



# Agroforestry for Climate Mitigation, Resilient Farming, and Food Security

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**Abstract:** *Agroforestry systems offer a sustainable land management approach that integrates trees, crops, and livestock to enhance productivity, resilience, and ecosystem services. This review explores the multifunctional benefits of agroforestry, including its potential for climate change mitigation, resilient agriculture, and food security. Agroforestry practices such as alley cropping, silvopasture, and multistrata systems contribute to carbon sequestration, soil fertility improvement, and biodiversity conservation. The global distribution and adoption of agroforestry vary across regions, influenced by climatic conditions, socio-economic factors, and ecological objectives. Agroforestry plays a crucial role in mitigating climate change by sequestering carbon in biomass and soil, with sequestration rates ranging from 1.5 to 7.2 tons of CO<sub>2</sub> per hectare per year, depending on the system and management practices. Agroforestry reduces greenhouse gas emissions by decreasing the need for chemical fertilizers and improving livestock management. Agroforestry enhances ecosystem resilience by increasing biodiversity, improving soil health, and providing multiple ecosystem services. It also contributes to food security by diversifying food sources, increasing crop yields, and providing economic benefits to farmers. However, the adoption of agroforestry faces challenges related to socio-economic constraints, land tenure issues, and limited policy support. Future developments in agroforestry management involve precision agriculture, biotechnology, and digital platforms to improve sustainability and productivity. Recommendations for promoting agroforestry include integrating it into national and global climate policies, establishing public-private partnerships, and conducting long-term interdisciplinary research. Agroforestry offers a promising solution for sustainable land management, climate change mitigation, and food security, but its widespread adoption requires supportive policies, investments, and capacity building.*

**Keywords:** *Agri silvicultural, Silvopastoral, Agrosilvopastoral, food security, soil fertility, biodiversity conservation.*

## **INTRODUCTION**

Agroforestry systems are a sustainable method of land management that combines trees with crops, and animals to increase productivity and perform other ecosystem functions (Pantera et al., 2021; Singh et al., 2025). This is done to maximize land use, a process achieved by combining food and fiber production while maintaining biodiversity, soil and water resources. Agroforestry's importance lies in its multifunctional benefits, which include carbon sequestration, improved soil fertility, and enhanced biodiversity conservation (Smith et al., 2012; Mcneely and Schroth, 2006). It enhances sustainable intensification, and therefore, it will form an important part of the global agendas of controlling climate change, attaining food security, and ensuring health of the ecosystems (Rizvi et al., 1999; Montagnini and Nair, 2004).

Agroforestry is an emerging and sustainable land management system where a profound combination of trees, crops and livestock builds up an efficient ecological and economic interrelationship. With their combination of agricultural with woody vegetation, agroforestry can promote biodiversity, soil fertility, and resilience in the face of climate change, as well as multiple other ecosystem services (Pantera et al., 2021). These are carbon sequestration, microclimate regulation, nutrient cycling, which contributes to sustainability in the environment. This system also supports the ecological intensification, whereby it uses resources in a more productive manner than traditional agriculture practices (Kumar et al., 2010). Although it has a wide array of advantages, agroforestry has potential difficult aspects related to policy integration and uptake especially in the developed areas where the conventional land use systems have deteriorated. However, wars with a global and regional focus on sustainability allow focusing on the capabilities of agroforestry to bring not only economic benefit to the farmers but also an environmental benefit to the society (Singh et al., 2025; Pancholi et al., 2023).

The practice of agroforestry has history going back a long way and has changed with time in a considerable manner. As traditional land-use systems, agroforestry has been applied by indigenous people throughout the planet over the course of centuries (Goncalves et al., 2021). Other areas, such as the Amazon, were already able to live sustainably with an advanced agroforestry system that was developed by the local communities long before being colonized by Europeans (Miller & Nair, 2006). The practise means combining tree with crops and animals in the hope to increase the diversity and sustainability. Interest in agroforestry emerged again in the late 20th century when it became a cherished technique in research centers as a land-use method to overcome environmental and agricultural problems (Mercer & Pattanayak, 2003). Agroforestry systems have today developed with an aim of achieving ecological sustainability and at the same time economic profitability in ensuring food security and mitigate climate changes (Schroeder, 1993; Papanastasis et al., 2009).

The solutions to climate change and food security are of exceptionally vital importance to the whole world because climate change and food security are inseparable and present a major challenge to the sustenance of human and ecology. Climate change is also a factor contributing to food security due to its effect on agricultural productivity, where changing weather conditions result in reduced agricultural yields and the inability to deliver food to those in need (Toromade et al., 2024). One way of reducing these effects is through the adoption of climate-smart agriculture (CSA) to boost crop resilience, efficiency in resource utilization, and general food productivity (Akinsemolu et al., 2023).

The application of CSA in vulnerable zones such as Sub-Saharan Africa has already been documented to be helpful in the development of resilient food systems in the face of uncertainties of climate conditions (Akinsemolu et al., 2023). A necessary way of addressing these global problems is global cooperation and investing in sustainable technologies as well as policy actions. These initiatives can foster an efficient, low-carbon and inclusive food system to stand climate-induced challenges with more and secure food (Dhankher and Foyer, 2018)

### **AGROFORESTRY SYSTEMS AND PRACTICES**

Agroforestry is a combination of trees and crops, or livestock within a single unit of land, which positively impacts the ecological functions and delivers a variety of benefits to the environment and the farmer. Agroforestry systems come in several important types, which all have their properties and benefits (Mercer and pattanayak, 2003). Alley cropping: This is the technique of planting lines of trees among the strips of crops and is usually implemented in order to ameliorate soil fertility and control the erosion. Silvo-pastoral is a system that incorporates trees with pasture and livestock to offer shade and shelter to the animals and an additional form of food. One other version, multistrata agroforestry, incorporates the natural patterns of forests taking several tiers of vegetative growth in order to maximize the use of the sunlight and space, to provide the biodiversity and increase the crop production (Oliveira and Carvalhaes, 2016). Silvoarable systems the aim of silvoarable systems is to combine the growing of trees with that of arable crops, typically in an effort to improve microclimatic conditions of the crops and to sequester carbon. Forest farming applies to the pre-existing woods in which crops that grow in the lower layer such as mushrooms or medicine crops are farmed. All these schemes are developed regarding diverse regional specifics and targets: carbon sequestration, soil amelioration, economic gains, and ecosystem restoration (Cardinael et al., 2018; Vaupel et al., 2025).

Alley cropping and silvo-pasture are two of the most prosperous agroforestry systems aimed at improving the sustainability of agriculture because they combine the use of trees with a crop or livestock practice (Diaz, 2016). Alley cropping refers to the practice of interplanting crops between tree rows or growing shrubs, where there are added advantages of better microclimate, soil and erosion control, and increasing biodiversity. It is possible to grow forest products and arable crops concurrently in this system, thus maximizing the output of land use (Li et al., 2017). Silvo-pasture on the other hand, combines trees and pasturelands where animals are pastured. This practice creates shade and shelter to animals, increases the quality of forage, and resilience of the land due to its diversified products (Diaz, 2016). Both alley cropping and silvo-pasture are valuable methods of sustainable agriculture as they provide carbon sequestration, stop the decline of biodiversity and enhance farm resilience (Li et al., 2017)

Agroforestry and other forest farming approaches combine forest use with agricultural production by incorporating crops or livestock into the forest or planting crops or livestock among trees. This increases biodiversity and sustainability. Silvo-pasture; silvoarable or alley-cropping, home gardens, and woody linear landscape strips integrate the agricultural and woodland domains to give a variety of ecosystem services (Mercer & Pattanayak, 2003). Agroforestry has been shown to enhance soil fertility, reduce climate change, and increase resistance to environmental fluctuation (Octavia et al., 2022). In Indonesia, intelligent agroforestry systems raise economic benefits and save resources in

the environment (Octavia et al., 2022). Agroforestry has been demonstrated in Ethiopia to preserve diversity of woody species and it is an alternative to monoculture which is biodiversity-friendly (Mengistu & Asfaw, 2016). Besides, in Vietnam, agroforestry plays a vital role in pinned areas since it serves to stabilize the soil and improve the livelihoods of people (Hoang et al., 2017). In general, the process of forest farming offers a sustainable farming practice which facilitates ecological and socio-economic positive outcomes. I am not able to come up with a whole essay but the following information is what I found out in literature about the forest farming methods and their application. Some examples of arming techniques include agroforestry, use of agricultural crops or livestock in forested landscapes, increased biodiversity and sustainability. Silvopasture, silvoarable or alley cropping, homegardens and woody linear landscape strips are some of the practices that combine agriculture and forestry to offer multiple ecosystem services (Mercer & Pattanayak, 2003). Improved adaptation to the continually changing environment, reduction of climate change, and increasing soil fertility are all benefits of agroforestry practices (Octavia et al., 2022). Smart agroforestry in Indonesia as an example, not only provides a higher economic output but also preserves the nature (Octavia et al., 2022). Traditional monoculture in Ethiopia can be substituted with an agroforestry system as it has been proved that agroforestry contributes to the maintenance of the species diversity of woody species (Mengistu & Asfaw, 2016). Furthermore, agroforestry practices can be of paramount importance in stabilizing soils and improving livelihood on mountains, which takes place in Vietnam, as well. On the whole, the practices of the forest farming offer sustainable alternatives to agriculture that conceptually carry out positive ecological and socio-economic consequences (Hoang et al., 2017).

Buffer strips in the riparian corridor are very important in the conservation of the environment since they serve as the key areas in countering the agricultural runoff pollutants to water bodies. The action of these strips is as an interception whereby surface runoffs are intercepted and therefore the movement of nitrogen, phosphorus, and sediments into water systems is limited (Stutter et al., 2012). Riparian buffers also contribute to biodiversity conservation hence, their ecological significance. They act as a prime habitat to other plant and animal species hence upholding ecological integrity and providing shelter to species that have developed riparian conditions (Hylander et al., 2002; Whitaker and Montevecchi, 1999). In tropical areas that also possess riparian forests, the border agriculture may be assisted with the riparian forests, which can be used to preserve endangered species and ecosystem services, but further study should be conducted with regard to its effectiveness in controlling larger populations of pests (Gray & Lewis, 2014). Nevertheless, riparian zones are not always effective because they tend to work well depending on the buffer widths and the quality of forest management practices adjoining them (Vesely and Mccomb, 2002; Luke et al., 2017).



**Figure 1.** Agrisilvicultural

Agrisilvicultural systems in agroforestry refer to the deliberate integration of agricultural crops and trees in a land management system. This type of agroforestry system combines woody perennials (trees or shrubs) with crops to leverage ecological and economic benefits through interactions between these components. Agrisilviculture is often employed to improve soil productivity, conservation, and nutrient cycling, which can enhance the overall sustainability of the land use system (Andablo et al., 2023; Fungo et al., 2021).



**Figure 2.** Silvopastoral

Silvopastoral systems are a form of agroforestry that integrate trees, shrubs, and pastureland for livestock grazing, creating a multifunctional land-use system. These systems combine the cultivation of trees and shrubs with the grazing of domesticated animals, fostering an environment that supports land productivity alongside environmental and climatic benefits (Cubbage et al., 2012; Broom, 2017).



**Figure 3.** Agrosilvopastoral

The agrosilvopastoral system in agroforestry integrates trees, crops, and livestock within the same land area to enhance productivity and sustainability. This system is particularly beneficial in regions like Italy, where traditional landscape management has involved the integration of multiple components such as crops, livestock, and forest trees, offering a variety of products and ecosystem services. It enhances biodiversity, soil fertility, and carbon sequestration, contributing to climate change mitigation (Moreno et al 2019; Vaupel et al., 2025).

### **GLOBAL DISTRIBUTION AND ADOPTION**

The prevalence of Agroforestry across various regions is diverse in that different conditions are facilitated by climatic conditions, socio-economic factors and ecological objectives. In Europe, agroforestry systems such as the Mediterranean's montado and dehesa, Continental orchards, and Atlantic chestnut and hedgerow systems are noted for enhancing ecosystem services, particularly in regulating biodiversity and reducing soil erosion (Kay et al., 2017). Agroforestry is allowing the Latin American arid and semi-arid zones to combat drought and optimise the economic and ecologic returns, enhancing soil fertility and presenting resistance to change in climate, although these are subject to issues when implementing the agroforestry measures (Krishnamurthy et al., 2017). Asia-Pacific and especially Southeast Asia needs emphasis on species selection in order to promote agroforestry in a context where it is constrained by such problems as deforestation, economic pressures, and the need to expand agroforestry (Zhang et al., 2023). Agroforestry is extensive in India; it has not only increased the production of biomass but also improved its carbon sequestration in different agro-climate modes (Panwar et al., 2022). On the other hand, agroforestry has a prospective role to play in temperate North America with respect to carbon sequestration as a CO<sub>2</sub> mitigation option and therefore there is a need to continue with research and to have uniformity in practices across varied systems (Udawatta & Jose, 2011). Such regional differences in agroforestry are referred to the adaptive approaches to fulfill particular environmental and socio-economic demands indicating its importance in sustainable land use and mitigation of climate change.

The level of technology adoption in the different countries is determined by a wide variety of factors that fall under technological, organizational, environmental, and individual. Super-important factors are technological drivers that relate to compatibility, ease of use, and usefulness of technological products used to assume that they encourage their assumption (Selase et al., 2019; Fuller et al., 2007). The top management support, digital culture, and human resource of an organization are highly influential factors, and the support of the top management usually enhances the process of adoption (Faiz et al., 2024; Dasgupta et al., 1999). The adoption of technology among regions also depends on the environmental factors such as government policies, competitive pressures which

make it necessary to establish favorable regulation (Dasgupta et al., 1999; Gonzalez, 2005). Moreover, the socio-cultural situation, including societal norms and demographic facts, plays an enormous role in accepting and implementing technology (Tesfaye & Tessema, 2023). The rate at which nations adopt new technologies is determined by these multidimensional aspects, many of which are interconnected, and what this means is that there is complexity in how it works in different contexts (Fuller et al., 2007; Tesfaye and Tessema, 2023).

Agroforestry practices are influenced by the non-science based but rich in knowledge rooted orphan approach of balancing between productivity and the ecological system, hence the integration of trees, crops and livestock. They include Western Ghats forests in India and satoyamas in Japan and such systems provide the important ecosystem services of biological diversity conservation and carbon sequestration (Kumar and Takeuchi, 2009; Papanastasis et al., 2009). Agroforestry has come a long way since it was established as a specific scientific area at the end of the 20<sup>th</sup> century due to the development of research and even global issues of food security, and combating climate change (Dagar & Tewari, 2017). The current trend responds to more economic profits and sustainability in marginal lands through high-quality crops and systems integrated farming approach (Mercer and Pattanayak, 2003; Dagar and Tewari, 2017). In spite of the disparities, both old and new systems stress the significance of agroforestry in addressing the existing environmental and farming problems and supplying a wide array of solutions in making land use sustainable worldwide (Mercer and Pattanayak, 2003; Kumar and Takeuchi, 2009).

### **CLIMATE CHANGE MITIGATION THROUGH AGROFORESTRY**

Agroforestry offers a great approach in controlling climate change by incorporating trees and farming activities to boost carbon sequestration, in addition to counteracting the risks of climate change. Agroforestry systems are important carbon sinks and buffering systems against climate extremes and hence have a large value in carbon budgets both locally and globally, which is often not measured in national inventories (Lasco et al., 2014; Zomer et al., 2016). They elevate microclimates, enhance soil productivity, and promote nutrient cycling, as such systems are critical to the farming of smallholder farmers exposed to unpredictable climatic changes (Aryal et al., 2019; Verchot et al., 2007). In addition, agroforestry can contribute to biodiversity and ecosystem enhancement and therefore improve adaptation and mitigation activities that alter the climatic disturbances by reducing temperature excesses and strengthening resistance to unfavorable weather conditions (Dobhal et al., 2024; Matocha et al., 2012). Such systems present a viable way of overcoming climate change and making livelihoods better, particularly in a place completely dependent on agriculture (Meragiaw, 2017; Nair, 2012)

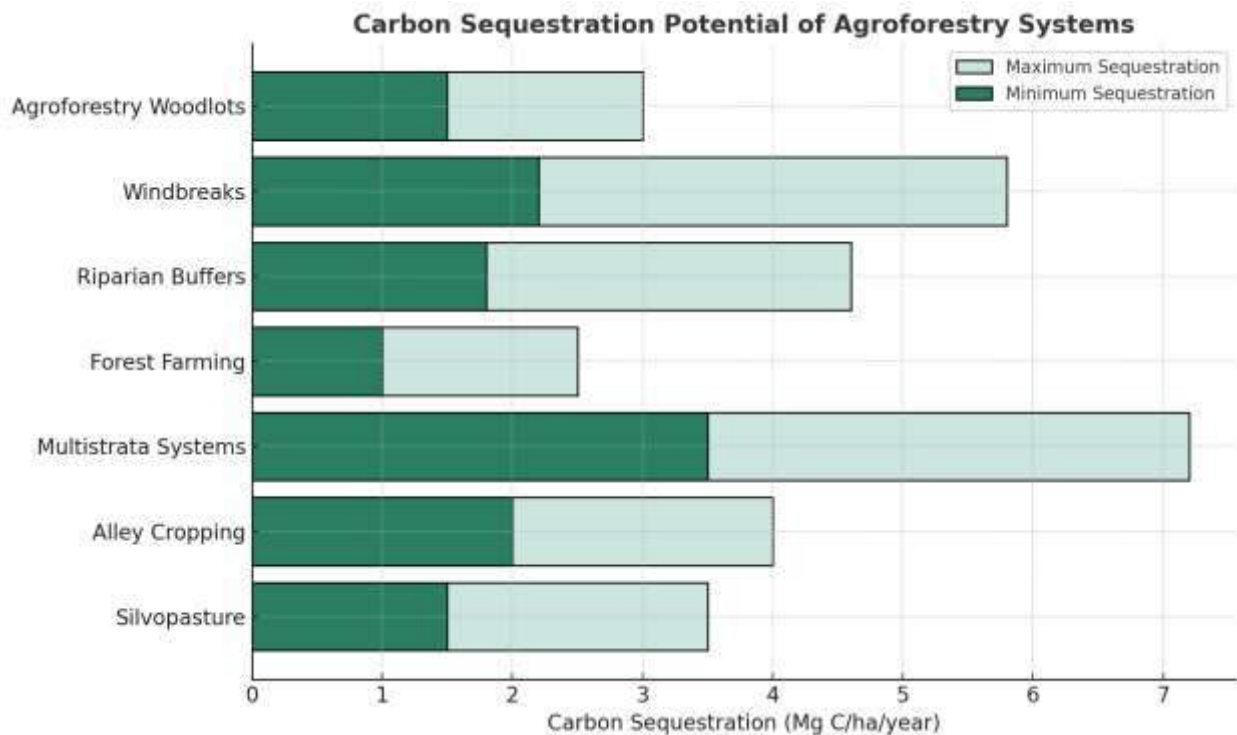
There is a great potential of using agroforestry systems as a way of carbon sequestration as it is a form of an integrated land use that incorporates both crops and/or livestock and shrubs or trees on the same land. The practice increases the amount of stored carbon aboveground and underground, and therefore, it is a very effective measure in tackling climate change. Regional variations in carbon sequestration potential diverge with smallholder systems in tropics having sequestration potentials ranging between 1.5 to 3.5 Mg C ha<sup>-1</sup> yr<sup>-1</sup> and 63 Mg C ha<sup>-1</sup> in moderate regions dependent on the system design and management practices (Montagnini & Nair, 2004). Carbon sequestration occurs in the standing biomass of trees and the soil organic matter that can be maximized with

appropriate agroforestry practices like the adoption of trees that can withstand local climatic conditions or even involving multistrata systems to increase the ecosystem diversity and resilience (Abbas et al., 2017; Bogale, 2025). In Ethiopia, the coffee-based agroforestry systems can sequester up to 7.2 tons of CO<sub>2</sub> per hectare per year, which demonstrates the potential of perennial crop-based agroforestry systems in carbon sequestrations (Bogale, 2025). Agroforestry indirectly helps protect the environment through reduced pressure on natural forests and soil conservation followed by enhanced carbon sequestration which also provides a long-term, sustainable land management practice to synergize agricultural productivity with environmental stewardship (Montagnini & Nair, 2004). In total, agroforestry is a viable and appealing option to promote carbon storage with economic and food security advantages (Torres et al., 2017).

Mathematic modeling on carbon levels of sequestration rates in different agroforestry management systems has shown that these systems have a very high power of acting as a carbon sink helping to reduce climatic changes. Other systems including agroforestry in temperate North America, and West Africa Sahel and Southern Africa have had different sequestration rates. As an example, woodlots in Southern Africa show a sequestration of carbon at 2.2–5.8 Mg C ha<sup>-1</sup> year<sup>-1</sup>, whereas in Brazil coffee agroforestry systems provide notable stocks of carbon of 1.38–0.63 Mg C ha<sup>-1</sup> at its earlier stages and 59.69–32.63 Mg C ha<sup>-1</sup> at its maturity (Goncalves et al., 2021; Montagnini and Nair, 2004; Luedeling et al., There is also a great potential of sequestration in American agroforestry practices, which can be used as an offset to the agroforestry practices in the country (Udawatta & Jose, 2011). Yet, the efficiency of such systems depends on numerous factors, such as the soil type, climate, management practice, and distributional economic factors (Cardinael et al., 2025). Agroforestry is indeed an option worth pursuing to increase carbon sequestration in various regions and practices, despite such challenges.

Agroforestry has been found to be one of the most effective land use systems of carbon storage among other land use models like conventional agriculture or even the monoculture forestry. It intercroops trees with crops and/or livestock which leads to a lot of carbon being sequestered in the form of the biomass and the soil. The storage capacity of carbon in agroforestry Systems is region specific, with averages as follows: in semi-arid regions 9 t C ha<sup>-1</sup>, in sub-humid regions 21 t C ha<sup>-1</sup>, humid regions 50 t C ha<sup>-1</sup>, and in temperate regions 63 t C ha<sup>-1</sup> (Schroeder, 1993; Schroeder, 1994). In addition, agroforests in the European climatic area emphasize their ability to function as carbon sinks with the potential to lower a carbon stock by 0.09 to 7.29 t C ha<sup>-1</sup> each year (Kay et al., 2019). In contrast to monocultures, agroforestry keeps carbon in the existing vegetation and precludes deforestation by decreasing agricultural encroachment in forests (Schroeder, 1993; Unruh et al., 1993). This two-fold carbon sequestration and conservation nature make agroforestry a long-term and desirable choice to farmers who want to counter the impacts of climate change without sacrificing agricultural yield (Abbas et al., 2017).

**Figure 4. Carbon sequestration potential of Agroforestry systems**



**Figure 4** The chart illustrates the carbon sequestration potential of various agroforestry systems, expressed in megagrams of carbon per hectare per year (Mg C/ha/year). It compares both minimum (green) and maximum (light green) sequestration capacities for each system. Multistrata systems show the highest potential, ranging from 3.5 to over 7 Mg C/ha/year, indicating their strong role in climate change mitigation. Windbreaks and riparian buffers follow, with maximum values reaching around 5.8 and 4.6 Mg C/ha/year, respectively. Systems like alley cropping, silvopasture, and woodlots display moderate sequestration capacity, while forest farming has the lowest range, peaking near 2.5 Mg C/ha/year. These variations reflect how different agroforestry practices contribute to carbon storage, soil health, and sustainable land use (Kumar et al., 2014; Ghale et al., 2021)

### REDUCTION OF GREENHOUSE GAS EMISSIONS

Agroforestry has proved to be a sustainable approach to agriculture that is capable of reducing greenhouse gases, methane (CH<sub>4</sub>) and nitrous oxides (N<sub>2</sub>O) which are a major concern in global warming. Agroforestry is a method of combining trees with crop and livestock systems that increase biodiversity and the health of the soil and lessen the need of chemical fertilizers. This decreases, by extension, N<sub>2</sub>O emission that is prevalent to the application of synthetic fertilizers (Singh et al., 2024). Moreover, the use of agroforestry practices leads to a decrease in methane as a result of increasing soil carbon, decreasing the release of methane during enteric fermentation in animals through the improved quality of pasture and reduction of grazing management (Popa et al., 2023). Although the exact magnitudes can vary depending on the actual practices and the condition on the ground, it is clearly seen that agroforestry can be very significant in designing climate-resilient

agricultural systems, and in the process, it is also able to respond to the ecological and socio-economic challenges of climate change (Schulze et al., 2009).

REDD commitments are important in addressing climate change as they ensure that forests are not cleared to other land use activities which cause huge emission of greenhouse gases. One of such projects is the EDD+ projects, which involve increasing forest carbon stocks, that helps in achieving maintenance of forest cover and hence avoidance of emissions. As an example, the implementation of the REDD projects in such an area as the Hyrcanian forests of Northern Iran has already proven to be capable of reducing the possible emissions of greenhouse gases by a lot and has therefore displayed the enhanced combat of climate change (Niknam et al., 2024). Moreover, agroforestry practice may offer viable solution by their integration into the carbon credit programs. Agroforestry is a good addition to the REDD+ project because, whereas the REDD+ projects are mainly about forest protection, the combined effect of the two (agroforestry and REDD+) on socioeconomic benefits is achieved by incorporating sustainable land use practices which will support not only carbon sequestration but also the livelihoods of people. Nonetheless there are complications of quantifying the emissions of forest disturbances though especially when mosaic topography is involved in agroforestry where there needs to be additional monitoring strategies and partnership governments (Mertz et al., 2012). As the possible integration is identified, and the measurement issues are resolved, carbon credit schemes have better chances to promote good global goals in the sphere of reduction of emission (Venter & Koh, 2011).

#### **ENHANCEMENT OF ECOSYSTEM RESILIENCE**

Agro forestry contributes significantly to the resilience of ecosystems and health and water holding capacity of soil. Agroforestry systems increase biodiversity, which is essential in the stability and adaptability of ecosystem (Diyaolu & Folarin, 2024). Such systems enhance soil structure, porosity, and the amount of organic matter which subsequently enhances the ability of water to infiltrate and retain water in the soil, and nutrient cycling and soil fertility (Sekhar et al., 2024). Also, agroforestry can serve as carbon sink, potentially contributing to climate change mitigation processes, and increasing the soil microbial diversity, hence, improving soil structure and health ecosystem services (Panda et al., 2023). Although multiple benefits are associated with the adoption of agroforestry, socio-economic barriers and knowledge and policy support are some of the challenges (Sekhar et al., 2024). As such, agroforestry will help in achieving sustainable land management due to enhanced farming productivity, resilience to environmental fluctuations, and ecosystem well-being in general (Satish et al., 2024).

Forest use is essential to solve the problem of biodiversity conservation and climate change adaptation because the implementation of sustainable forest management can serve these issues. In sustainable forest management, emphasis is placed on the genetic diversity and increasing the resilience of ecosystem of forests in face of climatic changes (Spittlehouse & Stewart, 2004). The options frequently considered in adaptation plans in forestry include diversification of forest species in order to help achieve resilience in various weather conditions and managing lands to foster connectivity in forest areas, thus providing species with the flexibility to move (Hylander et al., 2021). These measures will be important in preserving the ecosystem services, including carbon sequestration, which is fundamental in limiting the effects of climate change (Felton et al., 2023).

Further to this, the introduction of new technology in the forestry industry which includes high tech applications like Artificial intelligence and Climate-Smart Forestry is also helping in increasing such adaptive capacities without necessarily reducing the productivity of the various ecosystems where they are located as well as boost biodiversity (Wang et al., 2024). Hence, forestry works well to support biodiversity conservation through the promotion of an ecosystem resilience and also assists in the development of adaptive and mitigation measures required in taking action on climate change (Schlaepfer and Lawler, 2022; Hof et al., 2017).

**Table 1. Ecosystem Services Provided by Agroforestry Systems**

Category	Ecosystem Service	Agroforestry Function	Data	References
Provisioning	Food	Production of fruits, nuts, vegetables, crops, and animal fodder	Cocoa-agroforestry in Central America provides both cash crops and food staples	Akinsemolu et al., 2023
	Fuelwood and Timber	Tree species provide firewood, timber, and construction material	Multipurpose tree species like <i>Gliricidia</i> and <i>Leucaena</i> provide fuelwood and poles	Báder et al., 2023
	Medicinal and Non-Timber Products	Trees and shrubs yield medicinal herbs, oils, gums, and resins	Use of <i>Azadirachta indica</i> (Neem) and <i>Moringa oleifera</i> for ethnomedicine	Dawson et al., 2014
Regulating	Climate Regulation / Carbon Sequestration	Trees absorb atmospheric CO <sub>2</sub> , reducing GHG emissions	Carbon stock in tropical agroforestry: 7.2 t CO <sub>2</sub> /ha/year (Ethiopia, coffee-based systems)	Meragiaw et al., 2017
	Water Regulation and Purification	Roots enhance infiltration, reduce erosion and runoff	Riparian buffers reduce nitrogen and phosphorus movement into water bodies	Awazi et al., 2024
	Pollination and Natural Pest Control	Diverse flora supports pollinators and natural enemies of pests	Increased bee visitation rates in multistrata systems	Bentrup et al., 2014
	Air Quality	Tree canopies trap dust, absorb	Windbreak agroforestry systems capture	Udawatta,

	<b>Regulation</b>	pollutants	airborne particulates	2021
<b>Cultural</b>	<b>Cultural Heritage and Traditional Knowledge</b>	Maintenance of indigenous knowledge and land management practices	Satoyama systems in Japan, Western Ghats in India preserve traditional agroforestry	Weiwei et al., 2014 Ichikawa et al., 2012
	<b>Recreation and Aesthetic Values</b>	Landscaped agroforests offer natural beauty and ecotourism potential	Agro-tourism in Mediterranean silvo-pastoral systems	Barbieri et al., 2010 Pardini, 2017
	<b>Education and Awareness</b>	Demonstration plots and community-based learning	Agroforestry learning farms used in climate-smart agriculture training	Kessler et al., 2025
<b>Supporting</b>	<b>Soil Formation and Fertility</b>	Organic matter from leaf litter and root turnover enriches soil	Parkland systems increase organic C and N in degraded African soils	Bayala et al., 2018
	<b>Nutrient Cycling</b>	Nitrogen fixation and litter decomposition improve nutrient availability	<i>Faidherbia albida</i> fixes N, enhances cereal yields	Mokgolodi et al., 2011
	<b>Primary Productivity</b>	Higher net biomass through combined tree-crop systems	Multistrata agroforests produce 30–50% more biomass than monoculture	Scordia et al., 2023
	<b>Biodiversity Conservation</b>	Supports flora and fauna by providing diverse habitats	Buffer strips and homegardens support native species and genetic diversity	Nair et al., 2022

This table highlights the diverse ecosystem services delivered by agroforestry systems, categorized into provisioning, regulating, cultural, and supporting functions. Provisioning services encompass the production of food, fuelwood, timber, and medicinal products through the integration of multipurpose tree species. Regulating services include climate mitigation via carbon sequestration, improved water regulation, air purification, and enhanced pollination and pest control due to increased biodiversity. Cultural services reflect the preservation of indigenous knowledge, aesthetic landscapes, ecotourism opportunities, and educational value. Supporting services focus on soil

formation, nutrient cycling through nitrogen fixation, enhanced biomass productivity, and biodiversity conservation. Case studies from Central America, Ethiopia, and India demonstrate the multifunctional role of agroforestry

### **AGROFORESTRY AND FOOD SECURITY**

Agroforestry systems that combine trees in agricultural surroundings are fundamental in the improvement of food security by a number of ways. It aids nutritional requirements as a direct supply source of food materials like fruits and leafy vegetables and also enhancing production of staple crops by improving ecosystem services to them like pollination and soil retention (Jamnadass et al., 2013). In other areas, such as Indonesia, agroforestry has been particularly useful to smallholder farmers, providing the dual subsistence and commercial advantages that have added to food accessibility, income security, and environmental sustainability, which enhances climate resilience (Duffy et al., 2021). Moreover, agroforestry structures boost the presence and nutritional variety of food resources in the diets of people in need, as various crops can be grown besides the usual staple foods, and therefore decrease reliance on a single food and also minimize the risk of crop failure (Chemedda et al., 2024). To exploit the potential of agroforestry in food security, it is important to overcome the above policy obstacles, gain access to land and resources, and conduct research on the practice of agroforestry and its socioeconomic advantages (Jamnadass et al., 2013; Sudomo et al., 2023).

Agroforestry systems present a good way of diversifying foods and increasing crop species diversification as a way of overall sustainability in agriculture. These mechanisms introduce trees into farmers and ranchers fields, offering numerous advantages such as better soil conservation, nutrient recycling, and mitigation of climatic changes. An example can include nitrogen-fixing shrubs and trees, which are critical to the fertilizing of the soil and boosting crop production (Veste et al., 2024). Agro forestry is also contributing towards increase in biodiversity and ecosystem services where the diverse cropping systems are more productive and the ecology is maintained. The enhancement of biodiversity in agroforestry systems will enhance the stability of the agricultural production against climatic and economic hazards, contributing to resilience in food systems (Beillouin et al., 2021). In addition, such agroforestry practices as intercropping and the thoughtful use of trees species keep biodiversity and sustain the ecosystem services needed to produce food sustainably (Campera et al., 2024; Zuza et al., 2024). In spite of a couple of challenges like competition between trees and crop plants over resources, the location of the right tree species and management strategies may maximize the positive things that are achieved by these systems (Nyaga et al., 2017). In this way, agroforestry can be regarded as one of the potential and integrated approaches of land-use that may lead to food diversification and improve the resilience and sustainability of agricultural systems in the world.

Dietary diversity is a very significant aspect of intensifying nutritional security since it provides diversity of nutrients which are important to sustain good health in order to avoid being vulnerable due to crop failures and price fluctuations. Research firms have also been able to prove that crop diversification can go a long way in enhancing the dietary diversity which is critical towards food security. As an example, the study in Nepal shows that the agricultural diversity beneficially influences the diversity of the diets and food security of the smallholder farmers. Market access,

provisions of irrigation water, access to inputs like fertilizer and labor are some of the key issues that lead to such diversification (Nepali et al., 2024). Likewise, in Ghana improvements in crop diversity have been associated with a better dietary diversity and a food expenditure, which enables households to alleviate hunger and nutritional disorders in cases where food availability decreases (Frempong et al., 2023). Moreover, crop diversity helps farmers to withstand the climatic and economic shock better, facilitate new breeds, and better manage the risks (Zuza et al., 2024). In general, the diversification of agriculture approaches is an effective way to enhance food and nutritional security and resilience to exogenous shocks.

#### **IMPROVED SOIL FERTILITY AND CROP YIELDS**

Agroforestry has large potential of increasing soil fertility and yields due to its several ways of action. When perennial woody crops are combined with crops and livestock, the use of resources is maximized and soil physical, chemical and biological condition becomes favorable. The management method decreases nitrogen loss and soil erosion, enhances soil organic carbon and carbon sequestration, carbon augmentation as well as nutrient recycling (Fahad et al., 2022; Chaudhary and Ghaley, 2025). Tree planting is a practice that introduces heterogeneity in microclimates, augments soil moisture retention, and offers a habitat to a variety of organisms, resulting in the development of better biodiversity and ecosystem equilibrium via agroforestry (Fahad et al., 2022). In addition, agroforestry minimizes the use of chemical substances, enhances soil fertility, and promotes sustainable farming systems without translating to reduced farms yields (Tamburini et al., 2020). These various ecological services do not only make agriculture more resilient to climate extremes but also ensure long-term soil health and productivity thus making agroforestry a sustainable and economical solution toward improving food security as well as environmental sustainability (Fahad et al., 2022; Chaudhary and Ghaley, 2025).

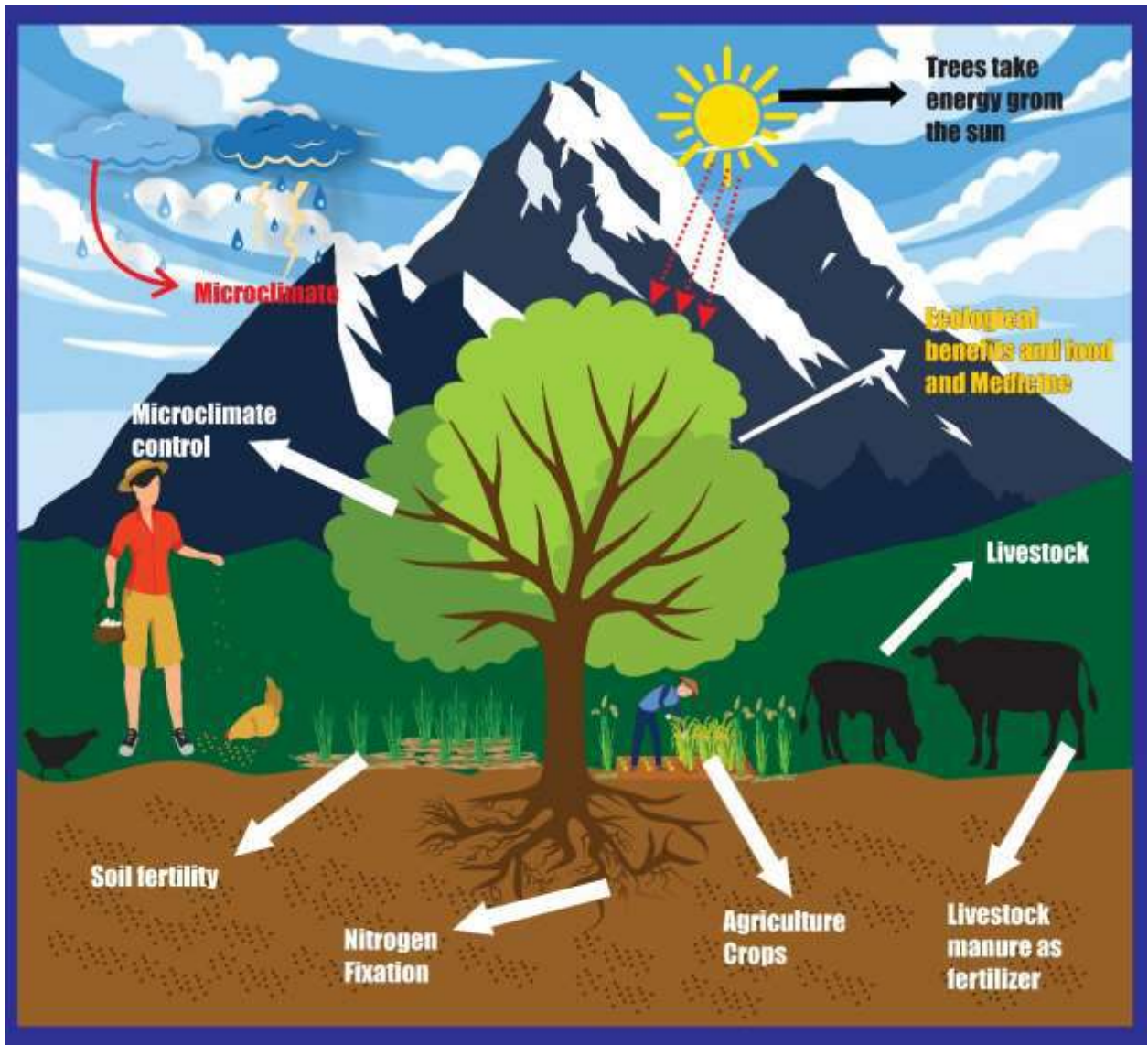
Agroforestry systems have presented a good option of solving the current crop yield challenges and long-term sustainability of soil fertility. Statistical studies have proven that agroforestry systems specifically promote organic carbon content in soils and the release of critical macro and micro-elements, thus, providing a favorable microclimate to plant communities (Pankaj et al., 2023). Agroforestry systems like coffee-based systems and parkland systems have been found to sequester a lot of carbon in Ethiopia and have been found to enhance soil fertility and help in climate change mitigation (Bogale, 2025). The practice of agroforestry which was embraced notably in the area of western Kenya has helped in improving soil quality significantly in the smallholder production soils that are found in Kenya (Nyuma et al., 2025). In addition, intelligent agroforestry has been identified as being able to keep soils fertile and, simultaneously, benefits the community income through the maximization of land output and income generated (Octavia et al., 2023). The fact that these systems not only contribute to sustainable agriculture, in terms of recycling soil nutrients, maintaining yield consistency, but also mitigate some of the environmental challenges obviates their significance in promoting sustainable land management (Arshad et al., 2024; Kaur et al., 2023).

#### **ECONOMIC BENEFITS FOR FARMERS**

Agroforestry farming systems are highly economical to farmers in that they provide a multiplicity in income, and financial stability. Integrating various crops together timber crops, fruits and non-food

productions helps the farmers to make more economical benefits than normal monoculture. To give a specific example, in some of the studies, agroforestry systems have been proven to be at least 100% more productive, providing higher returns than monocultures (Lehmann et al., 2020). This system enables farmers to take the advantage of the agricultural and the forestry aspects as seen in cocoa agro forestry systems where the other products such as bananas, oranges and timber play an important part in income and internal household consumption hence enhancing household savings and food security (Cerda et al., 2014). In addition, agroforestry can lessen income variability and offer economic stability to fluctuations in the marketplace and climatic upheavals (Pratiwi & Suzuki, 2018). Besides being a way of generating income, the implementation of agroforestry can also be described as a secure strategy that not only diversifies the output of farms but also promotes the overall well-being of resource-rich and resource-poor farm producers in diverse geographical settings (Cedamon et al., 2017).

The mitigation of risk due to product diversification and interpretation of the economic resilience of agroforestry systems against conventional farming bring to the fore, just to mention, the enormous benefits enjoyed by the diverse agricultural systems. Crop diversification is known as an act of growing a number of crops and mitigates the risk of climate change, pests, and market fluctuations due to maximum ecological stability and risk dispersion between the products (Mihrete & Mihretu, 2025). As compared to traditional agriculture, agro forestry integrates crops with other types of vegetation including trees and tree livestock, which enhances biodiversity and erects transients to climatic change (Pancholi et al., 2023; Schoeneberger, 2008). This intertwining not only captures carbon but also increases the soil health, contributes to the water management, and helps to diversify the economy, providing a solid approach to the fluctuations on the market (Waldron et al., 2017). Although traditional agriculture is mostly concerned about harvesting the biggest crop, sometimes sacrificing the quality of the environment, agroforestry is a multipurpose system that complies with sustainable development objectives as it combines the increase of food access, economic sustainability, and environmental improvement (Waldron et al., 2017; Octavia et al., 2022). Although it has a potential to benefit most people, the ultimate development of agroforestry has been hampered by few issues that include low environmental knowledge and institutional research and support, which should be solved by policy innovation and special training of people (Schoeneberger, 2008). This highlights the importance of comprehensive measures that can facilitate sustainable activities that lead to robust farming systems that can withstand any form of change in the environment (Bhanuwanti et al., 2024; Eswaran et al., 2024).



### ISSUES AND CONSTRAINTS

There is a large challenge and constraint to implementing and managing agro-forestry systems. Socio-economic impediments include the cost of adoption of agroforestry practices (high initial cost of adoption of the practices) and the lack of a structured market infrastructure, which inhibits farmers to adopt agroforestry practices (Atreya et al., 2021). The other major impediment is the insufficient technical knowledge and expertise involved in the proper management of these systems which are by all means complex owing to their integration of trees, crops, and livestock (Verma et al., 2024). Also, there are institutional challenges that act as limiting factors such as vague ownership rights of land and inappropriate policies (Paudel et al., 2022). The most appropriate way of dealing with these challenges is to have specific policies, capacity building, and community participation in promoting the adoption and sustainable management of agroforestry systems (Kumar et al., 2023).

Socio-economic limits and land property matters affect the utilization of agroforestry among the little cultivator farmers a lot. Factors like a high cost of implementation of agroforestry practices and resource access restrictions may also discourage the embarkation of an agroforestry practice by smallholder farmers (Mwase et al., 2015; Sekhar et al., 2024). Land tenure security is a key factor; where land tenure is well secured its adoption rates are high, as farmers will take more risks to invest in long term agroforestry practice (Arbuckle et al., 2008; Verma et al., 2024). On the other hand, insecurity in land will contribute to reluctance to adopting the agroforestry since there is a risk of losing the land without gaining returns to the investment. Additionally, non-operator landlords, who do not live on their land may be less motivated by interest in agroforestry due to specific financial interests in the property unless environmental or recreation values drive them (Arbuckle et al., 2008). Socio-economic challenges To increase the uptake of agroforestry, emphasis should be given to ways of addressing the following socio-economic issues and implementing policies to secure land rights, subsidize the outlay of initial investments, and create awareness of environmental and economic goodness of agroforestry (Satish et al., 2024; Pancholi et al., 2023).

### **THE POLICY AND INSTITUTIONAL LIMITATIONS**

The adoption of agroforestry is constrained by a number of policies and institutionally related factors observed in different studies across the world. A discrepancy between policy-oriented inquiry and policy action in Southern Africa causes the region to record a less enthusiastic implementation of agroforestry innovations (Ndlovu & Borrass, 2021). In Kenya's Vihiga County, challenges such as land shortages and lack of capital persist, with recommendations highlighting the need for better access to inputs and credit incentives to mitigate these barriers (Endeki et al., 2025). In the same way, in Vietnam, specific policies encouraging agroforestry are lacking which prevents this farming technique and an alternative comprehensive approach is needed involving the integration of agriculture and forestry (Simelton et al., 2016). The best approaches to adoptions would include enhancing the community participation, market orientations and use of technology (Swadhi, 2025). The policies that are able to support agroforestry should be aimed at developing integrated approaches that combine socio-economic and biophysical dimensions towards improving the scalability and adaptability of the agroforestry practices. The reforms are expected to ensure more effective use of funds towards capacity building and to create institutional support that will ensure there is harmony in the messages passed across the stakeholders (Mwase et al., 2015).

Some of the most outstanding lessons and success factors in agroforestry projects have been evidenced in various regions and hence have replication potential. To illustrate, participatory modelers focus on the necessity to integrate proper relationship building and local expertise, which is of paramount importance to enhance community buy-in and cooperation (Sterling et al., 2019). The projects also emphasize the significance of stakeholder engagement and a culturally acceptable knowledge creation. Also, they perceive that open communications and shared sense of objectives are important among all stakeholders of the agroforestry initiatives. The liveliness of the project design to fit the local conditions and needs also works in favor of the successful introduction of such projects (Sterling et al., 2019). These projects, thus, introduce the model of sustainable practices, emphasizing the fact that community-focused, diverse, and evolving practices are the right way of achieving the success and slate of the agroforestry initiatives in other regions. Although I will not be

able to produce a complete essay, here is some information on how successful these initiatives were according to what was written.

#### **FUTURE DEVELOPMENTS IN AGROFORESTRY MANAGEMENT**

Developing tech in agroforestry management involves new technologies and practices that are expected to facilitate the improvement of the sustainability and productivity of agroforestry systems. Such technologies are precision agriculture including the use of drones and sensors to check the health of crops, soil conditions and tree growth, to use resources more efficiently and to limit wastes (Raintree, 1983). Biotechnology has eased the creation of disease-resistant crop varieties and thereby increased the crop yields and their resistance to environmental stresses (Nazarov et al., 2024). Digital platforms have been equally important in the dissemination of knowledge and ensure that farmers gain access to real-time data and best practices and thus facilitating the bridge that exists between traditional practices and innovative modern approaches (Santiago-Freijanes et al., 2018). In addition, global policy and European policy initiatives are designed to promote agroforestry innovation through the integration of research with policy and practice, but their implementation on larger scales appears to have some obstacles (Kumar et al., 2023). Although all these are being done, there also exist the socio-economic obstacles that threaten to dampen the adoption of the novel technologies and it is therefore worth to note that supportive policies and investments towards acquiring education and training are required so as to enjoy the full potential of agroforestry systems (Mwase et al., 2015).

#### **FUTURE PROSPECTS AND RECOMMENDATIONS**

To promote agroforestry practices in large scale, some major strategies and alliances can be put in place. Barriers to such increased global adoption rates can be mitigated by lack of awareness, financial resources and secure land tenure while many of the positive attributes of agroforestry can be facilitated through greater understanding of its multi-functional capacities to promote healthier soils, increased biodiversity and offer economic alternatives to farmers (Satish et al., 2024). The combined effects of integrating agroforestry into national and global climatic policies can go further towards actualizing the climate action, carbon sequestration, and resilience building capability of agroforestry. Such a correlation can be used as a roadmap to create climate-smart agricultural landscapes as a means to achieving overall sustainability (Kumar et al., 2023; Aryal et al., 2019). PPPs are also essential in this process as they encourage innovation, promote research and technological development, and establish structures that would navigate the interaction of the stakeholders. Such alliances have the potential to use their resources creatively and nurse a wide range of networks so as to speed up the introduction of agroforestry systems making them more scalable and sustainable in different agricultural settings (Pattberg, 2010).

Research in agroforestry must have a narrower perspective on some of its priorities. One of the main points of focus is carrying out long-term researches to evaluate the ecosystem services and economic values with the help of agroforestation systems. The knowledge of how these systems will be sustained and their effects over prolonged durations will be of great benefit in describing their contribution towards conservation of biodiversity, soil health, carbon storage and economy. Also, it is necessary to promote interdisciplinary cooperation to solve multifaceted issues in the field of

research on agroforestry. In combination with ecology, economics, social, science, and agricultural sciences, researchers can come up with more resilient and adaptive practices of agroforestry. This necessitates concerted efforts in building a culture of interdisciplinary integration, which involves the full intellectual participation of various fields, creating innovative research frameworks, and addressing complex questions that extend beyond individual disciplines' capacities (Goring et al., 2014; Bellotti et al., 2016).

As a means to reduce greenhouse gases emissions in addition to sequestration of carbon, policies should focus on the twin measure of agroforestry in its implementation in climate change mitigation. As an example, it is possible to use agroforestry systems to conserve the carbon rich forests and use low emission methods of production, which are essential in climate change mitigation (Stevanović et al., 2016). Moreover, agroforestry practice would significantly improve food security of low-and middle-income countries due to the contribution of income diversification and crop yield increase. Activities like the integration of organic sources of nutrients and augmenting the crop diversity have been found to enhance food security and now this is in hand with fostering climate change adaptation (Dittmer et al., 2023). Finally, in order to facilitate the use of agroforestry, incentive mechanisms must be in place. These can involve financial incentives to smallholder farmers who are part of elaborate agroforestry systems, which have been found effective in creating climate resilience and livelihood maintenance in areas including Sub-Saharan Africa (Sudomo et al., 2023; Partey et al., 2017). Thus, developing supportive policies and comprehensive research on agroforestry's long-term benefits can facilitate these integrations effectively.

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