# AGROFORESTRY IN ETHIOPIA: REVIEW OF ITS ROLE IN ENHANCING SMALLHOLDER AGRICULTURE, ENVIRONMENTAL SUSTAINABILITY, AND ADOPTION CHALLENGES

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## ABSTRACT

Agroforestry, the integration of trees and shrubs into agricultural landscapes, has emerged as a promising strategy for enhancing smallholder agriculture in Ethiopia. The review's overall objective was to examine the impacts of various agroforestry systems on the country's agricultural productivity, food security, and environmental sustainability. However, synthesized fragmented evidence on adopting agroforestry systems among Ethiopian smallholders remains limited. The review used a combination of qualitative and quantitative methods to investigate agroforestry's impact on smallholder agriculture, environmental sustainability, and adoption issues. A total of 89 publications were included in the systematic review, focusing on economic functions (n=40), environmental functions (n=35), and adoption challenges (n=20). Agroforestry is a land management strategy that integrates trees, crops, and livestock to generate food, protect the environment, and provide habitats for wildlife. The findings showed that agroforestry provides environmental functions such as soil fertility improvement, biodiversity conservation, soil and water conservation, and carbon sequestration. Moreover, agroforestry improves the economy of smallholder farmers by providing timber and non-timber products in Ethiopia. The review result indicated that key challenges, including socio-economic barriers, limited resource access, and inadequate extension services, hinder the widespread adoption of agroforestry. The findings emphasize the need for targeted policies and support mechanisms to overcome these challenges and maximize the potential of agroforestry in contributing to sustainable agricultural development in Ethiopia. The review concludes by suggesting pathways to enhance adopting agroforestry systems in Ethiopia, emphasizing the need for integrated approaches combining scientific innovations with local practices to support sustainable agricultural development.

**Keywords**: Agroforestry, Smallholder Agriculture, Adoption Challenges, and Sustainable Development

## INTRODUCTION

Agroforestry systems, which integrate trees and shrubs into agricultural landscapes, are increasingly recognized for their potential to address various agricultural and environmental challenges. In Ethiopia, where agriculture is predominantly characterized by smallholder farming, agroforestry practices offer a promising strategy for enhancing agricultural productivity and environmental sustainability.

Ethiopia's agriculture largely depends on smallholder farmers who cultivate fragmented plots of land under diverse and often challenging conditions. The highlands of Ethiopia, in particular, are characterized by steep slopes, soil erosion, and declining soil fertility due to intensive agricultural practices and deforestation (Kang *et al.*, 2018). These environmental issues threaten agricultural productivity and food security, making sustainable land management practices crucial. Agroforestry systems, which combine trees with crops and/or livestock, have the potential to mitigate these challenges by improving soil health, enhancing water retention, and increasing biodiversity (Kumar & Nair, 2011).

One of the key benefits of agroforestry systems is their ability to enhance soil fertility. Trees in agroforestry systems contribute organic matter to the soil through leaf litter and root biomass, which improves soil structure and nutrient content (Alemayehu & Woldemariam, 2021). This organic matter helps in nutrient cycling and reduces soil erosion by stabilizing soil with its root systems. Furthermore, the presence of trees can improve water retention in the soil, reducing the risk of crop failure during dry periods (Girma *et al.*, 2020). These benefits are particularly important in Ethiopia, where water scarcity and soil degradation are significant concerns for smallholder farmers.

In addition to environmental benefits, agroforestry systems offer economic advantages. They provide opportunities for diversifying income sources through the production of timber, fuelwood, fruits, and other non-timber forest products (Asare & Osei, 2019). By integrating trees into farming systems, smallholder farmers can achieve greater economic resilience and reduce dependency on single-crop yields. Agroforestry also contributes to climate change mitigation by sequestering carbon dioxide from the atmosphere, which is a critical aspect given Ethiopia's vulnerability to climate change impacts (Girma *et al*., 2020).

Despite these benefits, the adoption of agroforestry systems in Ethiopia faces several challenges. Technical barriers, such as the lack of knowledge about appropriate tree species and management practices, can hinder the successful implementation of agroforestry systems (Asfaw & Shiferaw, 2020). Economic constraints, including the high initial costs of establishing agroforestry systems and limited access to credit, also pose significant challenges (Mekonnen & Guta, 2018). Social and cultural factors, such as resistance to change and limited awareness of the benefits of agroforestry, further complicate adoption efforts.

Addressing these challenges requires a comprehensive understanding of the local context and targeted interventions to support smallholder farmers in adopting agroforestry practices. Successful case studies and best practices can provide valuable insights into effective strategies for overcoming these barriers and promoting wider adoption of agroforestry systems in Ethiopia.

In general, agroforestry systems hold substantial promise for improving agricultural productivity, environmental sustainability, and economic resilience in Ethiopia. However, realizing these benefits requires addressing the various technical, economic, and social challenges that currently limit their adoption.

Therefore, the overall objective of the review was to synthesize and critically evaluate the role and impact of agroforestry systems in Ethiopia, focusing specifically on their effects on smallholder agriculture and the barriers to their adoption. Compiling fragmented scientific information on economic and environmental advantages associated with agroforestry, aimed at offering well-structured research evidence to relevant researchers, governmental organizations, decision-makers, non-governmental organizations, and stakeholders. The review will also identify and analyze key barriers to adoption, such as technical, economic, social, and policy-related obstacles, and propose strategies to address these challenges. Additionally, it will examine successful case studies of agroforestry implementation to extract lessons and best practices, providing actionable recommendations to promote the broader implementation of agroforestry systems in Ethiopia.

## MATERIALS AND METHODS

### Study design and literature search

This review employed a systematic approach to gather, analyze, and synthesize existing literature on agroforestry practices in Ethiopia. A combination of qualitative and quantitative data was utilized to provide a comprehensive understanding of agroforestry's role in enhancing smallholder agriculture and promoting environmental sustainability. A comprehensive literature search was conducted using Web of Science, Scopus, and Google Scholar to gather information on agroforestry's role in enhancing smallholder agriculture and promoting environmental sustainability. Keywords such as "agroforestry", "Ethiopia", "smallholder agriculture", "environmental sustainability", and "adoption challenges" were used to identify relevant articles, reports, and theses published from 1993 to 2024.

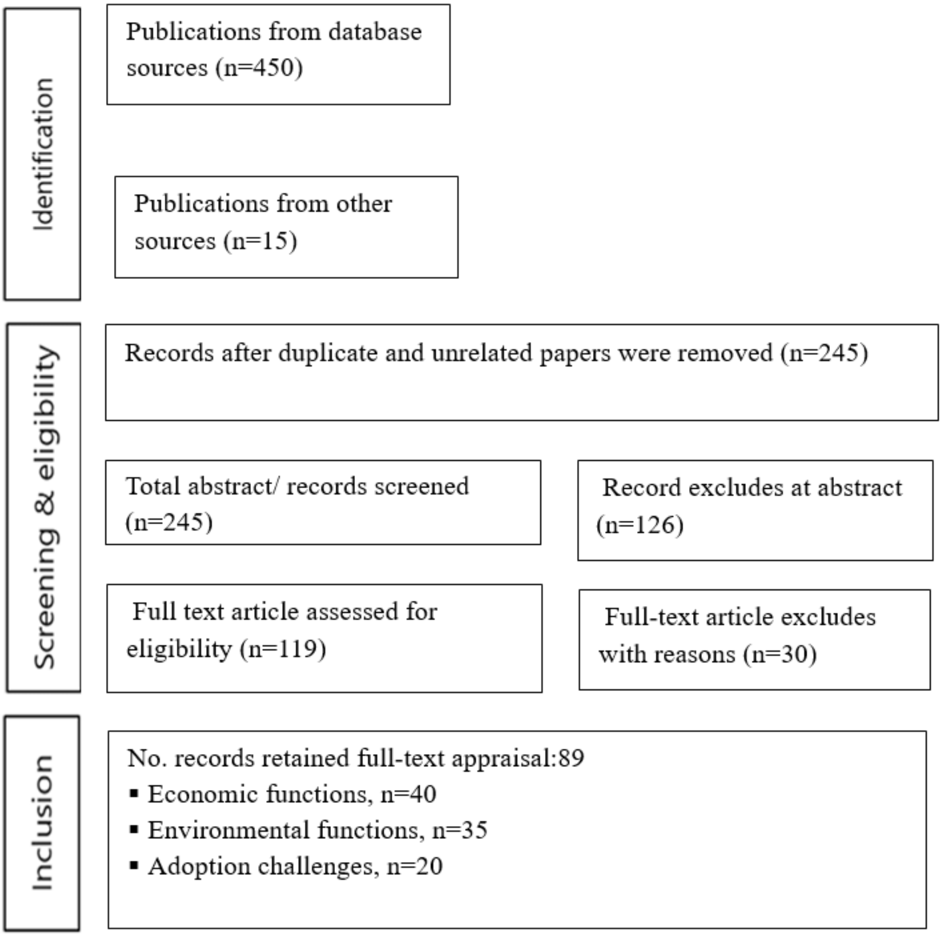
### Literature inclusion and exclusion criteria

This systematic review paper examines scientific and grey literature about agroforestry's contribution to enhancing smallholder agriculture and promoting environmental sustainability. To determine which scientific papers and grey literature to include or exclude in the systematic review, the following criteria were established: (i) Peer-reviewed articles focusing on agroforestry in Ethiopia were considered most relevant for inclusion; (ii) studies that provided either quantitative or qualitative data on addressing the impacts of agroforestry on smallholder agriculture and environmental sustainability; (iii) Research that discusses challenges related to the adoption of agroforestry practices and preference was given to studies with robust empirical analysis; (iv) only studies published in English were eligible for inclusion; and (v) Research not specific to Ethiopia and they did not focus on agroforestry or its socio-economic and environmental impacts were eligible for exclusion.

### Identification and screening of the studies

A flow diagram was used to screen articles and assess their relevance (Fig. 1). Following a comprehensive literature search, 450 potential records were identified. In the initial stage, 220 records were eliminated due to duplication by title or lack of relevance. In the second stage, the abstracts and summaries of the remaining 245 records were reviewed according to inclusion and exclusion criteria. Consequently, 126 of the 245 records were discarded after evaluation, mainly because they did not fulfill the selection criteria. A full-text assessment was then conducted on the remaining 119 records, resulting in the exclusion of an additional 30 due to limited relevance, poor data quality, and unpredictability. Ultimately, 89 publications were included in the systematic review, focusing on economic functions (n=40), environmental functions (n=35), and adoption challenges (n=20).

**Fig. 1: A systematic flow diagram depicting the process of literature searches and the screening of potential records**




## RESULTS AND DISCUSSION

### Definition and concepts of agroforestry

Agroforestry refers to a group of land-use systems where woody perennials, such as trees and shrubs, are intentionally cultivated alongside crops, pasture, and/or livestock within the same management area (Nair, 2012). This can occur through various spatial arrangements or through sequential planting over time. Agroforestry is a dynamic, ecology-focused natural resource management system that enhances and sustains production by incorporating trees into farms and agricultural landscapes, leading to greater social, economic, and environmental returns (Nair, 2012; Torralba *et al.*, 2016). There should be substantial ecological and economic interactions between the woody and non-woody components. A precise scientific definition of agroforestry should emphasize two key characteristics that distinguish it from other land use practices:

1. The intentional cultivation of woody perennials alongside crops and/or livestock on the same land unit, which can occur through either spatial mixing (spatial arrangement) or sequential planting (temporal arrangement).
2. There must be a notable interaction (either positive or negative) between the woody and non-woody components of the system, whether ecological or economic. This definition suggests that:
    - Agroforestry typically includes two or more species of plants (or a combination of plants and animals), with at least one being a woody perennial;
    - An agroforestry system consistently produces two or more outputs;
    - The duration of an agroforestry system extends beyond one year, and;
    - Even the most basic agroforestry systems are ecologically (in terms of structure and function) and economically more complex than monocropping systems

**Principles of agroforestry**

Agroforestry possesses four principles include:

- **Diversity**: Agroforestry systems are characterized by a diverse mix of trees, crops, and sometimes livestock. This diversity can enhance ecological stability, reduce pest and disease pressures, and improve resilience to climate variability (Kumar and Nair, 2011).
- **Sustainability**: Agroforestry aims to achieve sustainability by improving soil health, conserving water, and enhancing biodiversity. The integration of trees into farming systems helps in nutrient cycling, reduces soil erosion, and enhances water retention (Jose, 2009).
- **Productivity**: By combining different types of vegetation and animals, agroforestry systems can increase overall productivity. Trees can provide additional products such as timber, fuelwood, and fruits, while also benefiting the crops and livestock through improved soil and microclimate conditions (Nair, 2012).
- **Symbiosis**: Agroforestry systems promote symbiotic relationships among plants, animals, and the environment. Trees can provide shade, windbreaks, and organic matter that benefit crops and livestock, while the crops and livestock can give support to the trees through nutrient recycling and pest control (Kumar & Nair, 2011).

**Types of Agroforestry Systems and Practices**

In this review, we examined the following agroforestry practices: home gardens, parkland, woodlot, boundary plantation, alley cropping, Windbreaks (Shelterbelts), live fences, parklands, riparian buffers, and trees on pasture land (see Table 1). We classified these agroforestry practices into two distinct systems (Type 1: Agrosilvopastoral system: (Crop +trees + livestock; Type 2: Agri silvicultural system: (Crop +trees); Type 3: Silvopastoral system:(Trees +livestock) based on the different management approaches for enhancing smallholder agriculture, environmental sustainability, and adoption challenges in agroforestry.

The background of agroforestry systems and practices is outlined in the reviewed studies, which are categorized and described in Table 1. The definitions and categories of agroforestry were developed based on the functions or arrangement of agroforestry components. As a result, agroforestry types were grouped according to the level of detail used in the review studies. The most commonly used criteria for classifying agroforestry systems and practices include: structural (composition and arrangement of components), purposeful (main operation or role of components), socio-economic (scale and goals of the system), and ecological (environmental and ecological quality).

Trees serve as the primary elements of agroforestry systems and are distinguished by various practices, components, and functions (see Table 1). The review findings indicated that agrosilvopastoral systems are defined by agroforestry practices such as home gardens that incorporate livestock and the presence of fodder trees and shrubs on agricultural lands. Likewise, the agrosilvopastoral agroforestry system comprises different components, including trees and shrubs, food and cash crops, vegetables, and pasture.

The second type of agroforestry system is silvopastoral, which is defined by two agroforestry practices (AFPs): trees on pastureland and planted fodder trees or shrubs. Silvopasture is an agroforestry practice that combines the management of trees or shrubs with livestock grazing on the same land. This system integrates forestry and pastureland, allowing for the simultaneous production of timber, forage, and livestock. Silvopastoral enhances biodiversity, improves soil health, provides shade and shelter for animals, and can increase the overall productivity and sustainability of the land by optimizing the use of resources. The final type of agroforestry system is agrisilvicultural, which is the most widely practiced by farmers. This system is characterized by a diverse range of agroforestry practices, including home gardens, live fences, windbreaks, tree parkland, and coffee-based plantations, among others (see Table 1). It involves the integration of crops with tree cultivation on the same land. This system allows for the simultaneous production of food crops, cash crops, and timber or other tree products.

In Ethiopia, the most prevalent agroforestry practices (AFPs) include homegardens, parkland, alley cropping, woodlots, boundary planting, windbreak (shelterbelt), farm boundaries, trees on grazing lands, and riparian zone vegetation see Table 1 (Getachew & Mulatu, 2024). Many of these AFPs are specific to particular locations, and influenced by variations in agroecological conditions and types of niches (Gebre *et al*., 2019). For instance, parkland agroforestry features maize intercropped with Cordia africana in Bako and Western Ethiopia, as well as Faidherbia albida-based agroforestry in the Hararghe Highlands and Bushoftu area (Ereso, 2023). Additionally, multistorey home gardens are common in various regions of southern and southwestern Ethiopia. The structural complexity of these home gardens varies, with some, like those in Sidama, exhibiting intricate and diverse forms that include multiple species.

**Table 1: Description of different agroforestry systems and practices**

| Type of agroforestry practices | Description | Systems | References |
|---|---|---|---|
| Homegarden | Multistory agroforestry system that integrates trees, vegetables, and crops around the homestead; livestock may be included or excluded | Agrosilvopastoral system: (Crop +trees + livestock) | Kim *et al*. (2016); Gebre *et al*. (2019) |
| Parkland | Trees/shrubs are grown dispersed widely on farmers' fields while crops are grown in the understory. | Agri silvicultural system: (Crop +trees) | Gebrewahid *et al*. (2019); Manaye *et al*. (2021) |
| Woodlot | Single-species tree plantations are established on agricultural or degraded lands to generate fuelwood, provide materials for construction, and help in land rehabilitation. | Silvopastoral system: (Trees +livestock) | Kimaro *et al.* (2011); Manaye *et al*. (2021) |
| Boundary plantation | Trees that are intentionally preserved or planted along the edges of a farm. | Silvopastoral system: (Trees +livestock) | Manaye *et al*. (2021) |
| Alley cropping | Alley cropping is an agroforestry practice that involves planting rows of trees or shrubs alongside crops in the same field. | Agri silvicultural system: (Crop +trees) | Nair (1993); Kim *et al*. (2016) |
| Windbreaks (Shelterbelts) | Trees and/or shrubs, known as arboreal shelterbelts, are strategically planted to effectively decrease wind speed, thereby benefiting the crops located on the sheltered side. | Agri silvicultural system: (Crop +trees) | Amadi *et al*. (2016); Kim *et al*. (2016) |
| Life fence | A type of practice consists of a single row of densely planted trees or shrubs established to protect the adjacent croplands | Agri silvicultural system: (Crop +trees) | Albrecht and Kandji (2003); Henry *et al*. (2009); Kim *et al*. (2016) |
| Riparian buffer zone | Strips of permanent vegetation (such as trees, shrubs, or grasses) are established between agricultural fields or pastures and bodies of water like streams, lakes, wetlands, and ponds. | Silvopastoral system: (Trees +livestock) | Kim *et al.*, (2016) |
| Tree on grazing land | Planting trees in pasture land | Silvopastoral system: (Trees +livestock) | Kim *et al.*, 2016 |

## Historical Development of agroforestry

The practice of agroforestry in Ethiopia has evolved over centuries, deeply rooted in traditional farming practices. Historically, Ethiopian farmers have used various forms of agroforestry, including home gardens and mixed cropping systems, to sustain their agricultural activities. Traditional systems often incorporated trees such as olive, enset (a staple crop), and coffee into their farming systems, benefiting from the ecological and economic advantages these trees provided (Teshome & Tadele, 2020).

In recent decades, there has been increased formal recognition and promotion of agroforestry systems in Ethiopia. Efforts to integrate modern agroforestry practices have been supported by various national and international organizations aiming to address environmental degradation, improve soil fertility, and enhance food security. Projects and research have focused on developing and promoting agroforestry systems tailored to Ethiopia's diverse ecological zones and farming practices (Girma *et al*., 2020; Asare & Osei, 2019). These initiatives have contributed to the gradual adoption of more structured agroforestry systems, with growing support from governmental and non-governmental agencies.

## Agroforestry Impacts on Smallholder Agriculture

Agroforestry systems have profound implications for smallholder agriculture, particularly in regions like Ethiopia where farming is characterized by small-scale operations and diverse environmental challenges. These systems, which integrate trees and shrubs with crops and livestock, offer multiple benefits that address economic, environmental, and social issues faced by smallholder farmers. By examining these impacts, we gain insights into how agroforestry can enhance agricultural productivity, sustainability, and community well-being (Kumar & Nair, 2011; Jose, 2009).

### *Economic Impacts of agroforestry practices*

Various agroforestry practices provide a wide array of socio-economic advantages for farmers, extending beyond merely productivity and ecological sustainability (Table 2). The woody components within agroforestry systems offer numerous benefits, including food, fuelwood, construction materials, timber, furniture, resins, household items, and other socio-economic gains (Negash *et al*., 2012; Lelamo, 2021; Getachew & Mulatu, 2024). Economically, tree-based farming can improve economic resilience by diversifying product offerings (Amare *et al*., 2019; Girma *et al*., 2020; Amare & Darr, 2023;). Agroforestry contributes to income diversification by combining tree products with traditional crops and livestock. This diversification helps reduce dependence on a single crop, mitigating market fluctuations and crop failure risks. For instance, high-value products such as fruits, nuts, and timber offer additional revenue streams, enhancing financial stability (Asare & Osei, 2019; Girma *et al*., 2020). Including these products can also lead to increased economic resilience and opportunities for smallholders. The integration of woody components can increase the profitability of agroforestry while fulfilling multiple roles, such as providing alternative income sources and supplying fodder or food during times of scarcity, thereby helping rural communities to better withstand various challenges (Gebru *et al*., 2019). Additionally, certain wood products can command higher economic values, generating extra income for rural communities beyond the earnings from annual crops.

In the country where agroforestry practices are adopted, rain-fed agriculture is the main livelihood source for many farmers. In Ethiopian agroforestry, non-timber forest products and timber forest products including fruits, firewood, honey, spices, timber, poles, and charcoal—provide income for smallholder farmers (Negash, 2007; Melaku, 2014; Birhane *et al*., 2019; Nigatu *et al*., 2020; Manaye *et al*., 2021). While income levels can vary by location, this additional revenue is crucial in enhancing farmers' livelihoods, particularly during periods of climate-related disruptions and drought that impact crop yields, such as those caused by climate change (Eshetu *et al*., 2018; Cheru & Haile, 2023; Ereso, 2023; Getachew & Mulatu, 2024).

Agroforestry systems can improve market access by introducing new, high-demand products. Products like fruits, nuts, and timber often command higher prices and can open up new commercial opportunities. This diversification not only improves market competitiveness but also supports the economic viability of smallholder farming (Mekonnen & Guta, 2018). Research has shown that agroforestry can help farmers access broader markets and improve their bargaining positions (Girma *et al*., 2020).

The sale of trees and tree-derived products, such as fruits, firewood, fodder, construction poles, timber, traditional medicines, gums and resins, spices, and essential oils, serves as the primary source of cash income (Getachew & Mulatu, 2024). For example, fuelwood sourced from a *Millettia ferruginea* tree can yield an income between $14 and $17 (Negash, 2007). The research further revealed that sawn timber from Cordia africana is in strong demand and commands high prices in the market. On the other hand, research has indicated that farmers in the Kaffa zone derive 47 % of their income from non-timber forest products (Melaku, 2014). In the Wolayita zone, farmers earn between 800 to 1500 Ethiopian Birr (ETB) from these products (Agize *et al*., 2016), while those in the Jimma zone generate 1683 ETB from home garden agroforestry (Melaku *et al*., 2014). Over fifty percent of the plant species in home garden agroforestry are consumable by family members, providing as much as 30-40 % of the household's income (Wolde & Desalegn, 2020). In the Sidama zone, fruit tree-based agroforestry practices yield an average income of 2754 ETB per year (Adane *et al*., 2019), and overall, agroforestry contributes an average income of 32,199.16 ETB for farmers in Eastern Ethiopia (Girma, 2024).

Agroforestry reduces input costs and contributes to financial stability. The presence of trees can improve soil health, reducing the need for synthetic fertilizers and leading to more resilient farming practices. This resilience is crucial in buffering against adverse weather conditions and economic shocks (Kumar & Nair, 2011). Agroforestry systems help spread risks and reduce dependency on single-crop yields, promoting greater financial stability for smallholder farmers (Girma *et al*., 2020).

*Environmental impacts of agroforestry*

Another aspect of the benefits of agroforestry is its environmental contributions, which include enhancing soil fertility and water management, carbon sequestration, and conserving biological diversity (Lelamo, 2021). Among these ecological advantages, carbon sequestration stands out as a significant benefit of agroforestry (see Table 3). The integration of leguminous trees into agricultural lands and pastures through agroforestry practices can help improve soil fertility by reducing soil erosion and improving soil organic carbon, nitrogen content, and microbial activities.

**Table 2: Summary of agroforestry impact on economic benefit**

| Agroforestry practices | Economic functions | References |
|---|---|---|
| Homegarden | Food, firewood, medicinal use, fodder, shade, income, pole for construction, fruits, and farm tools | Negash (2007); Negash *et al*. (2012); Endale *et al*. (2017); Jemal *et al*. (2018); Betemariyam *et al*., (2020); Furo *et al*. (2020); Manaye *et al*. (2021); Sahle *et al*. (2021); Ereso (2023); Getachew and Mulatu (2024) |
| Parkland agroforestry | Medicinal use, fruit Food, fodder, firewood, income, shade, timber, pole for construction charcoal, and implements/tools farm | Kalame *et al*. (2011); Endale *et al*. (2017); Gebrewahid *et al*. (2019); Gebre *et al*. (2019); Mekonnen *et al*. (2021) Chiemela *et al*. (2018); Birhane *et al*. (2019); Tadesse *et al*. (2019); Tadele *et al*. (2020) |
| Boundary planting | Fodder, food, firewood, income,<br>shade, timber, charcoal, wood,<br>poles, bee forage | Duguma (2013); Nigatu *et al*. (2020); Endale *et al*. (2017); Reppin *et al*. (2020); Manaye *et al*. (2021); Fuchs *et al*. (2022); Getachew and Mulatu (2024) |
| Woodlot | Timber, firewood, fodder, income,<br>timber, pole for and construction | Gebreegziabher and van Kooten (2013); Endale *et al*. (2017); Mukangango *et al*. (2020); Reppin *et al*. (2020) |
| Alley cropping | Fodder, firewood, wood and timber | Hafner et al. (2021); Tadesse *et al*. (2021) |
| Fruit based agroforestry | Fruit cash income and food | Negash (2007); Negash *et al*. (2012; Admasu and Jenberu (2022) |
| Ensete based agroforestry | Food and cash income | Negash *et al*. (2012); Negash and Kanninen (2015); Negash and Starr (2015); Tesfay *et al*. (2022) |

Agroforestry impact on soil fertility improvement and water management

The agroforestry land use approach enhances soil and water management, serving as an ecological benefit for smallholder farmers (Table 3). In agroforestry systems, trees provide shade and mulch, particularly in integrated ensete-coffee agroforestry practices, which help control soil erosion, regulate moisture and temperature, and improve soil nutrition, thereby creating optimal conditions for crop growth (Lelamo, 2021). Agroforestry is vital for land enhancement and erosion control, as it strengthens and maintains agroecological processes related to soil fertility management (Sileshi *et al*., 2020). For instance, alley cropping enhances soil organic matter by 15 % compared to conventional systems and increases soil moisture retention by 25 % in Ethiopia (Mekonnen & Guta, 2018); Alemayehu & Woldemariam, 2021). Moreover, tree fallow agroforestry systems significantly reduced soil erosion by 30 % in the southern part of the Southern Nations, Nationalities, and Peoples' Region (SNNPR) (Teshome & Tadele, 2020) and Silvopasture improved soil pH from acidic to neutral in Oromia region (Girma *et al*., 2020). Agroforestry systems enhance soil fertility through the addition of organic matter from tree litter and root biomass. This organic matter improves soil structure and nutrient content, leading to better crop yields. Enhanced soil fertility and reduced soil erosion are critical in areas experiencing soil degradation (Alemayehu & Woldemariam, 2021; Nair, 2012). The integration of trees into farming systems helps maintain soil health and supports sustainable agricultural practices (Jose, 2009). Consequently, farmers view the presence of these tree species as crucial for delivering ecosystem services that support soil and water conservation, addressing various global challenges (Amare *et al*., 2018).

The relationship between trees and crops in various agroforestry systems significantly contributes to the enhancement of soil fertility, which subsequently influences crop productivity (Dori *et al*., 2022). In Ethiopia, agroforestry is a vital soil management strategy among several options, playing a crucial role in improving both the nutrient and physical characteristics of the soil and in restoring its fertility (Wolle *et al*., 2021; Mebrate *et al*., 2022). Moreover, agroforestry is an effective management approach that addresses both economic and ecological dimensions, helping to boost soil nutrient levels, improve water use efficiency, and enhance soil quality and health to ensure sustainable production and benefits (Asfaw, 2016).

Agroforestry's impact on carbon sequestration

Agroforestry systems in Ethiopia are crucial for carbon sequestration, as they contribute to the storage of carbon in both biomass and soil. Numerous studies emphasize the ability of these systems to strengthen carbon sinks, enhance soil health, and promote sustainable livelihoods, positioning them as an essential strategy for mitigating climate change in the region (Table 3). Therefore, the cultivation and maintenance of various multipurpose trees on farmers' agricultural land contribute to carbon sequestration (Gebrewahid *et al*., 2018) through their aboveground and belowground biomass (Zomer *et al*., 2016).

Furthermore, agroforestry significantly contributes to the global carbon pool and national carbon budgets (Zomer *et al*., 2016). For instance, the presence of scattered trees on agricultural land can greatly enhance the climate resilience of Ethiopia's green economy strategy (Negash & Starr, 2015; Gebrewahid *et al*., 2018). In the southeastern Rift Valley escarpment of Ethiopia, agroforestry has been found to sequester an average biomass carbon stock of 67 Mg per hectare, with trees representing 39-93 % of this carbon stock (Negash & Starr, 2015). Additionally, home gardens and coffee-based agroforestry systems help reduce emissions and increase carbon sinks in agricultural landscapes, and they can be integrated into other mixed cropping systems on cropland, pastureland, or rangeland to combat the impacts of climate change (Betemariyam *et al*., 2020).

Multi-strata agroforestry, homegarden, and coffee-based agroforestry have been identified as effective practices for maximizing carbon sequestration (Getachew & Mulatu,2024) The findings indicated that trees in agroforestry systems contributed to 61-79 % of carbon storage, with an average of 73 % of the total carbon in these systems (Getnet *et al*., 2023). Likewise, Negash and Starr (2015) and Betemariyam *et al*. (2020) reported that agroforestry practices accounted for 77 % and 67-85 % of carbon storage, respectively. For instance, in southern Ethiopia, agroforestry has the potential to mitigate 772.02 Mg CO2e per hectare (Molla & Kewessa, 2019) and 27.2 ± 13.5 Mg CO2e per hectare annually (Kim *et al*., 2016). The effectiveness of agroforestry in sequestering carbon varies based on local soil types, climate conditions, and specific agroforestry practices employed. There is a need for policies that promote sustainable agroforestry practices, including financial incentives and training for farmers.

## Agroforestry's impact on biodiversity conservation

Agroforestry, which involves incorporating trees and shrubs into agricultural environments, has become a promising strategy for improving biodiversity conservation while also bolstering agricultural productivity. This review explores the various effects of agroforestry on biodiversity, emphasizing its contributions to habitat preservation, species diversity, and the provision of ecosystem services.

Agroforestry creates habitats for wildlife, fosters high levels of biodiversity conservation, and encourages the natural regeneration of native species, which can aid in restoring plant diversity in a given area (Getachew & Mulatu, 2024). For instance, in the Ethiopian highlands, traditional management of agroforestry trees has provided sanctuary for a significant number of native woody species (Abate, 2020). These native tree and shrub species may continue to be preserved as tree resources on farmland, potentially serving as a key source for biodiversity restoration in the future. Additionally, parkland agroforestry is a prominent traditional practice found in many agroecosystems in the Ethiopian highlands, playing a vital role in biodiversity conservation (Bekele, 2018).

Findings indicated that agroforestry plays a significant role in conserving endangered species and key native tree species at the national level, including *Cordia africana*, *Hagenia abyssinica*, *Acacia abyssinica*, *Croton macrostachyus*, *Ficus vasta*, and *Faidherbia albida* (Getachew & Mulatu, 2024). This finding is supported by Eyasu *et al*. (2020), who noted that agroforestry systems are essential for the conservation of economically and ecologically important tree species such as *Cordia africana*, *Ficus sycomorus L.*, *Olea europaea* L., and *Ziziphus spina-christi*, which are no longer found in nearby natural forests in Northern Ethiopia. This demonstrates that agroforestry systems can function as in-situ conservation areas for native species, mitigating the effects of deforestation on natural forests and providing farmers with greater control over the management of scarce resources and agricultural land.

Additional research has shown that traditional agroforestry practices in Ethiopia include 50 woody species, with 85 % being indigenous and belonging to 31 different families (Molla & Kawessa, 2019). Agroforestry also can preserve a considerable number of native plant species that are declining or at risk of extinction in their natural environments (Mulatu & Hunde, 2019; Tesfaye *et al*., 2020). According to Mulatu & Hunde (2019), various agroforestry practices have conserved between 32 and 419 native tree species.

**Table 3: Summary of agroforestry's impact on environmental benefits**

| **Environmental elements** | **Environmental functions** | **References** |
|---|---|---|
| Soil fertility improvement and soil and water management | Increases soil organic carbon and nitrogen content, improves soil PH, increases soil moisture retention, controls soil erosion, enhances crop productivity, improves microbial activity and livestock productivity | Mekonnen and Guta (2018); Asare and Osei (2019); Bekele *et al*. 2020; Girma *et al*. (2020); Teshome and Tadele (2020); Girma *et al*. 2021; Alemayehu and Woldemariam (2021) |
| Carbon sequestration | Trees in agroforestry systems contribute significantly to carbon storage, accounting for approximately 61–79% of the total carbon storage, with estimates ranging from 67% to 85%. The carbon storage estimates (in Mg C ha−1) include aboveground carbon storage ranging from 2.1 ± 0.01 to 28.2 ± 6.0, belowground carbon storage from 1.9 ± 0.8 to 9.6 ± 2.8, and soil organic carbon varying between 14.5 ± 1.4 and 115.7 ± 15.1. These figures highlight the importance of agroforestry practices in enhancing carbon sequestration across different environments. Moreover, the study indicated that agroforestry systems in Ethiopia sequester an average of 40.04 ± 10.4 Mg C ha−1 in biomass and 68.9 ± 9.9 Mg C ha−1 in soil. | Negash and Starr (2015); Gurmessa *et al*. (2016); Gebrewahid *et al*. (2018); Sahle *et al*. (2018); Betemariyam *et al*. (2020); Furo *et al*. (2020; Nigatu *et al*. (2020); Manaye *et al*. (2021); Gebremeskel *et al*. (2021); Hagos *et al*. (2021); Getnet (2023); Getachew and Mulatu, 2024 |
| Biodiversity conservation | Agroforestry systems contribute to biodiversity conservation in several ways: (i) they create habitats for native plant and animal species that rely on forests ; (ii) they help preserve endangered tree species and their genetic diversity within fragmented landscapes; (iii) they can act as corridors and stepping stones for native species, connecting different habitats and facilitating gene flow ;(iv) they can function as buffer zones around protected areas, aiding biodiversity conservation by minimizing a human impact on core habitats, offering shelter, and creating a more favorable environment for species movement ;(v)and they promote biodiversity by providing habitats for organisms that disperse seeds, thereby enhancing the survival and conservation of native species. | Negash *et al*. (2012); Molla and Kewessa, 2015; Worku and Bantihun (2017); Gifawesen *et al*. (2020); Wolde and Desalgn (2020); Ereso (2023); Getachew and Mulatu, 2024 |

*Social Impacts of agroforestry*

The social impacts of agroforestry systems include effects on community well-being, gender roles, and labor dynamics:

Agroforestry systems enhance community well-being by improving food security and nutrition through diversified crop production. The availability of various products supports better dietary outcomes and contributes to local livelihoods. Additionally, agroforestry can improve health by reducing air pollution and providing shade (Asfaw & Shiferaw, 2020). The integration of trees into agricultural systems offers recreational and aesthetic benefits that enhance overall quality of life.

Agroforestry practices can influence gender roles within communities. Women often manage home gardens and small-scale agroforestry systems, and the diversification of income sources can empower them economically and socially. This empowerment leads to increased involvement in decision-making and community activities, contributing to gender equity (Teshome & Tadele, 2020).

Agroforestry systems create new employment opportunities in tree planting, maintenance, and harvesting. These tasks provide more stable income sources and promote community engagement. The collaborative nature of agroforestry projects also strengthens social networks and enhances labor efficiency within farming communities (Girma *et al*., 2020).

**Adoption and Implementation Challenges**

Despite the significant potential of agroforestry systems, their adoption and effective implementation in Ethiopia face several challenges. These challenges are multifaceted, encompassing technical issues, economic barriers, social and cultural factors, and policy and institutional constraints. Addressing these barriers is crucial for the successful integration of agroforestry practices and realizing their benefits for smallholder farmers.

*Technical Challenges of Agroforestry*

- **Pest Management**: Managing pests in agroforestry systems can be complex due to the diverse plant species and interactions within these systems. The presence of trees and shrubs can attract different pests or alter pest dynamics, potentially leading to increased pest pressure on both crops and trees. Effective pest management requires specialized knowledge and integrated pest management (IPM) strategies tailored to agroforestry systems. Farmers often lack access to this expertise, which can hinder the successful implementation of agroforestry practices (Nair, 2012; Jose, 2009). Research has shown that training and extension services are critical for developing effective pest management strategies in agroforestry systems (Kumar & Nair, 2011).
- **Species Selection**: The selection of appropriate tree and shrub species is a fundamental technical challenge. Species must be chosen based on their compatibility with local soil and climatic conditions, as well as their potential economic or ecological benefits. Inappropriate species selection can result in poor growth, reduced yields, and limited benefits. Comprehensive knowledge of local environmental conditions and species characteristics is essential for successful agroforestry implementation (Nair, 2012; Kumar & Nair, 2011). Studies emphasize the need for local research and participatory approaches to identify suitable species and practices (Garrity *et al*., 2010).

*Economic Barriers of Agroforestry*

- **Initial Investment Costs**: Establishing agroforestry systems requires significant initial investment, including costs for planting materials, labor, and infrastructure. These costs can be a major barrier for smallholder farmers, particularly those with limited financial resources. The high upfront costs associated with agroforestry can deter farmers from adopting these practices, despite their long-term benefits (Mekonnen & Guta, 2018; Asare & Osei, 2019). Economic analyses suggest that financial support mechanisms, such as subsidies or grants, can help offset these costs and encourage adoption (Girma *et al*., 2020).
- **Access to Credit**: Limited access to credit is another significant economic barrier. Smallholder farmers often face difficulties obtaining loans or financial assistance for agroforestry projects. This lack of access to credit can restrict their ability to invest in necessary inputs and technologies. Addressing this issue requires improved access to financial services and credit facilities tailored to the needs of smallholder farmers (Teshome & Tadele, 2020). Microfinance and other financial innovations have shown promise in supporting agroforestry adoption (Kumar & Nair, 2011).

*Social and Cultural Barriers of Agroforestry*

- **Cultural Attitudes**: Cultural attitudes and traditional farming practices can influence the adoption of agroforestry systems. In some communities, there may be resistance to integrating trees into agricultural systems due to longstanding farming traditions or skepticism about the benefits of agroforestry. Overcoming cultural resistance requires awareness-raising and education about the advantages of agroforestry and how it can complement traditional practices (Mekonnen & Guta, 2018). Participatory approaches that involve local communities in decision-making processes can help address these cultural barriers (Garrity *et al*., 2010).
- **Knowledge Gaps**: Knowledge gaps about agroforestry practices and their benefits can hinder adoption. Many smallholder farmers lack awareness or understanding of how to implement and manage agroforestry systems effectively. Providing education and training on agroforestry techniques and benefits is crucial for bridging these knowledge gaps (Nair, 2012; Kumar & Nair, 2011). Extension services and farmer field schools have been effective in improving knowledge and promoting agroforestry adoption (Garrity *et al*., 2010).

*Policy and Institutional Challenges of Agroforestry*

- **Policy Support**: Effective policy support is essential for promoting the adoption of agroforestry systems. However, in many cases, existing policies may not provide adequate support or incentives for agroforestry. Policymakers need to develop and implement policies that encourage agroforestry practices through subsidies, tax incentives, and technical support. The alignment of agricultural policies with agroforestry objectives can help create a conducive environment for adoption (Asare & Osei, 2019; Girma *et al*., 2020).
- **Institutional Frameworks**: Institutional frameworks and support programs play a crucial role in facilitating agroforestry adoption. Weak institutional frameworks, lack of coordination among agencies, and insufficient support programs can hinder the effective implementation of agroforestry practices. Strengthening institutional frameworks, improving coordination, and enhancing the delivery of support services are necessary steps for addressing these challenges (Teshome & Tadele,

2020). Case studies have demonstrated the importance of robust institutional support in successful agroforestry initiatives (Garrity *et al*., 2010).

- **Effective Tree-Crop Integration**: The success in Gojjam highlights the importance of selecting compatible tree species that enhance soil fertility and crop yields without competing with crops. *Faidherbia albida* has proven effective due to its ability to improve soil nutrient levels while allowing crops to thrive (Bekele *et al*., 2020). This underscores the need for region-specific tree species that complement existing agricultural practices.
- **Economic Diversification**: The integration of high-value fruit trees in East Gojjam demonstrates how agroforestry can enhance economic resilience. By providing additional income through fruit sales, farmers can better withstand crop failures and market fluctuations (Girma *et al*., 2021). This approach could be expanded to other regions to improve economic stability and food security.

## CONCLUSION

Agroforestry is a distinctive land use system that combines economic and environmental advantages. The integration of trees and shrubs into agroforestry systems not only boosts crop and livestock productivity but also contributes significantly to improve soil fertility, biodiversity conservation, and carbon sequestration. The review indicated that agroforestry provides multiple socio-economic benefits, such as income from timber and non-timber forest products, agroforestry systems can improve the livelihoods of smallholder farmers and foster resilience against climate change. Environmentally, agroforestry contributes to biodiversity conservation, soil and water preservation, carbon sequestration, and the reduction of deforestation.

Successful case studies demonstrate the potential of agroforestry to improve rural livelihoods and resilience against climate change. However, the review identifies the adoption of agroforestry practices faces several challenges, including socio-economic constraints, technical challenges, institutional barriers, and sociocultural barriers that hinder broader implementation. To overcome these challenges, a farmer-centered approach to research and development is essential. This involves recognizing and addressing the specific socio-economic and ecological conditions of different regions.

The findings of this review indicate that a farmer-centered approach to research and development in agroforestry is essential for promoting wider adoption. It is important to recognize and address the socio-economic and ecological contexts of specific areas to facilitate the adoption of agroforestry. Governments and non-governmental should focus on enhancing the institutional, socio-economic, and biophysical aspects of particular regions to expand agroforestry practices and improve socio-ecological benefits. The results of this study suggest that policymakers, researchers, and extension providers should work closely with farmers to identify appropriate agroforestry practices in Ethiopia for effective implementation and scaling. This collaboration could be supported by government policies that promote the broader adoption of agroforestry practices and enhance research and extension services.

## CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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