coffee-AF and Fruit-coffee-AF	58	86	Negash *et al,* 2012
Homegarden	36	25	Mulatu, 2019
Traditional AF	55	85	Molla and Kawessa, 2015
Traditional AF	77	33	Kassa et al(2018)
Farmland	77	70	Endale *et al.,* 2015
homegardens	419	247	Kabir and Webb, 2009
Different AF practice	231	78	De Souza, 2012
Homegarden, Parkland, woodlot	33	67	Bajigo *et al.,* 2015
homegarden, parkland and woodlot	32	69	Bajigo and Tadesse, 2015
Homegarden, Parkland, woodlot	80	71	Ashebir, 2011
Traditional agroforestry	86	83	Asfaw and Lemenih, 2010
Homegarden	120	100	Abebe, 2005

The above discussion also elucidated that the conservation role of agroforestry is higher than cereal based open agriculture and monocropping but lower than natural forest. Other studies (e.g. Rolim and Chiarello, 2004; Oke and Odebiyi, 2007) confirmed that, for instance, Cocoa agroforestry (*Theobroma cacao*) the so-called 'cabruca system' are not only less diverse and less dense than primary forests or reserved forest. Oke and Jamala (2013) also revealed that though agroforestry is contributing key role in conservation of plant species diversity, it contains less diversity than forest and higher than monocropping and other open agricultural landscapes. Though, agroforestry systems are a poor substitute for the natural forest, the heterogeneous mosaic landscape in which complex agroforestry forms part can be strategically managed to maximize the benefits of both sustainable agriculture production and conservation of plant diversity by acting as buffer between protected areas and intensively managed areas (Asase and Tetteh, 2010). Furthermore, agroforestry is the alternative for biodiversity conservation in environmental limited areas such as dry land areas with scarce moisture and degraded land in addition to area closures activities (Guyassa and Antony Raj, 2013).

In above research and other findings, different socio-economic factors determined the composition and diversity of woody species in different agroforestry system in different ecoregions. For instance, the management practices of 'cabruca system' in southeastern Brazil, such as thinning and clearing of native trees triggered the long-term survival of these forests questionable and limited their role in maintaining biodiversity in the long run(Rolim and Chiarello, 2004). Mukul and Saha (2011) disclosed that plant biodiversity is highly sensitive to management intensification hence different species group varied considerably on types of agroforestry systems, and the kind of , and the response of different plant functional groups to different management regimes management and expected products. The study also showed some practice such as betel-vine agroforestry system evolved through indigenous innovation and culture is more suitable for conservation of plant biodiversity and could offer a basis for sustainable forest management.

Furthermore, factors such as the contribution of tree species in agroforestry system on farmer income, farm size (Wafuke, 2012; Talemos *et al.*, 2013; Editha, 2016) and distance of farm from tree nursery (Najma *et al.*, 2016; Bachi, 2017) and education level of the household head (Zerihun *et al.*, 2014; Najma *et al.*, 2016; Ndolo *et al.*, 2016; Bachi, 2017) are also important. In addition to this, plant diversity in agroforestry is influenced by different factors such as socio-economic status, soil fertility, rainfall pattern, management system, proximity to market and roads, cultural preferences and personal preferences (Talemos *et al.*, 2013; Bachi, 2017). This implies that conservation role of agroforestry are determined by the biophysical setting of the landscape and socio-economic significance and practices of agroforestry. Therefore, understanding the limitation, potential and determining factors in of agroforestry for conservation of biodiversity is crucial to maximize plant biodiversity in agroforestry and ecosystem services.

2.2 Agroforestry for conservation of faunal diversity

Agroforestry is increasingly being acknowledged as an integrated land use that can create multipurpose ecosystem services for wild species. Tree in multiple-use can contribute to wild biodiversity through the maintenance of landscape connectivity, heterogeneity and complexity of vegetation structure, integrity of aquatic systems, and cleaner water. Trees can contribute nesting sites, protective cover against predators, access to breeding territory, access to food sources in all seasons, and encourage beneficial species such as pollinators (Swallow et al., 2006). Evidence from Amazonian rainforest area revealed agroforestry systems contain higher insect species richness and abundance than monocultures and degraded grasslands. Cocoa based agroforestry, currently cover vast hectares of tropical area are considered to be the biodiversity reservoirs for some of the rainforest insect species (Perry *et al.,* 2016). Agroforestry with multistrata characterized by a high diversity of trees, shrubs and annual plants in the undergrowth can form more complex and suitable environment for various insect species than cocoa agroforestry or mono-cropping fields. Rice and Greenberg (2000) and Bos *et al.* (2007) reported that the species abundances in cocoa are higher than mono-cropping which showed the contribution of cocoa species contribution. In Costa Rica, Harvey *et al.*(2007) reported bat and birds assemblages that were as (or more) species-rich, abundant and diverse as forests, however the species composition of birds assemblages was highly modified, with fewer forest dependent species, more open area species and different dominant species in agroforestry systems. Similarly, Greenler and Ebersole (2015) reported about 106 species, mostly those preferring open areas, occurred in agroforestry habitats such as shade-grown cacao, live fences, riparian forest buffers, and preserved late-successional rainforest but not rainforest study in Costa Rica. Other studies (e.g. Berges *et al.,* 2010; Seaman and Schulze, 2010) reported several types of tropical agroforestry systems, including live fences, riparian forests, and shade-grown crops, have been touted to benefit avian conservation and functionally extend adjacent preserves.

Several studies also indicated agroforestry systems provide habitat for diverse populations of birds, with the greatest amount of evidence pointing towards the habitat value of shade-grown coffee and cocoa systems in Southeast Asia and Central America (Buck et al., 2004). Harvey *et al.,* (2007) reported total of 132,460 dung beetles of 52 species and 913 tracks of 27 terrestrial mammal species in indigenous cocoa and banana agroforestry systems, which maintain an intermediate level of biodiversity (i.e. less than that of the original forest but significantly greater than that of plantation monocultures) and provide suitable habitat for a number of forest-dependent species. Bos *et al.* (2007) found that species richness of ants and beetles in the canopies of the cacao trees was similar to that found in lower canopy forest trees; however the composition of communities differed greatly between the agroforestry and forest sites. Studies in southern Cameroon and eastern Brazil have been credited the biodiversity conservation role of cocoa agroforestry in the humid forest zone, including birds, ants and other wildlife (Rice and Greenberg, 2000). Sileshi and Mafongoya (2006) reported about the same diversity and abundance of soil invertebrates as the miombo woodlands were harbored in agroforestry practices. This finding therefore suggested that protection of the remaining forest fragments will critical for the conservation of intact animal assemblages in agricultural landscapes and should continue to form the backbone of conservation strategies. Tree cover typically retained in agricultural landscapes in the neotropics may provide resources and habitats for animals. For example, over 20,000 individuals of 189 species including 14 endangered bird species were recorded in tropical agroforestry (Harvey *et al*., 2006). The study showed species assemblages of all animal taxa were different among tree cover types; so that that retaining tree cover within agricultural landscapes can help conserve animal diversity, but that conservation efforts need to target forms of tree cover that conserve the taxa that are of interest locally. Therefore, the above findings indicated agroforestry contributed important part in conservation of faunal diversity.

However, the role of agroforestry has been challenged by conflicts between human being and wildlife and offset by heavy hunting pressure. The loss of natural habitat and feeding site for wildlife species has led to the encroachment of wildlife population into the adjacent farm land and around living house caused conflicts with human being and have caused to the removal of plant species and reduction forest are some of challenge. For instance, farmers' strategies to mitigate crop damage by wild mammals such as baboons and bush pigs, e.g., migration and allocation of migrants on lands along forests, have contributed to a reduction in forest and tree cover in the agricultural landscape (Ango et al., 2014). Mulatu (2019) also reported that household in Jimma cities are forced to remove tree around their home because of wildlife disturbance. Furthermore, heavy hunting pressure tends to offset the potential beneficial effect of the agroforestry systems (McNeely and Schroth, 2006; Harvey *et al.,* 2007). For instance in Talamanca the reserves in Costa Rica, heavy hunting pressure major problem (McNeely and Schroth, 2006). The study also illustrated that diversified land use systems should be supplemented with other measures such as hunting control to maintain high levels of biodiversity in agricultural landscapes. However, indigenous agroforestry systems maintain lower level of biodiversity than original forest but higher than that of monocultures (McNeely and Schroth, 2006).

Therefore, the studies highlighted the need for faunal conservation perspective agroforestry management plan, integration wildlife conservation policy and strategy (e.g. controlling hunting) and conservation natural habitat to supplement conservation effect agroforestry system.

2.3 Agroforestry for climate change mitigation

Agroforestry is biological greenhouse gas (GHG) such as CO_2 mitigation strategy under the Kyoto Protocol (Nair et al., 2009). The tree components of agroforestry systems are the important sinks of atmospheric carbon (Henry *et al*., 2009; Gupta *et al.,* 2017). The key roles of agroforestry in climate change are mitigation of greenhouse gases (GHG) emissions (Morgan *et al,* 2010) through its manifold plant species and soil and indirect effects such as decreasing pressure on natural forest or soil erosion. Agroforestry systems show significant carbon accumulation in living biomass, as well as soil organic carbon (SOC), demonstrating the potential to offer the environmental service of carbon sequestration. It can also contribute to reducing CO_2 emissions by avoiding burning of forest-based fuelwood and conserving soil from erosion.

Empirical studies shows that the carbon sequestration potential in aboveground components of agroforestry systems is estimated to about 2.1×10^9 Mg C year^{-1} in tropical and 1.9×10^9 Mg C year^{-1} in temperate biomes (Oelbermann *et al.,* 2004). In humid tropics, over 70 Mg Cha^{-1} (e.g. Table 3) were sequestration in top 20 cm of the soil of agroforestry (Mutuo *et al.,* 2005). According to Nair *et al*. (2010), the available estimates of C stored in agroforestry range from 0.3 to 15 Mg C ha^{-1}year^{-1} above ground, and 30–300 Mg C ha^{-1} up to 1 m depth of the soil. Kassahun (2019) also recorded a total biomass carbon of about 2,877.13Mgha^{-1} in Jimma zone, Ethiopia. Bajigo *et al.* (2015) also described different amount carbon stored in different agroforestry practices in Ethiopia such that woodlot contained significantly higher total carbon (448 Mgha^{-1}) followed by homegarden (86 Mgha^{-1}) and parklands (51 Mgha^{-1}). Henry et al. (2009) obtained a largest above ground carbon pool in homegarden (31.1 Mgha^{-1}) next to woodland (162 Mgha^{-1}) and least in crop land (e.g. pasture 13.8Mgha^{-1}, cash crop 13.1Mgha^{-1} and cropland 10 Mgha^{-1}). Kassa *et al*. (2017) also reported carbon stock ranged from 29 to 87 Mgha^{-1} in soil layers (0-80cm) with a comparable total of 406 Mg ha^{-1} in agroforestry with respect to 412 Mg ha^{-1} recorded in evergreen forest of southwest Ethiopia. According to Denu et al. (2016), Ethiopia's semi-forest coffee agroforestry retains 75% of the carbon stored in natural forests. Atangana *et al*. (2014) also reported that shaded-perennial-crop-based agroforestry systems have great potential for soil carbon sequestration. The above research results suggested that agroforestry has a comparable potential to forest to mitigate GHG emissions.

Table 3. Potential carbon storage for agroforestry systems in different ecoregions

Agroecological zones	Major Agroforestry systems	SOC (Mg ha-1)
Humid tropical lowlands	Silvopasture	134.5
Arid and semiarid lowlands	Silvopastoral	91.82
Dry lowlands	Silvopastoral	132.5
Humid tropical high	Silvopastoral	143.5
Humid tropical low	Silvopastoral	207
Tropical highlands	Silvopastoral	152.5
Arid and semiarid lowlands	agrosilvopastoral	74.6
Humid tropical lowlands	agrosilvopastoral	113.5
Humid lowland	Agrosilvicutural	70.5
Arid and semiarid lowlands	agrosilvicultural	19.54

Source: Adapted from Krankina and Dixon (1994) and Nair *et al*. (2009)

However, more than a few researches revealed that natural forest have stored much more carbon stock than agroforestry. For instance, Abeysekara *et al*.(2018) reported a total 4,453.55 Mg ha^{-1} biomass carbon forest in Sri Lanka, which was higher than reported by Kassahun (2019) (884.18 Mgha^{-1})of above ground carbon in Jimma zone, Ethiopia. Justine *et al*. (2015) also estimating the capacity forest ecosystem to store up to 263.16 Mgha^{-1} carbon. Kassahun *et al.(*2015) also reported the mean total carbon stock density of 585.40Mgha^{-1}in natural forest. Ullah and Al-Amin (2012) also estimated the total carbon stock of the forest was 283.80 Mgha^{-1} in natural forest of Bangladesh. Moreover, the amount of carbon stock reported from different part of the world very largely affected by different factors such method of carbon estimation, natural variability of soil and inconsistency in use of term carbon stock (Atangana *et al*., 2014).

The environmental, socio-economic, tree species and system management factors that affect structure and function of vegetation have direct impact on total CO_2 sequestered by plant across the world (Albrecht and Kandji, 2003). Hu *et al*. (2015) demonstrate that both biomass carbon and soil carbon densities are sensitive to species composition and community structure. Rodríguez-Soalleiro et al. (2018) also reported that carbon concentrations increased with a trend to reach 50% in the older trees while Justine et al. (2015) showed the total carbon storage in the system varies with stand ages. Krankina and Dixon (1994) and Nair et al. (2009) also reviewed the influence of age and ecology on the amount carbon stored and sequestration potential of agroforestry in different ecoregion. Therefore, long term contribution of agroforestry in mitigation of CO_2 can be achieved through better management of agroforestry system with appropriate consideration of different factors responsible for variation of carbon stocks such as composition and diversity of woody components and their management in agroforestry and soil conservation.

2.4 Agroforestry for climate change adaptation

The tropical agricultures, particularly subsistence agriculture, are vulnerable to climate change (Verchot *et al.,* 2007). The agricultural production in Africa undergoing sustainability challenges due to degradation of soil fertility, water and biodiversity loss so that the yields of important cereals crops (e.g., maize) have stagnated at 1tone ha^{-1} (Carsan *et al.,* 2014). Hence, production of insufficient food for household in smallholder' farmers, especially in area vulnerable climate change and variability greatly threat their livelihoods. As smallholder farmers do not have adequate resources to adapt to climate change, agroforestry role to play in helping them to adapt to climate change (Ekpo and Asuquo, 2012; Lasco *et al*., 2014). Agroforestry is beneficial both at farm and landscape scales having the potential to enhance the resilience of smallholders to current and future climate risks including future climate change (Hoang *et al.,* 2014; Lasco *et al*., 2014). They are vital to sustain households even in area where water, soil and biodiversity are degraded (Hoang *et al.,* 2014). The trees component in farming has played a significant role in enhancing land productivity and improving livelihoods (Murthy *et al.,* 2013) through provision of multiple direct and indirect ecosystem goods and services.

According to Franzel et al. (2014), fodder trees in agroforestry system are particularly important in the highlands of Eastern Africa mainly to feed dairy cows meet production shortages in times of extreme climatic conditions such as droughts. Such fodder trees are easy to grow, require little land, labor or capital, have numerous by-products and often supply feed within a year after planting though there are key challenges constraining the uptake of fodder trees include limited species appropriate to different agroecological zones, shortages in seed and that farmers lack knowledge and skills needed to grow them.

Agroforestry practices such as parklands are important through trees and shrubs by providing soil cover that reduces erosion and buffers the impacts of climate change. They provide green fodder that complements crop residues for livestock feeds, and fruits and leaves for human consumption and for income generation of farmers in risk prone environments such as Sahelian zone of West Africa. The interactions between various components of agroforestry system influence the ecosystem service functions of trees of parklands (provisioning, regulating and supporting services) in several ways (Bayala *et al.,* 2014). Agroforestry also played critical role in energy provision in sub-Saharan Africa (SSA), and is predicted to remain dominant within the energy portfolio of the population in the coming decades through provision of woodfuels (Iiyama et al*.,* 2014). For instance, Asase and Tetteh*,* (2010), reported that out of the 20 species recorded in agroforestry in Ghana, 100% of them being used as fuel wood while 83% of them used for medicines. A study conducted in western Kenya also confirmed that presence of trees on farms provided a more accessible, safe and stable source of fuelwood for energy and income, particularly benefiting for women (Thorlakson and Neufeldt, 2012). As Syampungani et al. (2010) stated, well designed and properly managed agroforestry have some degree of beneficial effect on yield and income and potential for sustained production. For instance, species in homegarden play critical roles in small scale household honey production (Sileshi et al., 2007) (Figure 2) for income generation. Similarly, Bachi (2017) reported that about 24.4% and 10% of the respondents were used woody species for income and bee keeping respectively helps them to buy subsistence food at market. Various report also confirmed agroforestry adopter have better cash income (Linger, 2014; Kassa, 2016; Bachi, 2017) and in food security (Kassa, 2016). In southwest Ethiopia, Tadesse (2013) reported that coffee based agroforestry sources for 46% of the honey produced for market in 2010. Mekonen et al. (2015) described that about 25 % plant species recorded were used for food, 13% for medicine and 10 % for household tools in Ethiopia*.* Fertilizer trees species (FTS) are widely documented to substantially increase maize yields compared to maize production without fertilizer in Zambia (Pretty *et al.,* 2011).

Figure 2. Traditional bee hives hanged on *Acacia spp.* (left) *and Albizia schimperiana* (right) in agroforestry system in Jimma zone (Photo by Mulatu, 2019)

Trees components in agroforestry are also contribute to food security in Africa in the face of climate variability and change by providing environmental and social benefits as part of farming livelihoods (Mbow *et al.,* 2014). The amount of shade cover play direct role in mitigation of variability in microclimate and soil moisture conservation. This protect the crop of interest from extremes climate events hence reduce the risk of crop failure or reduction of crop productivity. For instance, coffee grown under heavy shade (60-80%) were kept 2-3°C cooler during the hottest times of the day than crops under light shading (10-30%) (Lin, 2007). Lin (2010) also reported that crop grown under open area losses of 41% and 32% moisture through soil evaporation plant transpiration. It was also reported that bean size of coffee under agroforestry (under tree) were higher than under full sun, though more fruiting and beans per node were observing under full sun (Youkhana and Idol, 2010). Agroforestry systems have also a potential to reconcile coffee production with biodiversity conservation under climate change and to contribute to some regulating and supporting ecosystem services (De Souza *et al*., 2012). Study also revealed the diverse traditional cocoa forest gardens may help in regulating pests and diseases and allow for efficient adaptation to changing socioeconomic conditions (Bisseleua *et al.,* 2008). According to Kebebew and Urgessa (2011), tree-based systems are more profitable and less risky than other agricultural options because of the variety of products and have less infected by pest thereby farmers can rescue from dangers. Agroforestry can protect farm production through their naturally occurring co-benefits including enhanced nutrient cycling, integrated pest management and increased resistance to diseases. Agroforestry systems also tend to have increased crop diversity within the agroforestry systems such that a greater diversity in food, fuel, and fodder items is produced for the smallholder farmer as well as by reducing wind damage up to two times the distance of windbreak height(Lin, 2014). Therefore, range of agroforestry systems potentially allow for many different types of adaptation to occur under a range of climatic conditions. However, levels of co-benefits depend on the amount of diversity integrated into the system, as more diversity within the agroforestry system will lead to greater co-benefits (Schoeneberger, 2009). Therefore, the ecosystem services provided by agroforestry directly and indirectly support people and other ecosystem to build resilience to climate variability and change effects.

3 Summary and future prospect

Biodiversity and their ecosystems form the foundation for the vast array of ecosystem services crucial for human well-beings. Agroforestry as integrated land use system can provide important add-on option to conservation of both flora and fauna, mitigating CO_2 and improving livelihood resilience to climate variability and change.

The tree component in agroforestry serve important role in conservation of fauna diversity, provision of ecosystem services (e.g. provision of food, fuel wood, improve crop productivity, increase cash income, etc.) including climate regulation services. They hosts a number of woody species diversity including indigenous and endangered and wild animals such as birds, ants, soil invertebrates and mammals by providing suitable habitat for forest-dependent species. It mitigate CO_2 through sequestration in live biomass and soil and reducing emission from deforestation and soil erosion through reducing burden on natural forestation. The collection of ecosystem services such as food, forage and fuel wood, increasing income and improving crop productivity through enhancing soil fertility, maintaining soil moisture, enhancing nutrient cycle, protecting pest and increased resistance to diseases, protecting wind damage are crucial in helping household to resist undesirable climatic change impacts.

However, agroforestry has less diversity and density of flora and fauna and low carbon storage potential than primary forests and secondary, but it is more diverse and important place than other land uses such as mono-cropping and open/cereal based agricultural landscape. The number of socioeconomic and environmental factor that limits the full potential of agroforestry for conservation and mitigation of CO_2 need to be understood and managed properly.

Besides, successful understanding the potential of agroforestry requires awareness to decision makers and public and support to landowners in terms of technical knowhow and access to and choice of appropriate planting species and management. Future research should emphasis on: identification of appropriate integration agroforestry components, diversification of different agroforestry components and management approaches; analysis of different ecosystem services of different agroforestry system should be emphasized; the role agroforestry for conservation of faunal and soil biodiversity should be improved through further research and the roles of urban agroforestry for conservation biodiversity and climate change regulation.

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