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

Kassahun Mulatu1*  Debelu Hunde2
1. Department of Natural Resource Management, College of Agriculture And Natural Resource, Mizan Tepi University, P. O. Box: 260; Mizan Teferi, Ethiopia
2. Department of Natural resource management, College of Agriculture and Veterinary Medicine, Jimma University, P. O. Box 307, Jimma, Ethiopia

Abstract
Biodiversity loss and climate change are the major global problems threatening 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 revealed that agroforestry has played a greater role for conservation of fauna and native flora diversity and mitigation of CO2 than monocropping and open cereal based agriculture but less than natural forest. The tree components of agroforestry are important for biodiversity conservation, CO2 sequestration and climate change adaptation. CO2 sequestration through above and ground biomass, offsetting CO2 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 CO2, ecosystem services.
DOI: 10.7176/JNSR/9-19-07
Publication date: October 31st 2019

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, 2005). 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 Demisew, 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 remnant 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 | Fallsows 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 Ziziphus 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 species 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 africana(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,
practices of ‘cabruca system’ in southeastern Brazil, such as thinning and clearing of native trees triggered the run (Rolim and Chiarello, 2004). Mukul and Saha (2011) disclosed that plant biodiversity is highly sensitive to 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 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 eco-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 eco-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

---

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

| Agroforestry practice | Total No of spp. | % native spp. | Sources |
|-----------------------|------------------|---------------|---------|
| 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, Greenener 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). Silesli 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 CO2 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 CO₂ emissions by avoiding burning of forest-based fuelwood and conserving soil from erosion.

Empirical studies show that the carbon sequestration potential in aboveground components of agroforestry systems is estimated to about 2.1×10⁷ Mg C year⁻¹ in tropical and 1.9×10⁷ Mg C year⁻¹ in temperate biomes (Oelbermann et al., 2004). In humid tropics, over 70 Mg C ha⁻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 2,877.13 Mg ha⁻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 Mg ha⁻¹) followed by homegarden (86 Mg ha⁻¹) and parklands (51 Mg ha⁻¹). Henry et al. (2009) obtained a largest above ground carbon pool in homegarden (31.1 Mg ha⁻¹) next to woodland (162 Mg ha⁻¹) and least in crop land (e.g. pasture 13.8 Mg ha⁻¹, cash crop 13.1 Mg ha⁻¹ and cropland 10 Mg ha⁻¹). Kassa et al. (2017) also reported carbon stock ranged from 29 to 87 Mg ha⁻¹ in soil layers (0-80 cm) 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.

| Agroecological zones          | Major Agroforestry systems | SOC (Mg ha⁻¹) |
|-------------------------------|-----------------------------|--------------|
| Humid tropical lowlands       | Silvopasture                | 134.5        |
| Arid and semi-arid 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 semi-arid lowlands   | agrosilvopastoral           | 74.6         |
| Humid tropical lowlands       | agrosilvopastoral           | 113.5        |
| Humid lowland                 | Agrosilvicultural           | 70.5         |
| Arid and semi-arid 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 Mg ha⁻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 Mg ha⁻¹ carbon. Kassahun et al. (2015) also reported the mean total carbon stock density of 585.40 Mg ha⁻¹ in natural forest. Ullah and Al-Amin (2012) also estimated the total carbon stock of the forest was 283.80 Mg ha⁻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 CO₂ 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 CO₂ 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 1 tonne 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
benefitting 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 loses 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 CO₂ 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 CO₂ 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 monocropping 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 CO₂ 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.

Reference

Abeysekara, A.M., Yatigammana, S.K. & Premakantha, K.T.(2018). Biomass and Carbon Stock Estimation of Udawattakele Forest Reserve in Kandy District of Sri Lanka. Journal of Tropical Forestry and Environment, 8(2), 13-28.

Gemechu, T.A., Börjeson, L., Senbeta, F., & Hylander, K. (2014). Balancing ecosystem services and disservices: smallholder farmers’ use and management of forest and trees in an agricultural landscape in southwestern Ethiopia. Ecology and Society, 19(1), 30.

Albrecht, A. & Kandji, S.T.(2003). Carbon sequestration in tropical agroforestry systems: Review. Agriculture, Ecosystems and Environment, 99, 15–27.

Asase, A. & Tetteh, D.A. (2010). The role of complex agroforestry systems in the conservation of forest tree diversity and structure in southeastern Ghana. Agroforest Syst, 79,355–368.
Asfaw, B. & Lemenih, M.(2010). Traditional Agroforestry Systems as a Safe Haven for Woody Plant Species: A Case Study from a Topo-Climatic Gradient in South Central Ethiopia. Forests, Trees and Livelihoods, 19, 359-377.

Ashebir, K.(2011). Woody Species Diversity and Management in Traditional Agroforestry Practices in Yeki Woreda, Sheka Zone, Southwestern Ethiopia. M.Sc. Thesis, College of Agriculture, Hawassa University.

Atangana, A., Khasa, D. & Chang, S., Degrande, A. (2014). Phytoremediation in Tropical Agroforestry. In Tropical Agroforestry. 343-351.

Bachi, W. (2017). Determinants of Woody Species Diversity in Traditional Agroforestry Practices in South-Bench District, Southwest Ethiopia. MSc. Thesis Submitted to School of Graduate Studies, Dilla University.

Bajigo, A., Tadesse, M., Moges Y. & Anjulo, A. (2015). Estimation of Carbon Stored in Agroforestry Practices in Gununo Watershed, Wolyaitta Zone, Ethiopia. J Ecosys Ecographe, 5, 157.

Barrosky, A.D., Matzke, N., Tomiya, S., Wogan, G.O., Swartz, B., Quental, T.B., Marshall, C., McGuire, J.L.; Lindsey, E.L.; Maguire, K.C. & Mersey, B. (2011). Has the Earth’s sixth mass extinction already arrived?. Nature, 471(7336), 51.

Bayala, J., Sanou, J., Teklehaimanot, Z., Kalinganire, A. & Ouedraogo, S.J. (2014). Parklands for buffering climate risk and sustaining agricultural production in the Sahel of West Africa. Current Opinion in Environmental Sustainability, 6, 28–34.

Berges, S.A., Schulte, L., Thomas, A.M., Richard, M.I., & Schultz, C. (2010). Bird species diversity in riparian buffers, row crop fields, and grazed pastures within agriculturally dominated watersheds. Agroforest Syst, 79, 97.

Bisseleua, D., Herve, B. & Stefan, V. (2008). Plant biodiversity and vegetation structure in traditional cocoa forest gardens in southern Cameroon under different management. Biodivers Conserv,17,1821–1835.

Boffa, J.M., Turyomurugyendo, L., Barnekow-Lillesø, J. & Kindt, R. (2005). Enhancing Farm Tree Diversity as a Means of Conserving Landscape-based Biodiversity. Mountain Research and Development, 25(3), 212-217.

Bos, M.M., Steffan-Dewenter, I. & Tscharntke, T. (2007). The contribution of cacao agroforests to the conservation of lower canopy ant and beetle diversity in Indonesia. Biodivers Conserv,16, 2429–2444.

Brockerhoff, E.G., Barbaro, L., Castagneryro, B., Forrester, D., Gardiner, B., Gonza ‘lezOlabarria, J., Lyver, P.O.B., Meurisse, N., Oxbrough, A., Taki, H., Thompson, I.D., van der Plas, F. & Jacel H(2017). Forest biodiversity, ecosystem functioning and the provision of ecosystem services. Biodivers Conserv, 26, 3005–3035.

Buyinza, J., Agaba, H., Ongodia, G., Eryau, K., Sekatubu, J., Kalanzi, F., Kwaga, P., Mudondo, S. & Nansereko, S. (2015). On-farm Conservation and Use Values of Indigenous Trees Species in Uganda. Research Journal of Agriculture and Forestry Sciences, 3(3),19-25.

Cadotte, M.W., Carscadden, K.& Mirotschhick, N. (2011). Beyond species: functional diversity and the maintenance of ecological process and services. J Appl Ecol, 48, 1079–1087.

Carsan, S., Stroebel, A., Dawson, I., Kindt, R., Mbow, C., Mowo, J.& Jamnadass, R. (2014). Can agroforestry option values improve the functioning of drivers of agricultural intensification in Africa? Current pinion in Environmental Sustainability, 6, 35–40.

Clough, Y., Barkmann, J., Juhrbandt, J., Kessler, M., Wanger, T.C., Anshary, A., Buchori, D., Cicuzza, D., Darras, K., Putra, D.D.& Erasmi ,S. (2011). Combining high biodiversity with high yields in tropical agroforests. Proceedings of the National Academy of Sciences, 108(20), 8311-8316.

Cotter, J.& Tirado, R. (2008). Food Security and Climate Change: The answer is biodiversity. A review of scientific publications on climate change adaptation in agriculture.

Dawson, I.K., Leakey, R., Clement, C.R., Weber, J.C., Cornelius, J.P, Roshetko, J.M., Vinceti, B., Kalinganire, A., Tchoudjue, Z., Masters, E. & Jamnadass, R. (2014). The management of tree genetic resources and the livelihoods of rural communities in the tropics: Non-timber forest products, smallholder agroforestry practices and tree commodity crops. Forest Ecology and Management, 333, 9-21.

de Souza, H.N., Ron de Goede, G.M., Brussaard, L., Cardoso, J.M, Duarte Edivania, M.G., Fernandes Raphael, B.A., Gomes, L.C. & Pulleman, M.M. (2012). Protective shade, tree diversity and soil properties in coffee agroforestry systems in the Atlantic Rainforest biome. Agriculture, Ecosystems and Environment, 146,179–196.

Editha, P.R. (2016). Motivational Factors on the Adoption of Natural Farming Technology International Science Congress Association. Research Journal of Agriculture and Forestry Sciences, 4(1), 14-19.

Ekpo, F.E. & Asuquo, M.E. (2012). Agroforestry practice as adaptation tools to climate change hazards in Itu Lga, Akwa Ibom State, Nigeria. Global Journal of Human Social Science Geography & Environmental Geosciences, 12(11), 27-36.

Endale, Y., Derero, A., Argaw, M. & Muthuri, C. (2016). Farmland tree species diversity and spatial distribution pattern in semi-arid East Shewa, Ethiopia. Forests, trees and LiveLihoods.

FAO. (2005). Agro-Ecological Zoning and GIS application in Asia with special emphasis on land degradation
assessment in drylands (LADA). Proceedings of a Regional Workshop, Bangkok, Thailand 10–14 November 2003.

Franzel, S., Carsan, S., Lukuyu, B., Sinja, J. & Wambugu, C. (2014). Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. Current Opinion in Environmental Sustainability, 6, 98–103.

Godfray, H.C., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. & Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. Science, 327(5967), 812-818.

Godfray, H.C. & Garnett T (2014). Food security and sustainable intensification. Phil. Trans. R. Soc. B., 369(1639).

Greenler, S.M. & Ebersole, J.J. (2014). Bird communities in tropical agroforestry ecosystems: an underappreciated conservation resource. Agroforestry systems, 89(4), 691-704.

Gupta, R.K., Kumar, V., Sharma, K.R., Buttar, T.S., Singh, G. & Mir, G. (2017). Carbon Sequestration Potential through Agroforestry: A Review. International Journal of Current Microbiology and Applied Sciences, 6 (8), 211-220.

Guyassa, E. & Joseph, Raj, A. (2013). Assessment of biodiversity in cropland agroforestry and its role in livelihood development in dryland areas: A case study from Tigray region, Ethiopia. Journal of Agricultural Technology, 9(4), 829-844.

Harvey, C.A., Medina, A., Sánchez, D.M., Vilchez, S., Hernández, B., Saenz, J.C., Maes, J.M., Casanoves, F. & Sinclair, F.L. (2006). Patterns of Animal Diversity in Different Forms of Tree Cover in Agricultural Landscapes. Ecological Applications, 16, 1986–1999.

Harvey, C.A. & Villalobos, J.A.G., 2007. Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. Biodiversity and Conservation, 16(8), 2257-2292.

Hoang, M.H., van Noordwijk, M., Fox, J., Thomas, D., Sinclair, F., Catacutan, D., Öborn, I. & Simons, T. (2014). Are trees buffering ecosystems and livelihoods in agricultural landscapes of the Lower Mekong Basin? Consequences for climate-change adaptation. Working Paper 177. Bogor, Indonesia: World Agroforestry Centre (ICRAF). Southeast Asia Regional Program.

Hoekstra, D., Torquebiau, E. & Bishaw, B. (1990). Agroforestry: Potentials and Research Needs for the Ethiopian Highlands. No. 21. Nairobi, Kenya: International Council in Agroforestry (ICRAF).

Iiyama, M., Neufeldt, H., Dobie, P., Ngema, M., Ndegwa, G. & Jamnadass, R. (2014) The potential of agroforestry in the provision of sustainable woodfuel in sub-Saharan Africa. Current Opinion in Environmental Sustainability, 6.

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems, 76: 1-10.

Jose, S. & Bardhan, S. (2012). Agroforestry for biomass production and carbon sequestration: an overview. Agroforestry systems, 86(2), 105-111.

Justine, M.F., Yang, W., Wu, F., Tan, B., Naeem Khan, M. & Zhao, Y. (2015). Biomass Stock and Carbon Sequestration in a Chronosequence of Pinus massoniana Plantations in the Upper Reaches of the Yangtze River. Forests, 6, 3665-3682.

Kassa, H., Dondeyne, S., Poesen, J., Frankl, A. & Nyssen, J. (2017). Impact of deforestation on soil fertility, soil carbon and nitrogen stocks: the case of the Gacheb catchment in the White Nile Basin, Ethiopia. Agriculture, Ecosystems and Environment, 247, 273-282.

Kassa, H., Dondeyne, S., Poesen, J., Frankl, A. & Nyssen, J. (2018). Agro-ecological implications of forest and agroforestry systems conversion to cereal-based farming systems in the White Nile Basin, Ethiopia. Agroecology and Sustainable Food Systems, 42(2), 149–168.

Kassahun, K., Soromessa, T. & Bellilethan, S. (2015). Forest Carbon Stock in Woody Plants of Ades Forest, Western Hararghe Zone of Ethiopia and its Variation along Environmental Factors: Implication for Climate Change Mitigation. Journal of Natural Sciences Research, 5(21).

Kassie, MD. (2015). Land Use/Cover Changes and the Role of Agroforestry Practices in Reducing Deforestation and Improving Livelihoods of Smallholders in Maytemeko Watershed, Northwest Ethiopia. Dissertation for obtaining a doctorate degree at the University of Natural Resources and Life Sciences, Vienna, Austria.

Kebebew, Z., Urgessa, K. (2011). Agro forestry Perspective in Land use Pattern and Farmers Copying Strategy: Experience from Southwest Ethiopia. World journal of Agricultural Science, 73-77.

Krankina, O.N., Dixon, R.K. (1994). Forest management options to conserve and sequester terrestrial carbon in the Russian Federation. World Resour. Rev., 6, 88–101.

Lasco, R.P., Delfino, R.J., Catacutan, D.C., Simelton, E. & Wilson, D. (2014). Climate risk adaptation by smallholder farmers: the roles of trees and agroforestry. Current Opinion in Environmental Sustainability, 6, 83-88.

Lin, B.B. (2007). Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee agriculture. Agricultural and Forest Meteorology, 144(1), 85-94.
Lin, B.B. (2011). Resilience in Agriculture through Crop Diversification: Adaptive Management for Environmental Change. BioScience, 61(3), 183-193.

Lin, B.B. (2014). Agroforestry adaptation and mitigation options for smallholder farmers vulnerable to climate change. Agroecology, Ecosystems, and Sustainability, 20, 221.

Linge, E. (2014). Agro-ecosystem and socio-economic role of homegarden agroforestry in Jabithenan District, North-Western Ethiopia: implication for climate change adaptation. Springer Plus, 3, 154.

López-Gómez, A.M., Williams-Linera, G. & Manson, R.H. (2008). Tree species diversity and vegetation structure in shade coffee farms in Veracruz, Mexico. Agriculture, ecosystems & environment, 124(3), 160-172.

Maxwell, J.J., Howarth, J.D., Vandergoes, M.J., Jacobsen, G.E. & Barber, J.G. (2016). The timing and importance of arboriculture and agroforestry in a temperate East Polynesia Society, the Moriori, Rekohu (Chatham Island). Quaternary Science Reviews, 149, 306-325.

Mbow, C., van Noordwijk, M., Prabhu, R. & Simons T (2014). Knowledge gaps and research needs concerning agroforestry’s contribution to Sustainable Development Goals in Africa Current Opinion in Environmental Sustainability, 6, 162–170.

McGinty, M.M. (2012). Native forest tree conservation in tropical agroforests: case study of cacao farm in the Atlantic Forest of Southern Bahia, Brazil. Doctoral thesis submitted in partial fulfillment of the requirements for Doctor of philosophy.

McNeely, J.A. & Scherr, S.J. (2003). Ecoagriculture: strategies to feed the world and save wild biodiversity. Island Press.

McNeely, J.A. & Schroth, G. (2006). Agroforestry and biodiversity conservation—traditional practices, present lessons, and futures for the future. Biodiversity & Conservation, 15(2), 549-554.

Mekonen T, Giday M, Kelbessa E (2015). Ethnobotanical study of Homegarden plants in Sebeta-Awas District of the Oromia Region of Ethiopia. Journal of Ethnobiology and Ethnomedicine, 11, 64.

Millennium Ecosystem Assessment (MEA) (2005). Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC.

Molla, A. & Asfaw, Z. (2014). Woody Species Diversity under Natural Forest Patches and Adjacent Enset-Coffee Based Agroforestry in the Midlands of Sidama zone, Ethiopia. International Journals of Biodiversity and conservation, 6(10), 708-723.

Molla, A. & Kewessa, G. (2015). Woody Species Diversity in Traditional Agroforestry Practices of Dello Menna District, Southeastern Ethiopia: Implication for Maintaining Native Woody Species. Hindawi Publishing Corporation: International Journal of Biodiversity, 1-13.

Morgan, J.A., Follett, R.F., Allen, L.H., Grosso, S.D., Derner, J.D., Dijkstra, F., Franzluebbers, A., Fry, R., Paustian, K. & Schoenebeerge, M. M. (2010). Carbon sequestration in agricultural lands of the United States, 65(1).

Mukul, S.A. & Saha, N. (2011). Ecological Trade-offs between Plant Biodiversity, Land-use and Management Intensification in Agroforestry Landscapes of Bangladesh.

Mukul, S.A.; Saha, N. (2017). Conservation benefits of tropical multifunctional land-uses in and around a forest protected area of Bangladesh. Land, 6(1), 2.

Murthy, I. K., Gupta, M., Tomar, S., Mushi, M., Tiwari, R., Hegde, G. & Ravindranath, N.H. (2013). Carbon Sequestration Potential of Agroforestry Systems in India. J Earth Sci Climate Change, 4, 131.

Mutuo, P.K., Cadisch, G., Albrecht Palm, C.A. & Verchot, L. (2005). Potential of agroforestry for carbon sequestration and mitigation of greenhouse gas emissions from soils in the tropics. Nutrient Cycling in Agroecosystems, 71: 43-54.

Nair, P.K.R. (1993). An introduction to agroforestry. Kluwer Academic publisher with cooperation ICRAF, Dordrecht, London, pp. 489.

Nair P.K.R., Garrity, D (2012). Agroforestry research and development: the way forward. In P. K. R. Nair & D. Garrity. (Eds.). Agroforestry - the future of global land use: advances in agroforestry. Volume 9.

Nair, P.K.R., Nair, V.D., Kumar, B.M. & Showalter, J.M. (2010). Carbon sequestration in agroforestry systems. Adv. Agron, 108: 237-307.

Nair, P.K.R., Nair, V.D., Kumar, B.M. & Haile, S.G. (2009). Soil carbon sequestration in tropical Agroforestry systems: a feasibility appraisal. Environmental Science and Policy, 12, 1099-1111.

Najma, D., Mutunga, C.N. & Katja, K. (2016). Socioeconomic and Biophysical Factors Affecting Tree Richness and Diversity in Machakos Country Eastern Kenya. International Journal of Plant Animal and Environmental Science, 6(3), 183-196.

Ndolo, M.C., Dharani, N. & Kehlenbeck, K. (2016). Socioeconomic and Biophysical Factors Affecting Tree Richness and Diversity in Machakos County, Eastern Kenya. International Journal of Plant, Animal and Environmental Sciences, 6(3), xx.

Negash, M., Eshetu, Y. & Olavi, L. (2012). "Potential of indigenous multistrata agroforests for maintaining native floristic diversity in the south-eastern Rift Valley escarpment, Ethiopia." Agroforestry systems, 85(1), 9-28.
Negawo, J.W. & Beyene, D.N. (2016). The Role of Coffee Based Agroforestry System in Tree Diversity Conservation in Eastern Uganda.

Negawo, W. & Beyene, D. (2017). The Role of Coffee Based Agroforestry System in Tree Diversity Conservation in Eastern Uganda. *Journal of Landscape Ecology*. 10(2):1-18.

Oelbermann, M., Voroney, R.P. & Gordon, A.M. (2004). Carbon sequestration in tropical and temperate agroforestry systems: a review with examples from Costa Rica and southern Canada Agriculture. *Ecosystems and Environment*, 104, 359-377.

Ofori, D.A., Gyau, A., Dawson, I.K., Asaah, E., Tchoundjeu, Z. & Jamnadass, R. (2014). Developing more productive African agroforestry systems and improving food and nutritional security through tree domestication. *Current Opinion in Environmental Sustainability*, 6,123-127.

Oke, D.O. & Jamala, G.Y. (2013). Traditional agroforestry practices and woody species conservation in the derived savanna ecosystem of Adamawa state, Nigeria. *Biodiversity Journal*, 4(3), 427-434.

Oliveira, J., Probst, K., Renner, I. & Riha, K. (2012). Ecosystem-based Adaptation (EbA): A new approach to advance natural solutions for climate change adaptation across different sectors. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Pretty, J. & Bharucha, Z.P. (2014). Sustainable intensification in agricultural systems. *Annals of Botany*, 114(8),1571-1596.

Pretty, J., Toulmin, C. & Williams, S. (2011). Sustainable intensification in African agriculture. *International journal of agricultural sustainability*, 9(1), 5-24.

Rolim, S.G., Chiarello, A.G. (2004). Slow death of Atlantic forest trees in cocoa agroforestry in southeastern Brazil. *Biodiversity and Conservation*, 13(14), 2679-2694.

Schoeneberger, M.M. (2009). Agroforestry: working trees for sequestering carbon on agricultural lands. *Agroforestry Systems*, 75, 27-37.

Schröth, G., Fonseca, G.A.B., Harvey, C.A., Gascon, C., Vasconcelos, H.L. & Izac, A.M.N (Eds.). (2004). *Agroforestry and biodiversity conservation in tropical landscapes*. Island Press, Washington, p 524.

Seaman, B.S. & Schulze, C.H. (2010). The importance of gallery forests in the tropical lowlands of Costa Rica for understory forest birds. *Biological conservation*, 143(2), 391-398.

Seneviratne, H.T.J., Sumansasekara, V.D.W. & Dissanayake D.M.M.R. (2015). Role of agroforestry in achieving food and nutritional security, climate change mitigation and environmental resilience: a review. *NBRO Symposium 2015—Innovation for Resilient Environment*.

Sileshi, G., Mafongoya, P.L., Kwaresa, F. & Nkunika, P. (2005). Termite damage to maize grown in agroforestry systems, traditional fallows and monoculture on Nitrogen-limited soils in eastern Zambia. *Agr. For. Entomol.*, 7, 61-69.

Tadesse, G., Zavaleta, E. & Shennan, C. (2014). Coffee landscapes as refugia for native woody biodiversity as forest loss continues in southwest Ethiopia. *Biological Conservation*, 169, 384-391.

Tadesse, E.G. (2013). Biodiversity and Livelihoods in Southwestern Ethiopia: Forest Loss and Prospects for Conservation in Shade Coffee Agroecosystems. A PhD dissertation submitted to University of California.

Talamos, S., Sebsebe, D. & Zemed, A. (2013). Home gardens of Wolayta, southern Ethiopia: An ethnobotanical profile. *Acad. J. Med. Plants*, 1(1),14-30.

Talamos, S., Sebsebe, D. & Zemed, A. (2013). Home gardens of Wolayta, Southern Ethiopia: An ethnobotanical profile. *Academia Journal of Medicinal Plants*, 1(1), 014-030.

Thorlakson, T. & Neufeldt, H. (2012). Reducing subsistence farmers’ vulnerability to climate change: evaluating the potential contributions of agroforestry in Western Kenya. *Agric Food Security*, 1,15.

Tschamntke, T., Clough, Y., Wanger, T.C., Jackson, I., Motzke, I., Perfecto I., Vandermeer, J. & Whitbread, A. (2012). Global food security, biodiversity conservation and the future of agricultural intensification. *Biol*.
Ullah, M.R. & Al-Amin, M. (2012). Above- and below-ground carbon stock estimation in a natural forest of Bangladesh. Journal of forest science, 58 (8), 372–379.

UNCCD. (1992). Secretary General’s Report on Land Chapter of Agenda 21 to Commission on Sustainable Development (CSD8, UN, New York 2000). UNCCD Agenda 21, Rio de Janeiro, 1992 and UNCCD Paris, 1994.

UNEP(2008). Africa: Atlas of Our Changing Environment. Division of Early Warning and Assessment (DEWA) United Nations Environment Programme (UNEP). Nairobi 00100, Kenya.

Verchot, L.V., Van Noordwijk, M., Kandji, S., Tomich, T., Ong, C., Albrecht, A., Mackensen, J., Bantilan, C., Anupama, K.V.& Palm, C. (2007). Climate change: linking adaptation and mitigation through agroforestry. Mitig Adapt Strat Glob Change.

Wafuke, S. (2012). Adoption of Agroforestry Technologies among Small Scale Farmers in Nzoia Location, Lugari District, Kenya. A Thesis Submitted to School of Graduate Studies in Partial Fulfillment for the Requirement of Master of Science Degree in Environmental Science, Egerton University. p 87.

Waldron, A., Garrity, D., Malhi, Y., Girardin, C., Miller, D.C., Seddon, N. (2017). Agroforestry Can Enhance Food Security While Meeting Other Sustainable Development Goals Tropical Conservation Science, 10, 1–6.

Worku, M., Bantihun, A. (2017) Review on Woody Species and SocioEconomic Roles of Traditional Agroforestry Practices in Ethiopia. J Fundam Renewable Energ., 7, 246.

World Agroforestry Centre. (2006). Agroforestry for improved livelihoods and Natural resources conservation. An Agroforestry Policy Brief. Kenya, Nairobi.

Youkhana, A.H.& Idol, T.W. (2010). Growth, Yield and Value of Managed Coffee Agroecosystem in Hawaii. Pac. Agric. Nat. Resour., 2, 12-19

Zerihun, F.M., Muchie, M.& Worku, Z. (2014). Determinants of Agroforestry Technology Adoption in Eastern Cape Province of South Africa. Journal Development Studies Research, 1 (1), 382–394.