AGROFORESTRY CONTRIBUTION TO NATIVE WOODY SPECIES CONSERVATION, CARBON SEQUESTRATION, AND LIVELIHOOD BENEFITS IN ETHIOPIA: A SYSTEMATIC REVIEW

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ABSTRACT

The conservation of endangered native species and climate change are currently the two most pressing environmental problems on the planet. Therefore, the general objective of the review was to synthesize evidence of the contributions of agroforestry systems to the conservation of native species, carbon sequestration, and livelihood benefits in Ethiopia. A total of 104 publications from 2000 to 2024 publication years were used to provide available evidence and research gaps on agroforestry contribution to native species conservation (n=21), carbon sequestration (n=33), and livelihood benefits (n=35) in Ethiopia. Furthermore, 38 papers from other parts of the world were used to support ideas and relevant evidence linked to the title. The review's findings confirm that agroforestry can serve as in-situ conservation for endangered native species including *Cordia africana Lam., Hagenia abyssinica (Bruce) J.F. Gmel., Acacia abyssinica Hochst. ex Benth*, *Croton macrostachyus Hochst. ex Delile, Ficus sur Forssk and Faidherbia albida (Delile) A. Chev*. The review systematic review indicated that agroforestry systems store an average of 40.04 ± 10.4 Mg C ha $^{-1}$ in biomass and 68.9 ± 9.9 Mg C ha- ^{1} in soil in Ethiopia. Hence, the above-ground carbon was highest for coffee-based agroforestry (17.12 ± 6.3 Mg ha^{-1}) followed by homegarden (16.6 ± 3.2 3 Mg ha^{-1}) and woodlot (7.1 ± 1.09 Mg ha^{-1}). Fuelwood, food, fodder, income, timber, fruits, and poles for construction were the main benefits of livelihood; which have been reported in 37, 30, 26, 25, 23, and 20,18 published articles, respectively. Empirical studies show that an agroforestry system, which can significantly reduce the vulnerabilities of households and store a large amount of carbon dioxide in the atmosphere, is an important strategy for climate adaptation and mitigation. Moreover, further scientific research on agroforestry on the sustainability of agroforestry is needed from responsible bodies in Ethiopia.

Keywords: Agroforestry, Biodiversity conservation, Carbon sequestration, Native species, Sustainable livelihoods

INTRODUCTION

Nowadays, the conservation of endangered native species and climate change are currently the two most pressing environmental problems on the planet. Ethiopia is rich in flora and fauna with endemic species (Mengistu and Asfaw, 2016; Gebre *et al.*, 2019). However, due to the conversion or degradation of natural forests, native flora diversity is declining, and its persistence in human-modified ecosystems is threatened by anthropogenic and environmental factors (Newbold *et al.*, 2015). Moreover, ecological services like biodiversity conservation and carbon sequestration are also threatened (Gebre *et al.*, 2019). Consequently, farmers' incomes and food security have severely declined. Therefore, agroforestry has become popular as a strategy for native species conservation, reducing climate change, and food security challenges (Negash *et al.*, 2012; Reppin *et al.*, 2020).

Parklands, homegardens, woodlots, coffee-based, enset-based agroforestry, boundary plantings, and agroforest have played a great role in biodiversity conservation in different parts of Ethiopia (Negash *et al.*, 2012; Endale *et al.*, 2017; Eyasu *et al.*, 2020; Gemechu *et al.*, 2021). Agroforestry can be used as in-situ conservation for native species and wild species diversity (Negash *et al.*, 2012). Researchers have looked into the mechanisms through which agroforestry systems conserve biodiversity including native endangered species (Mcneely & Schroth, 2006; Negash *et al.*, 2012; Molla & Kewessa, 2015). Agroforestry systems help to conserve biodiversity in many different ways: (i) it creates habitats for native plant and animal species that are partially dependent on forests and would not be able to survive in an exclusively agricultural landscape (Negash *et al.*, 2012; Molla & Kewessa, 2015); (ii) helps to maintain endangered tree species and their gene pool in the fragmented landscape; (iii) it can serve as corridors and steppe stone for native plant and animal species by bridging different habitats in the landscape and permit their gene flow to travel to freely (Nyhus & Tilson, 2004; Shennan-Farpón *et al.*, 2022); (iv) reduces deforestation and the impact on natural habitats by offering more products and long-term alternatives to an agricultural system (Montagnini & Nair, 2004; Iiyama *et al.*, 2014); (v) it can serve as buffer zones to protected areas and support biodiversity conservation by reducing human impact on core areas, providing habitats, and fostering a generally hospitable environment for movement (Nyhus & Tilson, 2004; Negash *et al.*, 2012); (vi) helps to maintain biodiversity by providing additional ecological services like erosion control and water recharge, which prevent degradation and loss of habitats (Molla & Kewessa, 2015); and (vii) conserving biodiversity through the provision of homes for creatures that spread seeds, hence enhancing the persistence and conservation of native species (Negash *et al.*, 2012).

Increased human-caused greenhouse gas emissions have been shown to damage natural ecosystems and the livelihood of communities (Stocker *et al.*, 2013). Of all GHG emissions, CO_2 emissions from industrial processes and the burning of fossil fuels account for about 78 % (Dhyan *et al.*, 2016). Climate change has an impact on many industries, and it has an impact on farmers' livelihoods due to decreased water resources, reduced crop productivity, and an increase in the frequency of droughts, diseases, and floods (Stocker *et al.*, 2013). Agroforestry is one of the options and is regarded as a win-win system that reduces vulnerability, increases the farming system's resilience, and protects farmers from the negative effects of climate change (Meragiaw, 2017; Gebre *et al.*, 2019). Agroforestry systems have been given attention due to their ability to sequester CO_2 emissions and store carbon through their biomass and soil (Nair *et al.*, 2010; Jose *et al.*, 2012; Nair, 2012). Nevertheless, agroforestry is left out of national measuring, reporting, and verification systems, in part due to the difficulty in quantifying carbon. While there has been considerable improvement in quantifying biomass carbon in agricultural landscapes, methodological issues have led to varying estimates in the literature that are currently available (Nair & Nair, 2014). This limitation must be addressed to realize the promise of agroforestry as a means of mitigating climate change.

Agroforestry can boost biomass carbon reserves since tree biomass comprises 46-51 % carbon (Lorenz & Lal, 2014; Kim *et al.*, 2016). Studies have demonstrated that agroforestry sequesters carbon in biomass and soil at global and tropical levels. Agroforestry systems store on average around 21.4 Mg C ha $^{-1}$ in biomass at the global level (Zomer *et al.*, 2016). In the tropic, the average carbon sequestration potential in agroforestry was the highest for temperate regions (63 Mg C ha^{-1}), followed by humid (50 Mg C ha^{-1}), sub-humid (21 Mg C ha^{-1}), and, semiarid (9 Mg C ha^{-1}) (Negash *et al.*, 2012). Some studies have doubtful scientific merit because they rely on generalizations or research based on false assumptions (Nair & Nair, 2014). A deeper understanding of the distribution and abundance of biomass carbon in agroforestry systems requires a quantitative synthesis of primary research data.

In addition to carbon sequestration, agroforestry is an effective way to secure food, and improve farmers' livelihood and many ecological benefits (Islam *et al.*, 2013; Reppin *et al.*, 2020). For example, agroforestry systems have been shown to increase farmers' income, improve agricultural production, improve soil fertility and preserve biodiversity (Nair, 2012; Leakey, 2014; Reppin *et al*, 2020). Agroforestry products provide benefits to rural households through food consumption and income (Negash, 2007; Akter *et al.*, 2022).

The benefits of trees in agricultural landscapes are widely documented and dominate the literature on agroforestry in Ethiopia. However, a systematic understanding of agroforestry's contribution to native species conservation, carbon storage, and livelihoods is still limited. Much of the existing scientific papers focus on the effects of agroforestry on crop productivity, agroforestry design, socio-economic aspect, biophysical aspect management, and productive and service role (Negash *et al.*, 2012; Jamala *et al.*, 2013; Iiyama *et al.*, 2017; Lelamo, 2021). In addition, studies on carbon sequestration depend on the geographical location and system (types of tree species, and management). Significant gaps exist in our knowledge of agroforestry's contribution to climate change adaptation, including the unequal geographic distribution of studies and our unfamiliarity with the advantages of agroforestry during certain climatic disasters (Quandt *et al.*, 2023).

Therefore, the overall objective of the review was to synthesize evidence of the contributions of agroforestry systems to the conservation of native species, carbon sequestration, and livelihood benefits in Ethiopia. Organizing fragmented scientific information regarding the role of agroforestry in the preservation of native species, sequestration of carbon dioxide, and livelihood benefits is essential to developing a conservation plan and sustainable utilization guidelines for native endangered species and agroforestry systems. This review paper also helps to facilitate the selection of priority tree species for domestication programs that link improved livelihood to adaptation and mitigation through agroforestry. Furthermore, the paper provides scientific information to researchers, governmental organizations, and decision-makers regarding biodiversity conservation, ecosystem services, and livelihood benefits provided by agroforestry systems. The focus on Ethiopia is driven by the fact that agroforestry offers promising opportunities in the climate agenda in Ethiopia and it is one of the levers to increase biodiversity and carbon sequestration in Ethiopia's Climate-Resilient Green Economy strategic plan documents (ECRGE, 2011).

MATERIALS AND METHODS

Literature search strategy and data source

A literature search was conducted on Web of Science, Scopus, and Google Scholar to collect information on agroforestry's contribution to native species conservation, carbon sequestration, and livelihood benefits. The literature search was carried out between January 2023 and May 2024. The search parameters included the type of agroforestry land use, the location of the research, and the benefits of agroforestry for native species conservation, carbon storage, and livelihood benefits. Many searches were carried out to make sure that a strict procedure was used to find the right literature and that the review did not overlook any important information. Ethiopia and its specific location in the country were included in the search keywords to restrict the number of search results returned and collect data that does not specifically pertain to the country or specific location where the study was done. Moreover, a search for international reports, a thesis, conferences, and unpublished materials was conducted by using websites and databases.

Literature inclusion and exclusion criteria

This review paper mainly focuses on the scientific and grey literature on agroforestry, biodiversity, carbon sequestration, and livelihood benefits. Therefore, the following criteria were used to select scientific papers and grey literature for inclusion and exclusion in the systematic review; (i) scientific and grey literature reported from 2000 to 2024 were foremost appropriate for inclusion;

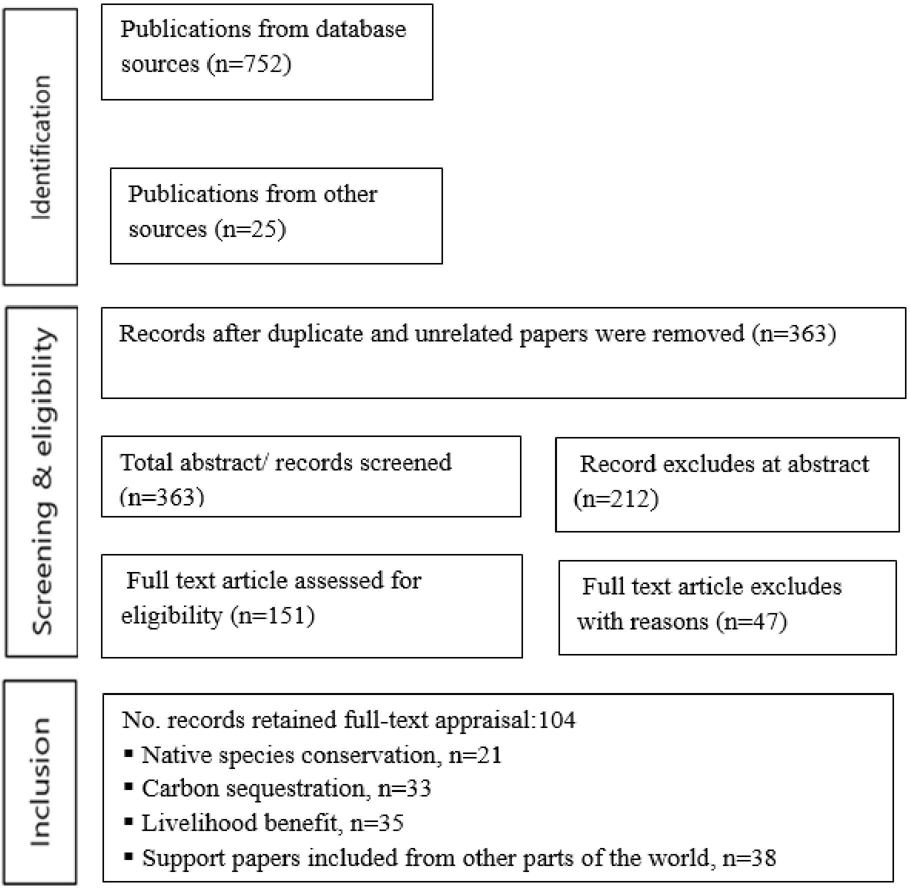
(ii) Scientific papers and grey literature providing quantitative or qualitative information on at least one result on native species diversity, carbon sequestration, and livelihood benefit were mostly suitable for inclusion; (iii) Studies with strong empirical analysis were preferred for inclusion; (iv) The studies written in the English language were qualified for inclusion; and (v) Studies conducted in Ethiopia mainly Southern, Northern, Eastern, Southwestern, South Eastern, and Middle Rift Valleys were fit for inclusion. Nevertheless, some studies from other parts of the world were included, when the studies supported ideas and relevant evidence linked to the content in Ethiopia.

The keywords and the parameters included in the search procedure were: (i) Agroforestry systems/practices (“Homegerden,” “Parkland,” “Woodlot,” “Livefence,” “Boundary planting,” “Enset-based agroforestry, “Coffee-based agroforestry,” “Agroforest,” “Fruit-based agroforestry,” “Enset-coffee agroforestry,” “Fruit-coffee agroforestry,” “Southern Ethiopia,” “Northern Ethiopia,” “Eastern Ethiopia,” “Southwestern Ethiopia,” “South Eastern Ethiopia,” “Middle Rift valleys Ethiopia,”; (ii) Native species conservation (“Biodiversity conservation,” “Tree species diversity,” “Native tree/shrub species,” “In situ conservation,” “Southern Ethiopia,” “Northern Ethiopia,” “Eastern Ethiopia,” “Southwestern Ethiopia,” “South Eastern Ethiopia,” “Middle Rift valleys Ethiopia,”; (iii) Carbon sequestration (“Allometric equations,” “Biomass equations,” “Biomass estimation,” “Biomass carbon, “Above ground biomass,” “Below ground biomass,” “Carbon sequestration,” “Southern Ethiopia,” “Northern Ethiopia,” “Eastern Ethiopia,” “Southwestern Ethiopia,” “South Eastern Ethiopia,” “Middle Rift valleys Ethiopia,” ; and (iv) Livelohood benefits (“Income,” “Food,” “Fruit,” “Timber and construction wood,” “Fodder,” “Firewood,” “Medicinal value” “Southern Ethiopia,” “Northern Ethiopia,” “Eastern Ethiopia,” “Southwestern Ethiopia,” “South Eastern Ethiopia,” “Middle Rift valleys Ethiopia,”.

Identification and screening of the studies

A flow diagram was employed to screen articles and evaluate their relatedness (Figure 1). Based on an extensive literature search,752 possible records were identified. In the first stage of checking for duplication by title and unrelated, 414 records were excluded. In the second stage, abstracts and summaries of the remaining 363 records were read based on inclusion and exclusion criteria. As a result, 212 of 363 records were excluded after reading the paper, primarily because they did not meet the selection criteria. Full-text evaluation was then performed on the remaining 151 records, of which a further 46 were omitted due to limited relevance, poor data quality, and unpredictability. Finally, a total of 104 publications were used for the systematic review of native species conservation (n=21), carbon sequestration (n=33), livelihood benefits (n=35), and papers from other parts of the world (n=38). Some publications covered native species conservation, carbon sequestration, and livelihood benefits.

Fig. 1: Systematic flow diagram illustrating the steps involving literature searches and screening of potential records



RESULTS AND DISCUSSION

The major agroforestry practices in Ethiopia

Agroforestry is a traditional land use practice and is one of the most important to conserve biodiversity, sequester carbon, and livelihood benefits for people in Ethiopia (Manaye *et al.*, 2021; Guzo *et al.*, 2024). Moreover, agroforestry is any practice that deliberately growing trees together with crops and/or animals on the same piece of land for different products and ecological services (Nair *et al.*, 2010; Jose *et al.*, 2012). In Ethiopia, there are several site-specific agroforestry practices such as parkland agroforestry, homegardens, boundary planting, woodlots, coffee-based agroforestry, fruit-coffee agroforestry, and enset-based agroforestry the most well-known site-specific agroforestry practices in Ethiopia (Negash *et al.*, 2012; Negash and Starr, 2015; Endale *et al.*, 2017; Gebrewahid, *et al.*, 2018; Eyasu *et al.*, 2020; Gemechu *et al.*, 2021; Manaye *et al.*, 2021).

Maize intercropping with *Cordia africana* in western Ethiopia, as well as *Faidherbia albida*-based agroforestry in the semi-arid and Central rift valleys are some examples of parklands agroforestry in Ethiopia (Sileshi, 2016; Haile *et al.*, 2021; Tadesse *et al.*, 2021). The "enset-coffee" homegarden, which combines *Enset ventricosum* and *Coffea arabica*, is a popular type of homegarden in Southern Ethiopia (Negash & Kanninen, 2015; Lulu *et al.*, 2020). In southern Ethiopia, there are also unique "enset-based" and "coffee-based" home gardens. Furthermore, there are also fruit tree-based agroforestry practices, boundary planting around homes and farms, and woodlot and live fence practices found in different parts of Ethiopia. These different agroforestry practices are important to conserve biodiversity, sequester carbon, and provide different forest products.

The role of agroforestry systems in maintaining native woody species in Ethiopia

Many studies have indicated the contribution of different agroforestry systems to native species conservation across Ethiopia in the periods (Table 1). Parkland, homegardens, enset-coffee agroforestry, enset-based agroforestry, fruit-based agroforestry, live fence, cultivated land, trees on grazing land, boundary planting, and woodlot, are the major agroforestry systems to conserve native species in various parts of Ethiopia (Negash *et al.*, 2012; Guyassa *et al.*, 2014; Endale *et al.*, 2017; Teshome *et al.*, 2019; Eyasu *et al.*, 2020; Gemechu *et al.*, 2021) (Table 1).

This review indicated that different agroforestry systems in Ethiopia conserve an average of 55 native wood species, which is equivalent to 76 % (Table 1). The percentage of native woody species for different agroforestry systems was found between 56 % and 100 % (Table 1). Northern Ethiopia had the highest percentage of native wood species (66 - 100%), followed by Southern Ethiopia (66.22 - 86 %), Eastern Ethiopia (76 %), Southwest Ethiopia (70 %), and Central Rift Valley (70 %), and Central Ethiopia (56 %) (Table 1). This review also has shown that agroforestry has a huge potential for preserving native tree species, which are essential for improving soil fertility, carbon sequestration, providing fodder, food, timber, medicine, and fuel wood, as well as for ecological and economic reasons (Negash *et al.*, 2012).

According to Negash *et al.* (2012), in southern Ethiopia, enset-based agroforestry conserves the highest percentage of native woody species (92 %), followed by enset-coffee agroforestry (89 %) and fruit-coffee-based agroforestry (82 %). *Cordia africana Lam., Millettia ferruginea (Hochst.) Bak., Balanites aegyptiaca (L.) Delilel, Croton macrostachyus, Coffea arabica L., and Albizia gummifera (J.F.Gmel.) C.A.Sm.* are among the common native species kept in agroforestry systems in southern Ethiopia (Asfaw & Lemenih, 2010: Negash *et al.*, 2012; Molla & Kewessa, 2015; Molla *et al.*, 2023) (Figure 2 A and B). This review finding was supported by Kebebew & Ozanne (2024) who reported that *Cordia africana*, *Millettia ferruginea*, *Croton macrostachyus*, and *Albizia gummifera* were the most abundant tree species compared to other species in southern Ethiopia. Moreover, *Vernonia amygdalina Del.*, *Cordia africana*, *Croton macrostachyus*, and *Albizia gummifera* are some of the tree species that are frequently used in southern Ethiopian agroforestry to provide shade for coffee plants (Negash *et al.*, 2012) (Figure 2 A and B). However, these species are highly preferred in areas for coffee and enset shade, high commercial value, medicinal values, fodder, and soil fertility improvement (Figure 2 A and B). The most common species in the agroforestry systems of southwest Ethiopia included *Cordia africana, Albizia gummifera, Millettia ferruginea, Ficus vasta, Ficus sur Forssk. Croton macrostachyus, Erythrina abyssinica Lam. ex DC., and Vernonia amygdalina Del.* (Yakob *et al.*, 2014; Gemechu *et al.*, 2021). These tree species were conserved by using the local knowledge of the farmers in the area.

Acacia seyal Delile, Balanites aegyptiaca, Acacia tortilis (Forssk.) Hayne, Opuntia ficus-indica (L.) Mill., Euphorbia tirucalli L., Faidherbia albida (Delile) A.Chev., Ziziphus spina-christi (L.) Willd., and Acacia etbaica Schweinf. are common native species integrated and conserved in the agroforestry systems (Guyassa *et al.*, 2014; Eyasu *et al.*, 2020). In the central region of Ethiopia, *Cordia africana, Acacia seyal, Acacia tortilis, Croton macrostachyus, Faidherbia albida, Acacia senegal (L.) Willd., and Balanites aegyptiaca* are the most important native tree species maintained in agroforestry systems (Endale *et al.*, 2017; Teshome *et al.*, 2019). In contrast, *Croton macrostachyus* and *Cordia africana* are native multipurpose plants that are frequently retained in the agroforestry system of Eastern Ethiopia (Mamo & Asfaw, 2017).

Acciaa abyssinica Hochst. ex Benth., *Millettia ferruginea*, *Celtis africana Burm.f.*, and *Ficus vasta* are not included in the list of 670 species reported in the ICRAF AgroforestryDatabase(https://apps.worldagroforestry.org/treedb/index.php?keyword=Boundary_barrier_support). From the tree species recorded in this review, only five species such as *Acacia nilotica (L.) Delile*, *Acacia tortilis, Acacia seyal*, *Olea europaea L.*, and *Faidherbia albida* are among the "top-100" tree species that tropical and subtropical areas prefer for planting (Kindt *et al.*, 2021). From tree species recorded in agroforestry systems *Olea europaea* and *Faidherbia albida* need high priority for the conservation (Khoury *et al.*, 2019) (Table 1). Thus, the survival of these two species is in doubt due to the constant demands of the locals and the slower rate of replanting. This review shows that a strong conservation effort must be launched right now to conserve the rapidly disappearing native of the two species. Moreover, tree species reported in *Cordia africana*, *Acacia nilotica*, and *Albizia gummifera* are known as commercial timber wood species in the global timber trade (Table 1) (Mark *et al.*, 2014).

This review shows that agroforestry conserves endangered species and important native tree species at the national level, including *Cordia africana*, *Hagenia abyssinica, Acacia abyssinica*, *Croton macrostachyus, Ficus vasta and Faidherbia albida*, which are all mentioned in various agroforestry systems (Table 1). This review finding was supported by Eyasu *et al*. (2020) who reported that agroforestry systems are crucial to conserving economic and ecological tree species such as *Cordia africana, Ehretia cymosa Thonn., Ficus sycomorus L., Olea europaea L., and Ziziphus spina-christi*, which are no longer present in a nearby natural forest in Northern Ethiopia. This proves how agroforestry systems can serve as in-situ conservation for native species, lessening the impact of deforestation on the natural forests, and giving farmers more control over the management of limited resources and farmland.

Fig. 2: Diversity of native species in Enset agroforestry(A), Coffee-based agroforestry (B), and parkland (C, D) (Photo taken from Gedeo zone (A and B) (Photo: Negash, 2013) and Western Hararghe Zone (C) by Author

Table 1: Summary of studies on the floristic diversity of native found in various agroforestry systems of Ethiopia

Agroforestry systems	Total the number of species	Percentage of native species	Major native species conserved in the system	Locations (Area in Ethiopia	References
Traditional agroforestry systems (Homegerden and farmlands)	90	62.22	*Croton macrostachyus Hochst. ex Delile, Cordia africana Lam., and Millettia ferruginea (Hochst.) Baker*	Southern Ethiopia	Molla *et al.* (2023)
Traditional agroforestry systems (Homegerden, Parkland, and live fence)	86	*83*	*Balanites aegyptiaca (L.) Delile, Euphorbia tirucalli L., Cordia africana Lam., Ficus vasta Forssk., Croton macrostachyus Hochst. ex Delile, and Acacia etbaica Schweinf.*	Southern Ethiopia	Asfaw and Lemenih (2010)
Traditional agroforestry systems (Homegarden, parkland, and live fence)	55	*85*	*Croton macrostachyus Hochst. ex Delile, Entada abyssinica A.Rich., Catha edulis (Vahl) Endl., Rhus natalensis Bernh. ex C.Krauss, and Syzygium guineense (Willd.) DC.*	Southern Ethiopia	Molla and Kewessa (2015)
Enset agroforestry, Enset -coffee agroforestry, Fruit-coffee agroforestry	58	*86*	*Brucea antidysenterica J.F.Mill., Cordia africana Lam., Millettia ferruginea (Hochst.) Baker Coffea*	Southern Ethiopia	Negash *et al.* (2012)

			arabica l., Croton macrostachyus Hochst. ex Delile, Vernonia amygdalina Del. and Albizia gummifera (J.F.Gmel.) C.A.Sm.		
Grazing land, Boundary planting, Parkland, Homegarden	44	*75*	*Acacia abyssinica Hochst. ex Benth., Olea europaea L., Ficus vasta Forssk., Ficus vasta Forssk., Croton macrostachyus Hochst. ex Delile, Millettia ferruginea (Hochst.) Baker, Cordia africana Lam.,and Albizia gummifera (J.F.Gmel.) C.A.Sm.*	Southwest Ethiopia	Gemechu *et al.* (2021)
Home garden	32	*66*	*Ziziphus spina-christi (L.) Willd., Acacia seyal Delile, Balanites aegyptiaca (L.) Delilel, and Acacia tortilis (Forssk.) Hayne*	Northern Ethiopia	Eyasu *et al.* (2020)
Parkland and Homegarden	35	*100*	*Opuntia ficus-indica (L.) Mill., Euphorbia tirucalli L., Faidherbia albida (Delile) A.Chev. Acacia nilotica (L.) Delile, Acacia abyssinica Benth. and Acacia etbaica Schweinf.*	Northern Ethiopia	Guyassa *et al.* (2014)
Parkland	48	*56*	*Celtis africana Burm.f., Croton macrostachyus Hochst. ex Delile, Prunus africana (Hook.f.) Kalkman, Ficus sur Forssk., and Acacia seyal Delile*	Central Ethiopia	Teshome *et al.* (2019)
Farmland (Homestead, Parkland, line planting, Woodlot)	77	*70*	*Croton macrostachyus Hochst. ex Delile, Acacia tortilis (Forssk.) Hayne, Acacia senegal, Balanites aegyptiaca (L.) Delilel and Faidherbia albida (Delile) A.Chev. and Ziziphus mucronata Willd.*	Central Rift Valley	Endale *et al.* (2017)
Parkland	17	*76.5*	*Croton macrostachyus Hochst. ex Delile, Erythrina abyssinica Lam. ex DC. Hagenia abyssinica (Bruce) J.F. Gmel.and Cordia africana Lam.,*	Eastern Ethiopia	Mamo, and Asfaw (2017)
Agoforetsy practices (Homegarden, Gesho-based and coffee-based agroforestry)	61	*76*	*Acacia abyssinica, Croton macrostachus, and Cordia africana*	Northwestern Ethiopia	Tebkew *et al.* (2023)
Average	**55**	***76%***			

The contribution of agroforestry to climate change mitigation

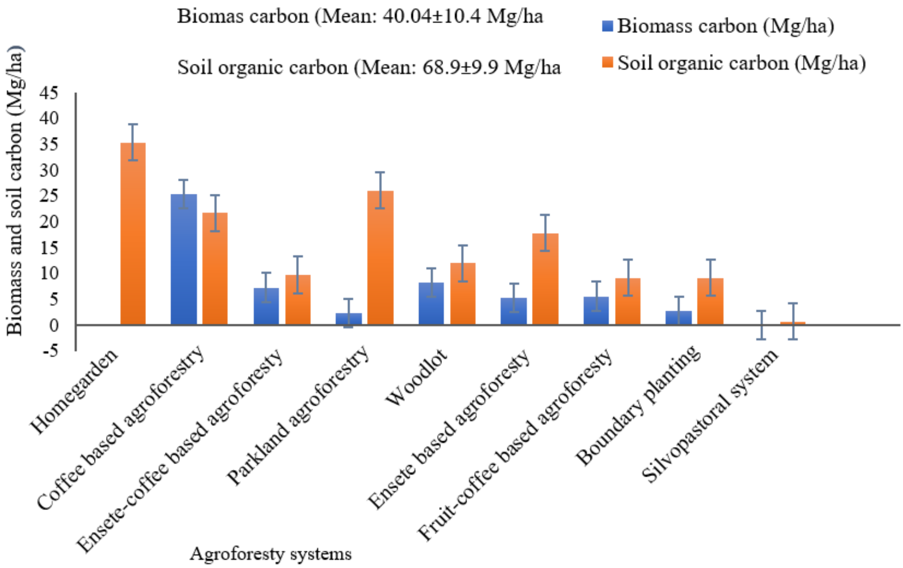
Carbon sequestration is the process of removing CO_2 from the atmosphere and storing it for a long time in many different carbon pools, such as soils, dead wood, litter, and above- and below-ground biomass. Therefore, this review paper indicated that Ethiopian agroforestry systems store an average of 40.04 ± 10.4 Mg C ha $^{-1}$ in biomass and 68.9 ± 9.9 Mg C ha^{-1} in soil (Figure 3). The estimated value of biomass and soil in agroforestry systems was higher than compared to agro silvicultural systems of Africa's humid tropical regions (29–53 Mg C ha^{-1}) of agro-silvicultural systems in the humid tropics of Africa (Albrecht & Kandji, 2003). The capacity of agroforestry systems to store carbon is influenced by several variables, including species composition, age, location, land use types, climate, soil characteristics, crop-tree mixtures, and management methods (Jose & Bardhan, 2012; Negash & Starr, 2015).

In Ethiopia, numerous studies have emphasized the capacity of agroforestry systems to store carbon (Figure 3). For instance, agroforestry systems can store atmospheric carbon in soil and plant tissues, when compared to monocropping systems (Yasin *et al.,* 2023). Also, Getnet *et al.* (2023) reported that agroforestry systems contributed to carbon sequestration through the increase in tree biomass, litter inputs, and improved soil organic carbon content. Indigenous agroforestry systems in Ethiopia's southern rift valley escarpment stored an average of 67 Mgha^{-1} of biomass carbon, with trees comprising 39–93 % of the carbon stock (Negash & Starr, 2015). According to Betemariyam *et al.* (2020), homegardens and nearby coffee-based agroforestry systems can enhance carbon sinks on agricultural landscapes and reduce emissions.

Moreover, international conferences and scholarly research recognized that agroforestry has the greatest potential for storing carbon in both developing countries and developed countries (Solomon, 2007; Verchot *et al*., 2007). For instance, the Kyoto Protocol (Leggett, 2020) and the International Panel on Climate Change (Watson *et al*., 2000), have identified agroforestry as one of the accepted approaches for reducing the effects of climate change. Currently, agroforestry is used on 1000–1023 Mha^{-1} across the globe, and it can store between 30 and 322 C Pg annually (Jose & Bardhan, 2012). By improving tree management techniques, an additional 12,000 Mg of carbon dioxide (Mg) could be stored annually, and by 2040, that quantity would rise to 17,000 Mg. The study indicated that at a median age of 14 years, agroforestry sequestered 7.2 t ha $^{-1}$ y^{-1} of carbon dioxide, with soil carbon sequestration making up about 30 % of the total and biomass carbon sequestration making up about 70 % (Kim *et al*., 2016).

Agroforestry systems not only sequester carbon but also offer additional climate change mitigation co-benefits. A study by Jinger *et al.* (2022) reported that agroforestry enhanced ecosystem functions like soil erosion control, water conservation, and microclimate regulation, lowering vulnerability to the impacts of climate change. Agroforestry can be used to increase the use of trees for farming system intensification, diversification, and buffering, increasing the resilience of farming systems and farmers' livelihood strategies to recent climate variability as well as long-term climate change (Lasco *et al*., 2014). The tree, one of the main components of agroforestry, is essential for reducing vulnerability, enhancing the adaptability of farming systems, and defending households against climate-related risks (Negash & Starr, 2015; Gebrewahid & Meressa, 2020). Furthermore, agroforestry's ability to diversify income sources through marketable tree products contributes to climate change adaptation and resilience at both household and community levels (Sudomo *et al*., 2023).

Fig. 3: The mean value of biomass and soil organic carbon in different agroforestry systems from 33 publications that reported carbon sequestration in Ethiopia



Carbon stocks in above-ground biomass of various agroforestry systems in Ethiopia

We gathered information to estimate the aboveground carbon stock of nine agroforestry systems in different regions of Ethiopia (Table 2). To estimate this carbon stock, different authors developed different allometric equations. For instance, Kuyah *et al.* (2012) using the allometric equation, the aboveground biomass of trees, which includes their leaves, branches, and stem bark was determined. Coffee and enset plant aboveground biomass was estimated using allometric equations developed from on-site harvested plants (Negash *et al.* 2013a, b). The above-ground carbon was highest for coffee-based agroforestry (17.12 ± 6.3 Mg ha^{-1}) followed by homegarden (16.6 ± 3.2 3 Mg ha^{-1}) and woodlot (7.1 ± 1.09 Mg ha^{-1}) (Table 2). Coffee-based agroforestry and homegarden are a kind of agroforestry systems where annual and perennial crops are combined with multipurpose tree species (Nair *et al.*, 2021). In coffee-based agroforestry and homegarden agroforestry, we think the high tree density is caused by the high above-ground biomass carbon (AGC) stock. Our study above-ground biomass carbon stock was lower than the range of tropical African agroforestry systems (12–228 Mg ha^{-1}) (Albrecht & Kandji, 2003) and West African Sahel (0.64-48.9 Mg ha^{-1}) (Takimoto *et al*, 2008). Several factors, including tree density, site characteristics, land use types, plant species, management practices, stock density, and diameter size, may have an impact on the variation in mean aboveground biomass carbon stocks in different agroforestry systems and sites (Negash & Starr, 2015; Mengistu & Asfaw, 2019; Manaye *et al.*, 2021). In addition, the allometric model selection used to calculate agroforestry biomass, soil characteristics, water accessibility, altitude, and slope gradients, could also have an impact on the variation in storing carbon in agroforestry (Manaye *et al.*, 2021).

On the other hand, the silvopastoral system (0.08± 0.07 Mg ha^{-1}) and parkland agroforestry (1.3 ±0.5 Mg ha–^{1}) had the lowest above-ground carbon stock per hectare (Table 2). The lower above-ground biomass carbon stock found in the silvopastoral system and parkland agroforestry was due to low diameter size and stem number per hectare. Furthermore, the trees in these types of agroforestry systems are typically harvested before those in complex agroforestry systems, primarily for use as fuel and fodder. Another study indicated that agroforestry systems that produce firewood and fodder have low carbon sequestration potentials (De Giusti *et al*., 2019). Therefore, management activity is necessary to enhance the carbon storage capacity of silvopastoral systems and parkland agroforestry.

Carbon stock in below-ground biomass of various agroforestry systems in Ethiopia

Belowground biomass carbon stocks account for about 20% of total biomass and are one of the five most significant carbon pools for various vegetation and land use types. In terms of agroforestry systems, coffee-based agroforestry was sequestered the highest below-ground carbon (4.5 ± 1.12 Mg ha^{-1}), followed by homegarden agroforestry (2.04 ± 0.7 Mg ha^{-1}) and fruit-coffee based agroforestry (1.3 ± 0.65 ha^{-1}) (Table 2). These agroforestry systems play a significant role in carbon sequestration and climate change mitigation because they have higher below-ground carbon stocks than other agroforestry systems in Ethiopia. On the other hand, the silvopastoral system and boundary planting had the lowest carbon stock in below-ground biomass (Table 2). The amount of below-ground carbon stored in an agroforestry system was influenced by factors such as the age of the trees, management techniques, human disturbances, different estimation methods, individual error, and the environment (Negash & Starr, 2015; Gebrewahid & Meressa, 2020). In general, the difference in trees in terms of species diversity, stocking levels, and tree size was generally attributed to the uneven distribution of biomass carbon stocks throughout the agroforestry systems.

Soil organic carbon (SOC) of various agroforestry systems in Ethiopia

Soil is essential for reducing atmospheric CO2 levels in agroforestry systems and is the most significant carbon pool among the organic carbon pools due to its longest residence time (Manaye *et al.*, 2021; Tsedeke *et al*., 2021). A summary of soil organic carbon concentrations with soli depth in various types of agroforestry is shown in Table 2. According to this review, the mean soil organic carbon was highest in homegarden (35.34± 6.1 Mg ha^{-1}) followed by coffee-based and parkland agroforestry with 0 to 60 cm of soil depth. Even with ongoing harvests of annual crops and tree products, soil organic carbon is predicted to be steady in complex agroforestry systems. Agroforestry systems that are complex in nature are distinguished by their capacity to produce substantial amounts of litter and prunings that enhance soil organic matter. Furthermore, in these systems, the buildup of soil organic carbon is further facilitated by organic materials from root decay. For instance, Negash *et al*. (2022) found that the rate of annual soil organic carbon loss was three times greater in areas that transitioned from forest to khat monoculture as compared to agroforestry systems that included both khat and coffee. Soil organic carbon was 117.3 mg C ha $^{-1}$ in agroforestry plots aged 32–54, compared to 94.1 mg C ha $^{-1}$ in a khat monoculture aged 15–27 and 171.8 mg C ha^{-1} in a forest (Negash *et al*., 2022).

Similar to belowground carbon, soil organic carbon was lowest in silvopastoral systems and boundary planting compared to other agroforestry systems (Table 2). This variation was caused by changes in management practices as well as changes in tree and stand variables (Negash & Starr, 2015; Manaye *et al*., 2021). Moreover, study conducted by Negash & Starr (2015), the percentage of the forest ecosystem's carbon stock in biomass increases toward the tropics, going from 16 % at high latitudes to 50 % at low latitudes, and the highest SOC stocks were found at high latitudes (343 Mg ha^{-1}), while the lowest SOC stocks were found at low latitudes (121 Mg ha^{-1}). These findings suggest that our agroforestry systems significantly sequester more carbon than tropical forest ecosystems. High SOC levels are required to keep agroforestry systems productive, which supports household livelihood as a means of subsistence.

More research is still required to fully understand belowground carbon in agroforestry and greenhouse gas (GHG) emissions in various agroforestry systems in Ethiopia. Agroforestry's carbon sequestration and greenhouse gas emissions have a well-established theoretical basis. Nevertheless, there is limited empirical evidence to support the theoretical concept. For example, below-ground biomass was not recorded in 13 of the 33 publications that examined biomass carbon. Thus, using the root-to-shoot ratio, belowground carbon was calculated as a percentage of aboveground carbon. In addition, there were very few papers detailing agroforestry systems in comparison to the number of studies demonstrating livelihood advantages. Besides, one important problem that still exists is the lack of a standard method, particularly when it comes to comparisons. Due to this data shortage, it is impossible to account for all carbon pools that affect the dynamics of carbon in agroforestry. It is challenging to assess the carbon changes brought about by the addition of trees to farms since there are very few studies that compare soil organic carbon in agroforestry and adjacent land types. Almost all studies did not provide information on the age of the trees, which restricts the computation of carbon sequestration rates.

In Ethiopia, agroforestry systems provide substantial potential for carbon sequestration while simultaneously supporting livelihoods, although most of them have only the co-benefit of reducing climate change. For example, coffee-based and home-garden agroforestry accomplish long-term carbon sequestration while enhancing the household's social and economic well-being. The little evidence on agroforestry's ability to sequester carbon suggests that farmers and other land users may not fully hold the potential benefits of mixing trees with agricultural activities.

Table 2: Mean ± standard error of above-ground biomass carbon stock, below-ground carbon stock, and soil organic carbon (at 0–60 cm depth, Mg C ha $^{-1}$) of various agroforestry systems in Ethiopia (n=35)

Agroforestry system	Aboveground carbon	Belowground carbon	Soil organic carbon	Locations	References
Boundary planting	2.7 ± 0.19	0.048 ± 0.04	3.4 ± 0.98		Nigatu *et al.* (2020) ; Manaye *et al*. (2021)
Coffee based agroforestry	17.12 ± 6.3	4.5 ± 1.12	21.7 ± 1.2	Southwest Ethiopia, Southern Ethiopia, Western Ethiopia	Tadesse *et al*. (2014); Negash and Kanninen (2015); Denu *et al*. (2016); Mengistu and asfaw (2019); Laekemariam (2020); Betemariyam *et al*. (2022); Chemeda *et al*. (2022); Niguse *et al*. (2022); Tesfay *et al*. (2022)
Ensete based agroforestry	2.24 ±1.7	0.73 ±0.5	17.8 ±1.63	Southern Ethiopia	Negash and Kanninen (2015); Negash and Starr (2015); Laekemariam (2020); Tesfay *et al*. (2022)
Ensete-coffee based	2.9 ± 1.2	0.94 ± 0.4	9.7 ± 2.2	Southern	Negash and Kanninen

agroforestry				Ethiopia	(2015); Negash and Starr (2015); Tesfay *et al*. (2022)
Fruit-coffee based agroforestry	4.3 ± 2.5	1.3 ± 0.65	9.2 ± 2.05	Southern Ethiopia	Negash and starr (2015); Tesfay *et al.* (2022)
Homegarden	16.6 ± 3.2	2.04 ± 0.7	35. 34 ± 6.1	Central Ethiopia, Northern Ethiopia, Southwest Ethiopia, Southern Ethiopia	Bajigo *et al*. (2015); Gebre *et al*. (2019) ; Mensgistu and asfaw (2019); Semere (2019); Birhane *et al*. (2020); Lulu *et al*. (2020); Nigatu *et al*. (2020); Gebremeskel *et al*. (2021); Haile *et al*. (2021); Manaye *et al*. (2021); Sahle *et al*. (2021); Betemariyam *et al*. (2022); Kassa *et al*. (2022); Semere *et al*. (2022); Getnet *et al*. (2023); Maryo *et al*. (2023); Setota *et al* *(*2024)
Parkland agroforestry	1.3 ± 0.5	0.5 ± 0.14	26.05 ± 2.52	Central Rift Valley, Southwest Ethiopia, Southern Ethiopia, Northern Ethiopia	Gelaw *et al*. (2014); Bajigo *et al*. (2015); Denu *et al.* (2016); Gurmessa *et al*. (2016); Gebrewahid *et al.* (2018); Dilla *et al*. (2019); Gebrewahid and Meressa (2020); Laekemariam (2020); Lulu *et al*. (2020); Hagos *et al*. (2021); Manaye *et al. (*2021); Tsedeke *et al*. (2021); Semere *et al*. (2022) ; Getnet *et al*. (2023); Maryo *et al*. (2023); Setota *et al.* *(*2024)
Silvopastoral system	0.08 ± 0.07	-	0.7 ± 0.2	Northern Ethiopia, Southern Ethiopia, Southwestern Ethiopia	Gelaw *et al*. (2014); Denu *et al*. (2016); Gurmessa *et al*. (2016)
Woodlot	7.1 ± 1.09	0.6 ± 0.2	11.98 ± 2.13	Central Ethiopia, Southern Ethiopia, Northern Ethiopia,	Bajigo *et al*. (2015); Semere (2019); Gebre *et al.* (2019); Lulu *et al*. (2020) ; Nigatu *et al.* (2020); Manaye *et al.* (2021); Semere *et al*. (2022); Getnet *et al*. (2023)

Livelihood benefits of agroforestry systems in Ethiopia

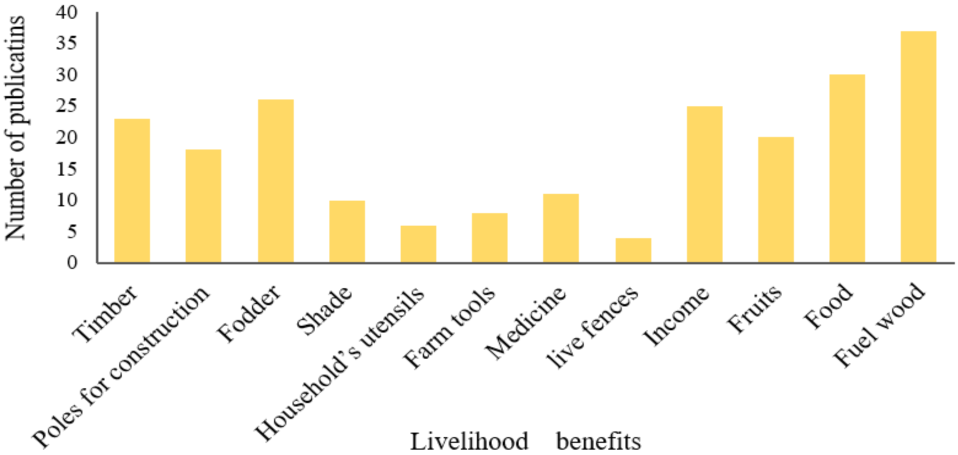
Agroforestry contributes to the livelihood of rural farmers through tangible services (provisioning services) and intangible services (regulator services, cultural services, and supporting services) forest products (Figures 5 and 6). However, fuel wood, food, fodder, income, timber, fruits, and poles for construction were the most frequent livelihood benefits mentioned; they were mentioned in 37, 30, 26, 25, 23, and 20,18 published articles, respectively (Figure 4). Medicine, shade, farm tools, household utensils, and live fences were reported in fewer than eleven publications.

Fuel wood

In Ethiopia, producing and using firewood is a major livelihood strategy. Rural households in Ethiopia almost exclusively use firewood and other traditional biomass energy sources, including charcoal, animal dung, and agricultural wastes, to meet their energy demands for cooking and heating and source of income. Future plans indicate that there will continue to be a demand for firewood because of things like population growth, lack of more low-cost alternatives, and preferences.

A total of 33 publications provided evidence for the contribution of agroforestry to the supply of firewood in Ethiopia (Figure 4). Also, firewood was mentioned as a by-product of agroforestry systems to soil erosion control and subsidiary livestock production through cut and carry systems. Species such as *Cordia Africana*, and *Croton macrostachyus*, *Millettia ferruginea* were the major tree species used for firewood (Appendix 1). For instance, fuelwood from a *Millettia ferruginea* tree generated an income ranging from 14 to 17$ (Negash, 2007). The findings also demonstrated that sawn *Cordia africana* timber and *Eucalyptus* poles are in high demand and fetch high prices in the market. A mature standing *Cordia africana* tree costs around $18 (Negash, 2007). These results lead us to the conclusion that tree products in agroforestry play an important role in ecological as well as economic strategies used by farming households to support their livelihoods.

Fig. 4: The number of publications reporting on the livelihood benefits of agroforestry systems in Ethiopia (n=35)



Food and nutrition

Agroforestry provides edible goods and increases livestock production and crop yield, which support food and nutritional security. A total of 31 tree species were recorded for food and nutrition security with *Mangifera indica L., Carica papaya L.,* and *Persea americana Mill.* as the most mentioned species (Appendix 1). *Persea americana* and *Musa* integrated into agroforestry systems provide food that secures nutrition (Figure 5). Fruit trees such as *Mangifera indica, Persea americana, Ziziphus spina-christ*i, *Balanites aegyptiaca,* and other food-producing woody species, as well as vines, are the main features of homegarden (Linger, 2014; Biazin *et al*., 2018). Also, homegardens agroforestry with their resulting variability assurances minimal input year-round provisioning, yield stability, and variety of food products. Perennial tree-crop systems that provide food were mostly linked to fruit tree-based agroforestry (Nigussie *et al*., 2019; Admasu & Jenberu, 2022) and coffee-based agroforestry (Biazin *et al*., 2018; Aragaw *et al*., 2021). Trees like *Balanites aegyptiaca* and *Cordia africana* provide edible leaves as a source of food. Fruit species indicate the extent to which farmers depend on home-grown food in northwestern Ethiopia (Linger, 2014) and the sale of forest products to increase cash income and to purchase food in the west Hararge zone, Ethiopia (Mamo & Asfaw, 2017).

Fodder value

Twenty-six publications have reported, that one of the main reasons for maintaining trees on farms is fodder gain from agroforestry system (Figure 4). *Cordia Africana, Croton macrostachy*us, *Millettia ferruginea,* and *Leucaena leucocephala (Lam.) de Wit* were the most important tree species used for fodder production (Appendix 1). *Faidherbia albida, Acacia nilotica,* and *Acacia seyal* are the main native fodder species that support livestock production in Tigray (Guyassa *et al*., 2014). On the other hand, *Millettia ferruginea, Cordia africana,* and *Vernonia amygdalina* are the most important tree species for livestock feed and boost household-level milk production in southern Ethiopia (Negash, 2007). According to Abebe *et al*. (2013), the existence of livestock, the interaction of various factors, the variety of food crops, the great diversity, and the standing stock of trees, and these factors all work together to contribute to the stability and sustainability of the agroforestry system. In Gedeo Southern Ethiopia, the lack of grazing pasture makes livestock's contribution to contemporary agroforestry systems less significant. To manage this, farmers used a cut-and-carry technique to produce fodder and to protect the seedlings of important native species that have regenerated naturally (Negash, 2007) (Figure 5). Also, the species *Millettia spp., Vernonia spp.,* and *Erythrina spp.* are used as fodder and greatly increase milk production.

Incomes

A total of 25 publications were reported on the benefit of agroforestry to income (Figure 4). Sales of trees and tree products, including fruits, firewood, fodder, poles for constrictions, timber, traditional medicines, gums and resins, spices, and essential oils are the main sources of cash income. *Mangifera indica, Catha Edulis Forsk, Coffee arabica L.,* and *Persea americana* were the major sources of income (Appendix 1). When compared to traditional farming, agroforestry provides farmers with a higher income. The sale of fruits and other forest products was a crucial source of income due to the lack of viable alternatives for a living. For instance, the national and regional economies, as well as the drought-prone areas, benefit greatly from the production of gum and resin in Ethiopia. A study conducted by Adane *et al*. (2019) indicated that fruit-tree-based agroforestry systems can enhance income for farmers in Southern Ethiopia. Farmers with higher incomes may save more money and have greater shock tolerance than farmers with lower incomes (Kim *et al.*, 2016; Adane *et al.*, 2019). Cash from agroforestry tree products also helps farmers cover unexpected expenses during the off-season, especially during seasonal droughts and when the price of other crops declines (Negash, 2007). The financial advantages of agroforestry systems, such as higher incomes and more employment options, allow rural households to invest in things like constructing houses in urban areas (Tega & Bojago, 2023). Also, the agroforestry systems play a significant part in lowering poverty and enhancing rural communities' standard of living. To ensure that smallholder farmers can successfully practice agroforestry over the long term, training in various agroforestry topics is necessary.

Timber and poles for construction

A total of twenty-three and eighteen publications were reported on the benefit of agroforestry to timber and poles for construction respectively (Figure 4). *Cordia Africana, Croton macrostachyus,* and *Albizia gummifera* were the most preferred tree species for timber and poles for construction (Appendix 1). *Cordia africana* is one of the most recognized native woody species for quality timber in Ethiopia (Lelamo, 2021). Tree species such as *Cordia africana* and *Croton macrostachyus* are used by rural households for building and furniture purposes in southern Ethiopia (Lelamo, 2021). Further research revealed that *Afrocarpus falcatus (Thunb.) C.N.Page, Millettia ferruginea, and Cordia africana* were the most preferred for making timbers and lumbers in southern Ethiopia (Figure 5).

Fruits

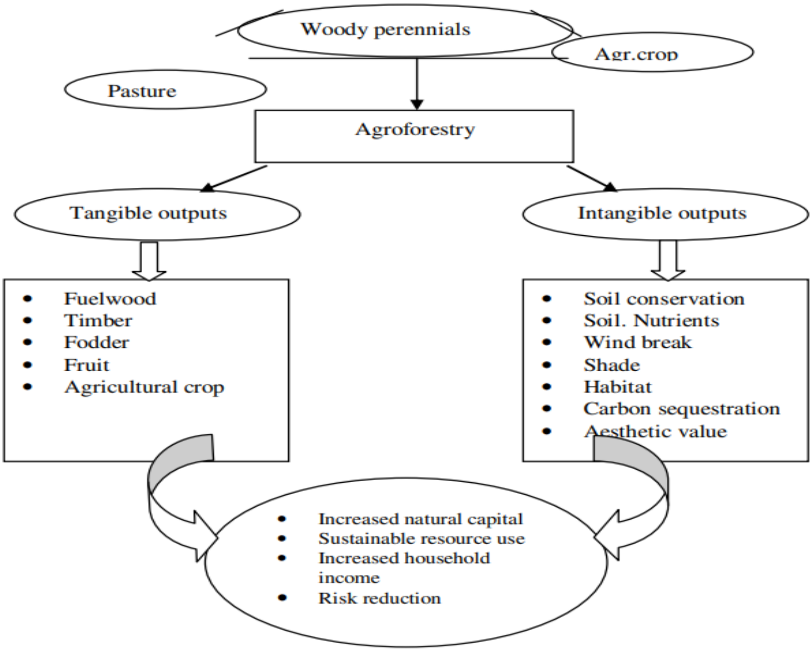
A total of 22 fruit woody species were reported in this review (Appendix 1). *Mangifera indica* and *Persea americana*, *Cordia africana*, and *Ziziphusspina-Christi* were the most popular fruit trees and shrub species in the literature review. Fruit trees were frequently seen in household gardens, as solitary trees planted around homes, or in coffee-based agroforestry (Biazin *et al.*, 2018; Birhane *et al.*, 2020). The research found that planting *Persea americana* next to enset and coffee enhanced fruit yields in Ethiopia (Biazin *et al.*, 2018). Better management practices, such as proper spacing, pruning, manure application, mulching, and irrigation during the dry season, were attributed to the research on the good yields for trees growing together with coffee (Biazin *et al.*, 2018). According to farmer evidence, apple-based agroforestry improved food security and nutrition, enhanced financial stability, and created additional job possibilities (Nigussie *et al.*, 2019; Admasu & Jenberu, 2022). Moreover, domesticating native species can help the Ethiopian fruit tree-based agroforestry development. The use of native fruit species was traditionally dependent on gathering them from their natural habitat. However, as access to natural habitats becomes increasingly limited and many rural households shift from subsistence to a cash-oriented economy, the cultivation of wild fruit trees has gained importance.

Other livelihood benefit of agroforestry systems

Bee forage, ornamental construction, perfume, stimulants, condiments, edible oil, handicrafts and carvings, additives, gum and resin dye, honey, and the use of trees as a shield during the conflict were other livelihood benefits obtained from agroforestry systems in Ethiopia. Agroforestry systems have greatly enhanced the human, financial, natural, and social capital of farmers. Products from agroforestry contributed to the creation of physical capital. Apple's production contributed to the development and improvement of infrastructure and services related to health, education, and communication in Ethiopia (Admasu & Jenberu, 2022). The production and selling of apple fruits and seedlings are credited with these developments (Admasu & Jenberu, 2022). The money from agroforestry allowed some farmers to buy motorcycles to cover the costs of transporting their products to markets. The findings were supported by Negash (2007) and Adane *et al.* (2019), who highlighted that the adoption of agroforestry has improved house conditions and communication assets in Ethiopia.

Fig. 5: Provisioning services of Gedeo agroforestry systems, Southern Ethiopian (Photo: Mesele Negash, 2006)

Fig. 6: Agroforestry and improvement of livelihood for rural farmers (Essa *et al.*, 2011)



CONCLUSION AND RECOMMENDATIONS

This was conducted to synthesis of evidence of the contributions of agroforestry systems to the conservation of native species, carbon sequestration, and improvement of livelihood in Ethiopia to support policy development. It is also important to identify knowledge gaps and the limitations of different scientific works.

The systematic review indicated that agroforestry systems have played an important role in the conservation of native woody species, reducing CO_2 emissions and enhancing the resilience of rural people to climate change issues. The review confirms that agroforestry conserves endangered species and important native tree species at the national level, including *Cordia africana*, *Hagenia abyssinica*, *Acacia abyssinica*, *Croton macrostachyus*, *Ficus vasta*, and *Faidherbia albida*. This indicated how agroforestry systems can serve as in-situ conservation for native species, lessening the impact of deforestation on the natural forests, and giving farmers more control over the management of limited resources and farmland.

In agroforestry systems, the soil and plant biomass also store significant amounts of carbon. Coffee-based and homegarden agroforestry are the most useful agroforestry systems since they provide the most benefits for livelihood, as well as the highest amount of carbon stored in the soil and aboveground biomass. Huge carbon stocks, widespread use in Ethiopia, and widespread acceptance worldwide as a strategy for mitigating and adapting to climate change make agroforestry an attractive low-hanging fruit that can assist the country in meeting its nationally Determined Contribution (NDC) commitments while fostering resilient livelihoods and landscapes.

Agroforestry systems have significantly improved the livelihood of rural households by providing food, timber, building materials, fuelwood, fodder, medicinal benefits, financial rewards, honey production benefits, and cultural benefits of trees while also supplying extra products used by people facing climate-related challenges. Agroforestry systems have also improved natural capital by including trees on farmland, helping rural residents meet a range of needs, and assisting in the fight against climate change.

The systematic review of evidence indicated that traditional agroforestry systems in Ethiopia, improve livelihoods and are significant for carbon sequestration and hence contribute to reducing climate change risks. Establishing and promoting traditional agroforestry systems in human-modified areas are essential to conserve biodiversity conservation and reduce greenhouse gas emissions. In addition to this, further scientific research on agroforestry and ongoing support from responsible bodies are needed to make sure that Ethiopian farmers can successfully practice agroforestry systems in the long run and thereby pay for improved livelihoods and the sustainability of their farming systems and the review validated the IPCC's recent decision to include agroforestry has become popular as an approach for reducing greenhouse gases emission.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data will be made available on request from the corresponding author.

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APPENDIX 1

Table 1: Number of publications and livelihood benefits of different trees/shrub species in Ethiopia

Tree/ shrub species	Food	timber	Poles for construction	fuelwood	Fodder	shade	household's utensils	farm tools	medicine	live fences	Income	Fruit	Number of livelihood benefits	Total number of publications
Acacia abyssinica (Hochst.) ex. Benth.						2							1	2
Acacia mellifera (Vahl) Benth.					1								1	1
Acacia nilotica (L.) Delile		1			4								2	5
Acacia senegal (L.) Willd.			1	2	1	1							4	5
Acacia seyal Delile					3								1	3
Acacia tortilis (Forssk.) Hayne			2	1	1	1			1		1		6	7
Albizia grandibracteata Taub				1		1			1				3	3
Albizia gummifera (Gmel.) C.A.Sm.		2	3	1		6			3				5	15
Albizia schimperiana Oliv.							1	1					2	2
Annona senegalensis Pers.												1	1	1
Anona reticulata Linn.	2												1	2
Balanites aegyptiaca (L.) Delilel	3		1	2	4		1					2	6	13
Becium grandiflorum (Lam.) Pic.Serm.					1								1	1
Berchemia discolor (Klotzsch) Hemsl.	1												1	1
Bridelia micrantha (Hochst.) Baill.				1	1				1			1	4	4
Cajanus cajan (L.) Millsp.					1					1			2	2
Carica papaya L.	3										1	1	3	5
Carissa edulis (Forssk.) Vahl	2												1	2
Casimiroa edulis Lal lave	3											1	2	4
Casuarina equisetifolia L.			1	1	1								3	3
Catha edulis (Vahl) Forssk.Ex Endl.					1				2		6		3	9
Celtis africana Burm.F.			2		1								2	3
Citrus medica L.												1	1	1
Citrus reticulate B.												1	1	1
Citrus sinensis (L.) Osb.	1											2	2	3
Coffee arabica L.				1	2	2					5		4	10
Combretum aculeatum Vent.				1									1	1
Combretum molle R.Br. ex G Don				1									1	1
Commiphora africana (A. Rich.) Engl.	1												1	1

(continued)

Tree species	Food	timber	Poles for construction	Fuelwood	Fodder	shade	household's utensils	farm tools	medicine	live fences	Income	Fruit	Number of livelihood benefits	Total number of publications
Cordia africana Lam.	1	5	5	4	5	4	1	1	2		3	3	11	34
Cordia monoica Roxb.	1												1	1
Cordia sinensis Lam.					1								1	1
Croton macrostachyus Hochst. ex Delile		2	4	7	2	5	2	1	6				8	29
Dichrostachys cinerea (L.) Wight & Arn				1									1	1
Dovyalis abyssinica (A.Rich.) Warb.				1	1	1							3	3
Ehretia cymosa Thonn.			2		1	1		1					4	5
Ensete ventricosum (Welw.)											1		1	1
Erythrina abyssinica Lam. ex DC.				1	2	2							3	5
Erythrina brucei Schweinf.					1				2				2	3
Eucalyptus camaldulensis Dehnh.			1	1							2		3	4
Eucalyptus globulus Labill									1				1	1
Euphorbia candelabrum Welw.									1				1	1
Euphorbia tirucalli L.										5			1	5
Faidherbia albida (Delile) A.Chev.		1		1	5	2							4	9
Ficus sur Forssk.	1	1	1	1	1	1	2	1	1				9	10
Ficus sycomorus L.					1	1							2	2
Ficus thonningii Blume.			1	1		1							3	3
Ficus vasta Forssk.	2		1	1		1			1			1	6	7
Grewia damine Gaertn.	3				3								2	6
Grewia ferruginea Hochst. ex A.Rich.	2												1	2
Grewia villosa Willd.	1												1	1
Hagenia abyssinica (Bruce) J.F.Gmel.			1										1	1
Leucaena leucocephala (Lam.) de Wit					5								1	5
Malus domestica Borkh.	1										1	1	3	3
Mangifera indica L.	7			1		3					7	9	5	27
Maytenus arbutifolia (Hochst. ex A.Rich.) R.Wilczek				1									1	1

(continued)

Tree/ shrub species	Food	timber	Poles for construction	Fuelwood	fodder	shade	household’s utensils	farm tools	Medicine	live fences	Income	Fruit	Number of livelihood benefits	Total number of publications
Maytenus senegalensis (Lam.) Exell	1			1									2	2
Millettia ferruginea (Hochst.) Baker		1	2	5	3	5	2	2	3	1			9	24
Mimusops kummel Bruce ex A.DC.	1											1	2	2
Moringa stenopetala (Baker f.) Cufod.	1					1			3	1			4	6
Musa acuminata Colla	1										1	1	3	3
Olea africana Mill.					1								1	1
Olea capenssis L.			1										1	1
Olea europaea L.			1		1				1				3	3
Opuntia ficus-indica (L.) Mill												1	1	1
Oxytenanthera abyssinica A. Rich.	1												1	1
Persea americana Mill.	4					2					3	5	4	14
Podocarpus falcatus Thunb.			1	1		1		2			2		5	7
Prunus africana (Hook.f.) Kalkam			2	2			1	2			1		5	8
Prunus persica Stokes	1			1							1	1	4	4
Psidium Guajava L.	2										1	2	3	5
Rhamnus prinoides L.Herit.									2				1	2
Ricinus communis L.										1	1		2	2
Rosa abyssinica R.Br. ex Lindl.	1												1	1
Sesbania sesban (L.) Merr.					1								1	1
Syzygium guineese (willd.) DC.	1		2	2			1	1		1			6	8
Tamaridus indica L.	2												1	2
Trichilia emetica Vahl.									1				1	1
Vernonia amygdalina Del.					4	5			4			1	4	14
Vernonia schimperi Sch.Bip. ex Hochst.					1								1	1
Ximenia americana L.	3											1	2	4
Ziziphus mucronata Willd.	1			1	1	1			1	1		1	7	7
Ziziphusspina-christi(L.) Desf	2		1	1	1	1				5		4	7	15
Total count species	**31**	**7**	**21**	**30**	**33**	**24**	**8**	**9**	**19**	**8**	**16**	**22**		