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Agroforestry Systems: A Pathway to Resilient and Productive Landscapes

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Author's contribution

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Agroforestry, the integration of trees, crops, and livestock on the same land, offers a sustainable approach to enhancing agricultural productivity while mitigating environmental challenges. This review highlights the important role agroforestry systems play in promoting resilient and productive landscapes, particularly in the face of climate change, land degradation, and biodiversity loss. Agroforestry systems, including alley cropping, silvopasture, and home gardens, provide significant ecological benefits such as carbon sequestration, reduced greenhouse gas emissions, improved soil health, water conservation, and enhanced biodiversity. These systems not only stabilize microclimates and reduce soil erosion but also improve soil fertility and water infiltration, making them vital for climate adaptation. Socio-economically, agroforestry diversifies income sources for smallholder farmers by generating products like timber, fruits, and fodder, while contributing to food security through year-round crop availability and improved nutrition. Despite these benefits, the adoption of agroforestry faces substantial barriers, including socio-cultural resistance, knowledge gaps, inadequate policy support, and limited access to markets and credit. High initial costs, perceived risks, and competition for resources between trees and crops further impede its widespread implementation. Addressing these challenges requires enhancing extension services, policy reforms, financial incentives, and market access to support smallholder farmers. Future directions emphasize integrating agroforestry into national agricultural policies and climate action plans, supported by research on optimizing species selection, pest management, and sustainable resource use. By the synergies between agroforestry, regenerative agriculture, and Sustainable Development Goals, agroforestry presents a viable pathway for transforming agricultural systems into more resilient, productive, and sustainable models. Scaling up agroforestry can help restore degraded lands, sequester carbon, and enhance the livelihoods of rural communities, contributing to global efforts to combat climate change and promote sustainable development.

Keywords: Agroforestry; agricultural productivity; climate change; land-use management.

1. INTRODUCTION

1.1 Agricultural Challenges in the 21st Century

1.1.1 Climate change impacts on agricultural productivity

Agriculture is at the forefront of sectors impacted by climate change, with direct consequences on crop yields, livestock health, and overall food security (Table 1). Global temperature increases, erratic precipitation patterns, and extreme weather events like droughts and floods are already threatening agricultural productivity worldwide. Research indicates that crops like wheat, maize, and rice the staples that feed much of the world could see yield reductions of 3-7% for every 1°C increase in global temperature (Neupane et al., 2022). Rising temperatures exacerbate pest pressures and disease outbreaks. For example, the spread of the Fall Armyworm (*Spodoptera frugiperda*), which devastates maize crops, has been accelerated by warming temperatures and changing rainfall patterns. These challenges highlight the urgency of adopting sustainable agricultural practices that can adapt to and mitigate the effects of climate change.

1.1.2 Issues of land degradation, soil erosion, and biodiversity loss

In climate change, modern agriculture faces significant challenges related to land degradation. An estimated 24 billion tons of fertile soil are lost annually due to unsustainable agricultural practices, primarily through erosion, nutrient depletion, and salinization (Hossain et al., 2020). This degradation affects nearly 33% of the world's arable land, resulting in declining soil fertility and reduced crop productivity. Soil erosion, driven by deforestation and conventional monoculture farming, is a important issue. Studies indicate that intensive tillage and monocropping can reduce soil organic matter by up to 50% in a few decades. This not only lowers agricultural productivity but also contributes to increased greenhouse gas emissions. The loss of biodiversity due to habitat destruction and pesticide use is concerning, as biodiversity is crucial for ecosystem stability, pollination, pest control, and nutrient cycling (Isenring, 2010). The combined effects of climate change, soil degradation, and biodiversity loss create a complex web of challenges that require innovative and sustainable solutions to ensure food security, environmental protection, and economic stability.

1.2 Importance of Agroforestry

1.2.1 Agroforestry as a land-use management practice integrating trees, crops, and livestock

Agroforestry is an integrated land-use management system that incorporates trees, crops, and livestock on the same plot of land. This practice aims to create synergies between different biological components to enhance the productivity, sustainability, and resilience of agricultural systems (Gil et al., 2017). Agroforestry is the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal production systems to benefit from the resulting ecological and economic interactions (Mosquera-Losada et al., 2009; Torralba et al., 2016). The key principle behind agroforestry is the optimization of resources by using different plant and animal species that complement each other, leading to higher land-use efficiency compared to traditional monoculture systems. Agroforestry systems can take various forms, such as alley cropping (where trees are grown in rows with crops in between), silvopasture (combining trees with livestock grazing), and home gardens that integrate multiple layers of vegetation for household sustenance. For example, alley cropping with nitrogen-fixing trees like Gliricidia sepium can increase maize yields by 30-50% by improving soil fertility and reducing the need for synthetic fertilizers. The presence of trees in agricultural landscapes has been shown to moderate microclimates, reduce wind speeds, and enhance water infiltration, which are crucial under changing climate conditions (Jacobs et al., 2022). In AGROFORESTRY systems there are both ecological and economical interactions between the woody and non-woody components in agroforestry (Sultana & Bari, 2021).

1.2.2 History and global relevance

The concept of integrating trees with agricultural activities is not new. Traditional agroforestry systems have been practiced for centuries by indigenous communities across Asia, Africa, and Latin America. The *taungya* system in Southeast Asia and the *chitemene* system in Zambia demonstrate how traditional societies have sustainably managed forests and agricultural lands. However, with the advent of industrial agriculture, many of these practices were abandoned in favor of monocropping, which prioritizes short-term yields over long-term sustainability. In recent decades, there has been a resurgence of interest in agroforestry due to its potential to address multiple global challenges simultaneously. Agroforestry can contribute to 9 out of the 17 Sustainable Development Goals (SDGs), including zero hunger, climate action, life on land, and sustainable cities and communities. For example, agroforestry systems are estimated to sequester between 0.7 to 1.6 gigatons of CO_2 per year, making them a crucial component of climate change mitigation strategies (Udawatta et al., 2022).

1.3 Objectives and Scope of the Review Paper

1.3.1 To analyze the potential of agroforestry in enhancing resilience and productivity

The main objective of this review paper is to comprehensively evaluate the potential of agroforestry systems to enhance the resilience and productivity of agricultural landscapes. By integrating trees with crops and livestock, agroforestry can help buffer against the adverse effects of climate change, improve soil health, and diversify farm income sources. This review aims to highlight the ecological, economic, and social benefits of adopting agroforestry as a sustainable alternative to conventional agriculture. Studies have shown that smallholder farmers practising agroforestry in East Africa have increased their household incomes by 20-30% due to diversified production (Nyaga et al., 2015).

1.3.2 To synthesize current research findings on different agroforestry systems

This paper also aims to synthesize the latest research findings on various types of agroforestry systems, identifying best practices, success stories, and areas where further research is needed. The review will cover both traditional and innovative agroforestry practices across different agroecological zones, providing insights into how these systems can be scaled up to address contemporary agricultural challenges. According to a meta-analysis, agroforestry has been shown to increase crop yields by up to 100% in degraded lands, emphasizing its potential for land restoration and

Table 1. Agricultural Challenges in the 21st Century (Sources: Neupane et al., 2022, Sultana & Bari, 2021)

Challenge	Description	Impact on Agriculture	Proposed Solutions
Climate Change	Rising temperatures, altered precipitation patterns, and extreme weather events.	Reduced crop yields, shifts in growing seasons, increased pest and disease prevalence.	Adoption of climate-resilient crops, improved water management, and climate-smart agricultural practices.
Soil Degradation	Loss of soil fertility and structure due to erosion, over-cultivation, and chemical contamination.	Decline in crop productivity, increased reliance on fertilizers.	Implementation of conservation agriculture, crop rotation, and organic amendments.
Water Scarcity	Decreasing availability of freshwater for irrigation and other agricultural needs.	Lowered crop productivity, conflicts over water use, and reduced food security.	Efficient irrigation systems like drip and sprinkler irrigation, and adoption of water harvesting methods.
Population Growth	Increasing global population demanding higher food production.	Stress on resources, need for intensified farming practices.	Promoting sustainable intensification, reducing food waste, and improving food distribution systems.
Biodiversity Loss	Decline in genetic, species, and ecosystem diversity due to habitat destruction and monocropping.	Reduced ecosystem services, loss of pollinators, and increased pest outbreaks.	Conservation of biodiversity through agroforestry, crop diversification, and habitat restoration.
Pest and Disease Pressure	Increased outbreaks due to climate change, global trade, and pesticide resistance.	Yield losses, higher production costs, and food insecurity.	Integrated Pest Management (IPM), biopesticides, and development of resistant crop varieties.
Energy Dependence	Reliance on fossil fuels for mechanization, fertilizers, and pesticides.	High carbon emissions and vulnerability to fluctuating energy prices.	Adoption of renewable energy sources and development of low-carbon farming technologies.
Technological Gap	Uneven adoption of modern technologies among farmers.	Reduced productivity and competitiveness, especially in developing countries.	Capacity building, investment in rural infrastructure, and subsidies for technology adoption.
Food Security and Nutrition	Ensuring access to affordable, nutritious, and safe food for a growing population.	Increased malnutrition, hunger, and socio-economic disparities.	Promotion of biofortified crops, reducing post-harvest losses, and enhancing food policies.
Urbanization and Land Use Changes	Expansion of urban areas into agricultural land.	Loss of arable land, fragmentation of farmland, and reduced food production capacity.	Land use planning, promotion of vertical farming, and urban agriculture initiatives.
Market and Policy Constraints	Inadequate access to markets, volatile prices, and ineffective agricultural policies.	Economic instability for farmers, reduced investment in agriculture.	Strengthening farmer cooperatives, implementing fair trade policies, and enhancing rural market infrastructure.

food security (Gupta et al., 2020). By exploring the multifunctional benefits of agroforestry, this review intends to provide a comprehensive understanding of how agroforestry can serve as a pathway to resilient and productive landscapes, contributing to sustainable agricultural transformation.

2. AGROFORESTRY SYSTEMS

2.1 Classification of Agroforestry Systems

2.1.1 Structural classification: Agrisilvicultural, silvopastoral, agrosilvopastoral systems

- Agrisilvicultural Systems: These systems integrate trees and crops on the same plot of land. Growing maize alongside fruit or timber trees like *Grevillea robusta* is a common practice in East Africa (Ekhuya, 2013). Agrisilvicultural systems are known to enhance soil fertility, reduce erosion, and improve crop yields by providing shade and organic matter.
- Silvopastoral Systems: This type involves the integration of trees with livestock grazing. For example, in Latin America, planting *Leucaena leucocephala* in pastures has been shown to improve livestock productivity by providing high-protein fodder while simultaneously sequestering carbon. These systems help to enhance soil structure, improve water retention, and increase biodiversity.
- Agrosilvopastoral Systems: The most complex of the three, this system combines trees, crops, and livestock on the same land. For example, in India, combining cereal crops like sorghum with leguminous trees like *Acacia nilotica* and goats can optimize land use and boost resilience against climatic stressors (Dagar et al., 2017). These systems offer multiple outputs such as food, fodder, and fuelwood, promoting diversified income sources.

2.1.2 Functional classification: Protective, productive, and socio-economic systems

- Protective Systems: These are primarily aimed at environmental protection, such as soil and water conservation. For example, shelterbelts and windbreaks can reduce wind erosion by up to 40% and increase crop yields by 15-20% in arid regions (Aili et al., 2024).
- Productive Systems: These systems are designed to enhance the productivity of agricultural land. Integrating nitrogen-fixing trees like *Gliricidia sepium* with maize can improve yields by enriching soil nitrogen levels, reducing the need for synthetic fertilizers by 30-50%.
- Socio-Economic Systems: These systems focus on improving livelihoods and social well-being. By providing diverse products (e.g., timber, fruits, fodder), agroforestry systems increase household incomes and enhance food security. Studies from Ethiopia show that smallholder farmers practising agroforestry have increased their income by 25% compared to conventional agriculture (Amare et al., 2019).

2.2 Major Types of Agroforestry Systems

2.2.1 Alley cropping

Alley cropping involves planting rows of trees or shrubs with crops grown in the alleys between them (Fig. 1). Trees like *Leucaena leucocephala* or *Sesbania sesban* are commonly used, especially in semi-arid regions, due to their nitrogen-fixing capabilities. Alley cropping systems enhance soil fertility by adding organic matter through leaf litter and root turnover. Studies in Nigeria showed that integrating *Gliricidia* trees with maize increased crop yields by 35% while reducing soil erosion by 50% (Sileshi et al., 2020). The trees act as habitat for beneficial insects and predators, reducing pest pressure. For example, in the Philippines, alley cropping reduced the incidence of pests like stem borers in rice fields by up to 30%.

2.2.2 Agro-Silvopastoral systems

These systems are particularly effective in maximizing land use efficiency. In Brazil, integrating cattle grazing with *Eucalyptus* plantations increased beef production by 15% and timber yields by 20%, while reducing greenhouse gas emissions (Monteiro et al., 2024). By combining crops, livestock, and trees, these systems optimize nutrient cycling. For example, trees like *Acacia* can enhance phosphorus availability in soils, which benefits adjacent crops. The integration of livestock helps recycle nutrients through manure, which improves soil organic matter content, thereby increasing crop productivity by 20-30%.

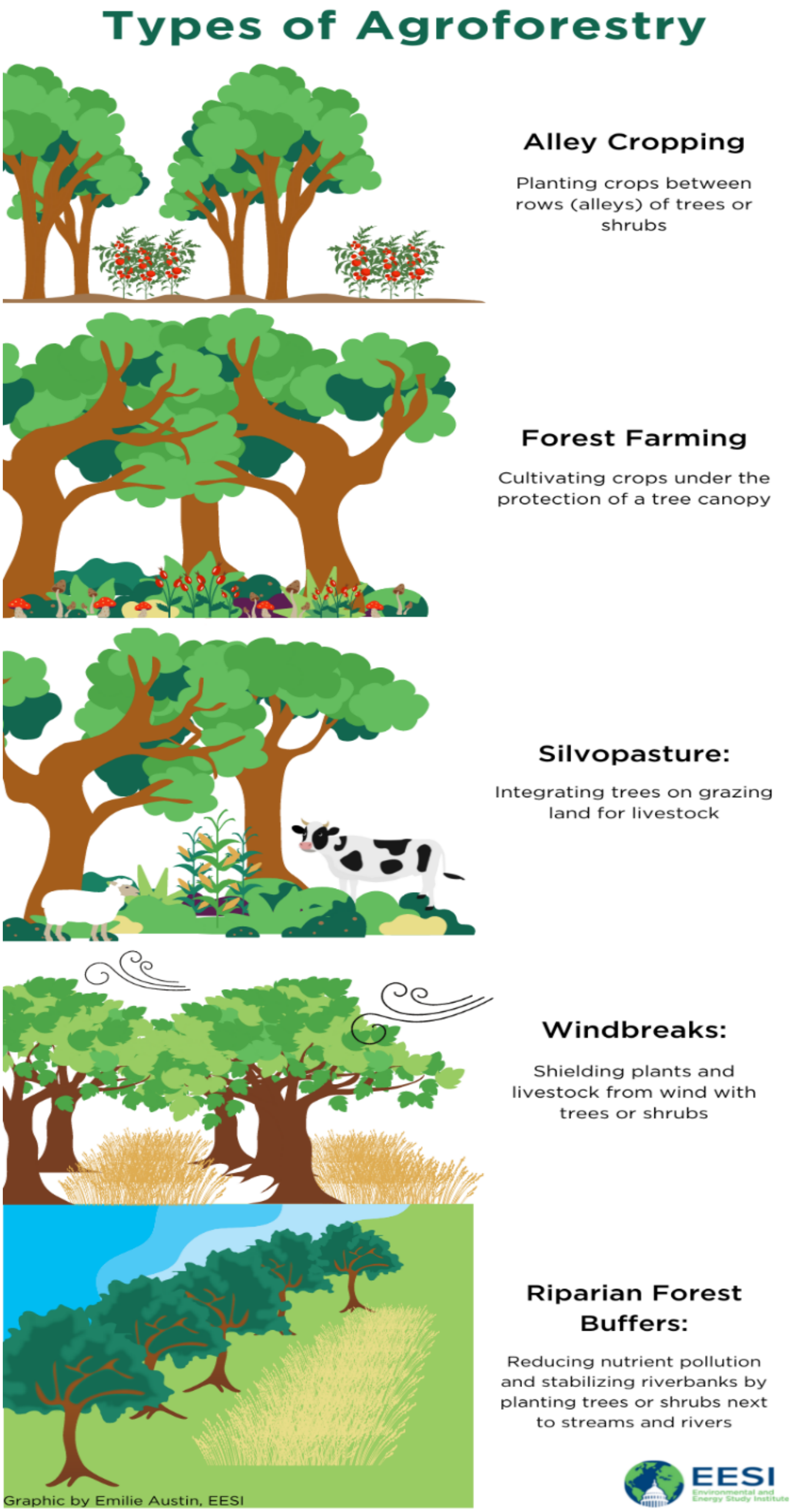

Fig. 1. Different types of agroforestry practices (Source: EESI)

2.2.3 Silvopasture

Silvopasture integrates trees with pasture for grazing livestock, providing multiple benefits such as shade for animals and additional fodder resources. In the southeastern United States, silvopasture systems using loblolly pine and cattle have been shown to increase land productivity by 35% compared to traditional grazing (Pent et al., 2021). Tree roots stabilize the soil and reduce compaction caused by livestock trampling. Research from Spain indicates that silvopasture can reduce surface runoff by 40%, enhancing groundwater recharge. Silvopastoral systems sequester more carbon than conventional pastures, with estimates of 3-6 tons of CO_2 per hectare per year (Ortiz et al., 2023).

2.2.4 Home gardens and multistrata systems

Home gardens are complex agroforestry systems that integrate multiple plant species, including trees, shrubs, herbs, and crops, often in multiple layers. These systems are common in tropical regions like Indonesia and India, where they contribute significantly to household food security and nutrition. Home gardens provide a continuous supply of food products such as fruits, vegetables, and medicinal plants. For example, households in Kerala, India, obtain 60% of their annual fruit and vegetable needs from home gardens (Peyre et al., 2006). Multistrata systems mimic natural forests, enhancing biodiversity. Studies in Sri Lanka show that home gardens support over 300 species of plants, providing habitat for a wide range of pollinators and wildlife.

3. ECOLOGICAL AND ENVIRONMENTAL BENEFITS OF AGROFORESTRY

3.1 Climate Change Mitigation

3.1.1 Carbon sequestration potential of trees

Agroforestry plays a important role in climate change mitigation by enhancing carbon sequestration (Table 2). Trees in agroforestry systems absorb atmospheric CO_2 through photosynthesis and store it in their biomass and soil. According to a study, agroforestry systems globally sequester between 0.7 to 1.6 gigatons of CO_2 per year, making them an effective tool for climate mitigation (Udawatta et al., 2022). Silvopasture, one of the most efficient systems, can sequester up to 9.5 tons of CO_2 per hectare annually. Agroforestry systems not only capture carbon in trees but also increase soil organic carbon (SOC) levels, with estimates suggesting an increase of 2-4 tons of carbon per hectare in the topsoil over 5-10 years. In regions like sub-Saharan Africa, integrating trees with crops can significantly enhance carbon storage, contributing to national climate commitments (Bryan et al., 2010).

3.1.2 Reduction of greenhouse gas emissions

In addition to sequestering carbon, agroforestry helps reduce greenhouse gas (GHG) emissions, particularly methane (CH_4) and nitrous oxide (N_2O). The integration of nitrogen-fixing trees reduces the need for synthetic fertilizers, which are a major source of N_2O emissions. A study in Kenya found that using leguminous trees like *Sesbania* reduced N_2O emissions by 45% compared to conventional maize farming. Silvopastoral systems reduce methane emissions from livestock by improving the quality of available forage. Research in Colombia showed that integrating *Leucaena leucocephala* in pastures reduced methane emissions from cattle by 20-30% (Rivera et al., 2023).

3.2 Enhancement of Soil Health

3.2.1 Soil erosion control and fertility improvement

Agroforestry systems are highly effective in reducing soil erosion, which is important in regions facing land degradation. The presence of trees and shrubs stabilizes the soil, reduces surface runoff, and improves water infiltration. For example, alley cropping systems in West Africa have reduced soil erosion rates by 50-60% compared to traditional monocropping. The leaf litter and root biomass from trees contribute to soil fertility. Studies indicate that agroforestry can increase soil organic matter by 20-30% and enhance nutrient cycling, resulting in improved crop yields (Sileshi et al., 2020). The use of nitrogen-fixing trees like *Gliricidia sepium* can boost soil nitrogen content, reducing the need for chemical fertilizers by 40%.

3.2.2 Role in increasing soil organic matter and microbial activity

The integration of trees in agricultural landscapes promotes microbial activity in the soil, which is essential for nutrient cycling and soil structure. Agroforestry systems can increase soil microbial biomass by 30-50%, enhancing soil health and productivity. Trees with deep root systems, such as *Faidherbia albida*, access nutrients from deeper soil layers and deposit them on the surface through leaf litter, enriching the soil. In agro-silvopastoral systems, livestock manure further contributes to the increase in soil organic matter, fostering a thriving soil microbiome and promoting sustainable agriculture (Fahad et al., 2022).

3.3 Water Management and Conservation

3.3.1 Reducing surface runoff and enhancing groundwater recharge

Agroforestry improves water management by reducing surface runoff and increasing groundwater recharge. Trees slow down the movement of water across the soil surface, allowing more time for infiltration. In the semi-arid regions of India, agroforestry practices have been shown to reduce surface runoff by 30%, leading to a 25% increase in groundwater recharge (Owuor et al., 2016). Tree roots act as natural filters, removing pollutants from water before they reach aquifers, thus improving water quality.

3.3.2 Mitigating drought impacts through improved soil moisture retention

Agroforestry systems enhance the soil's ability to retain moisture, making them an effective strategy for mitigating the impacts of droughts. By providing shade and reducing evaporation rates, trees in agroforestry systems can increase soil moisture content by 10-15% compared to open fields. Studies in sub-Saharan Africa show that farmers who adopted agroforestry systems experienced higher crop yields during drought years compared to those practicing conventional agriculture (Awazi & Tchamba, 2019). This is particularly important in regions where climate variability poses a significant threat to food security.

Table 2. Ecological and Environmental Benefits of Agroforestry

Benefit	Description	Examples
Soil Conservation	Reduces soil erosion and improves soil structure and fertility through tree roots and organic matter.	Alley cropping prevents erosion; leguminous trees improve nitrogen content in soils.
Carbon Sequestration	Captures and stores atmospheric carbon in trees and soil, mitigating climate change.	Agroforestry systems store 50–75 Mg C/ha in tropical regions.
Biodiversity Conservation	Provides habitat and food resources for various plant and animal species, enhancing biodiversity.	Shelterbelts and live fences support pollinators, birds, and other beneficial organisms.
Water Resource Management	Improves water infiltration, reduces surface runoff, and protects water quality.	Riparian buffer zones reduce sediment and nutrient runoff into water bodies.
Microclimate Regulation	Moderates local temperature, humidity, and wind speed, creating a favorable microclimate.	Windbreaks protect crops from wind damage and reduce evapotranspiration.
Air Quality Improvement	Trees in agroforestry systems filter air pollutants and release oxygen.	Poplar and eucalyptus plantations act as air pollutant sinks in agroforestry systems.
Reduced Greenhouse Gas Emissions	Minimizes emissions by reducing reliance on chemical fertilizers and promoting organic matter recycling.	Agroforestry reduces methane and nitrous oxide emissions from farming systems.
Enhanced Ecosystem Services	Provides a range of ecosystem services such as nutrient cycling, pest control, and pollination.	Mixed agroforestry systems promote natural pest predators and efficient nutrient recycling.
Land Rehabilitation	Restores degraded lands by improving soil fertility, water retention, and vegetative cover.	Reforestation projects combined with crop farming improve productivity on degraded lands.
Climate Resilience	Enhances the resilience of agricultural systems to climate extremes like droughts and floods.	Drought-tolerant tree species reduce vulnerability in semi-arid farming systems.

3.4 Biodiversity Conservation

3.4.1 Agroforestry's role in creating habitat corridors

One of the important ecological benefits of agroforestry is its ability to enhance biodiversity. By integrating trees into agricultural landscapes, agroforestry creates habitat corridors that connect fragmented natural habitats, promoting the movement of species and increasing genetic diversity. For example, agroforestry systems in the Amazon have been found to support 75% of the bird species present in adjacent primary forests. Agroforestry can also support populations of pollinators and natural pest predators, which are vital for the health of agricultural ecosystems. In cocoa agroforests in West Africa, the diversity of pollinators increased by 60%, leading to improved crop yields (Bisseleua et al., 2009).

3.4.2 Preservation of native species and genetic diversity

Agroforestry systems help preserve native species by mimicking the structure of natural forests, thus providing habitats for various flora and fauna. In regions like Southeast Asia, traditional multistrata agroforestry systems have been shown to conserve over 200 plant species per hectare, many of which are endangered. Agroforestry promotes in situ conservation of genetic resources, which is essential for the adaptation of species to changing environmental conditions. For example, incorporating wild fruit trees like *Irvingiagabonensis* in agroforestry systems helps conserve genetic diversity while providing farmers with additional income sources (Dawson et al., 2009).

4. SOCIO-ECONOMIC BENEFITS OF AGROFORESTRY

4.1 Livelihood Diversification and Rural Development

4.1.1 Income generation through multiple products (timber, fruits, fodder)

Agroforestry significantly diversifies income sources for rural communities, enabling farmers to generate revenue from various products, such as timber, fruits, fodder, medicinal plants, and non-timber forest products (NTFPs). This diversification reduces financial risks associated with dependence on a single crop. For example, in Kenya, farmers practicing agroforestry with trees like *Grevillea robusta* and *Calliandra calothyrsus* reported a 35% increase in household income due to the sale of timber and fodder (Wanjira & Muriuki, 2020). Integrating fruit trees like mango, guava, and jackfruit with traditional crops has increased annual farm income by 40-60%. Similarly, in Latin America, shade-grown coffee agroforestry systems generate up to 30% higher returns compared to conventional coffee monocultures, thanks to the added income from timber and other forest products. The sale of timber from agroforestry systems in Brazil can provide an annual income boost of $300-500 per hectare, especially when fast-growing species like *Eucalyptus* are integrated into pastures (Wunder & Wertz-Kanounnikoff, 2009).

4.1.2 Employment opportunities and social benefits

Agroforestry systems also contribute to rural employment, reducing migration to urban areas by creating job opportunities in tree planting, harvesting, processing, and marketing of diverse agroforestry products. According to a study, agroforestry initiatives in Africa have created 10-15% more rural jobs compared to conventional agriculture. Agroforestry encourages community-based resource management, fostering social cohesion and collective decision-making. In Southeast Asia, integrating agroforestry into rural development projects has been linked to increased women's participation in local economies, as women often manage the sale of fruits, medicinal herbs, and small livestock (Kiptot & Franzel, 2012). This socio-economic empowerment contributes to poverty alleviation and improved quality of life in marginalized communities.

4.2 Food Security and Nutrition

4.2.1 Contribution of agroforestry to diversified diets

Agroforestry enhances food security by promoting the cultivation of a variety of crops, fruits, and vegetables on the same land, thereby providing a more diverse and nutritious diet. Home gardens, which are a form of agroforestry, contribute significantly to household nutrition, especially in countries like Sri Lanka and Indonesia, where they account for 20-30% of household food consumption. These systems provide nutrient-rich foods such as leafy greens, legumes, and fruits, which are often missing from conventional monoculture systems. In Malawi, households practising agroforestry with nutrient-rich trees like *Moringa oleifera* and *Faidherbia albida* experienced a 25% increase in protein intake and reduced incidences of malnutrition among children (Paracchini et al., 2020). Furthermore, the integration of leguminous trees improves soil health, which enhances the productivity of staple crops, thereby ensuring a stable food supply.

4.2.2 Year-round availability of food and non-food products

Unlike seasonal crops, agroforestry systems provide year-round availability of food and non-food products, thus stabilizing food supplies even during periods of adverse weather. Fruit trees such as mango, citrus, and avocado integrated into farms in Africa and Asia can produce harvests at different times of the year, providing consistent nutrition and income. In Ethiopia, farmers practicing agroforestry reported that access to fruits, nuts, and honey improved during the dry season when other food sources were scarce (Dagar et al., 2020). This consistent supply is crucial for food security, particularly in regions prone to drought and crop failures.

4.3 Cost-effectiveness and Long-term Economic Returns

4.3.1 Reduced input costs compared to monoculture systems

Agroforestry systems are cost-effective because they reduce the need for expensive agricultural inputs like synthetic fertilizers and pesticides. By leveraging natural processes such as nitrogen fixation, pest control, and soil regeneration, agroforestry reduces input costs by 20-50% compared to conventional monoculture farming. For example, in Zambia, integrating *Gliricidia sepium* with maize reduced fertilizer costs by 40%, while maintaining comparable crop yields. Agroforestry systems often improve soil fertility over time, leading to increased long-term productivity. In Niger, the practice of growing *Faidherbia albida* trees among millet fields resulted in an increase in crop yields by 150% without additional inputs, saving farmers up to $100 per hectare annually on fertilizers (Clottey et al., 2015).

4.3.2 Resilience against market fluctuations and climate shocks

Agroforestry offers farmers greater resilience to market volatility and climate-induced shocks by diversifying income streams and improving farm productivity under changing climatic conditions. During the 2015-2016 El Niño event, farmers in Central America who practised agroforestry with shade-grown coffee experienced 30% fewer losses than those who relied solely on monoculture coffee. The diversity of products available in agroforestry systems (e.g., fruits, fuelwood, and medicinal plants) allows farmers to adapt to market changes. If one product faces a price drop, they can rely on others, thereby reducing economic vulnerability. In India, agroforestry farms were able to recover more quickly from market fluctuations in the price of staple crops like rice and wheat by shifting their focus to higher-value timber and medicinal plants (Teli, 2023). Agroforestry enhances climate resilience by improving soil health and water retention, which are important for sustaining agricultural productivity during droughts and floods. A study in Burkina Faso found that farmers who adopted agroforestry practices experienced 20-40% higher yields during drought years compared to those using conventional practices.

5. AGROFORESTRY'S ROLE IN ENHANCING AGRICULTURAL RESILIENCE

5.1 Improving Farm Resilience to Climate Extremes

5.1.1 Buffering against droughts, floods, and extreme temperatures

Agroforestry systems provide a natural buffer against climate extremes such as droughts, floods, and temperature fluctuations. By integrating trees into agricultural landscapes, these systems improve microclimates and soil conditions, making farms more resilient to environmental stressors. Trees reduce surface temperatures in agroforestry systems by up to 5°C and increase soil moisture retention by 20-30%, which is crucial during prolonged dry spells (Fahad et al., 2022). Trees with deep root systems, such as *Faidherbia albida* and *Acacia senegal*, access water from deeper soil layers, maintaining soil moisture even during droughts. Studies in Niger indicate that millet yields increased by 150% when grown under the canopy of *Faidherbia* trees, even during dry years. Agroforestry systems help control flooding by reducing surface runoff through increased water infiltration and soil stabilization. In India, integrating *Moringa* trees in rainfed systems reduced surface runoff by 30%, thereby reducing the impact of floods (Kaushal et al., 2021).

5.1.2 Adaptive capacity in changing environmental conditions

Agroforestry systems enhance farms' adaptive capacity to changing environmental conditions by diversifying crops and incorporating resilient tree species. The presence of perennial trees helps buffer crops from extreme weather events, such as heatwaves and cold snaps. For example, in the Sahel region, incorporating trees like *Parkia biglobosa* has improved farmers' ability to adapt to erratic rainfall patterns, increasing crop productivity by 25-40%. By diversifying income sources through the cultivation of trees, crops, and livestock, agroforestry reduces the risk of total crop failure due to climate extremes. In East Africa, smallholder farmers practicing agroforestry were found to be 50% less vulnerable to drought-related crop losses compared to those using monocultures (Altieri et al., 2015).

5.2 Integrated Pest and Disease Management

5.2.1 Enhancing ecosystem services (e.g., natural pest predators)

Agroforestry systems contribute to integrated pest management (IPM) by enhancing ecosystem services, such as providing habitats for natural pest predators like birds, insects, and spiders. According to research, the presence of shade trees in coffee agroforestry systems increased the abundance of pest predators by 60%, leading to a significant reduction in coffee berry borer infestations. The diversity of plant species in agroforestry systems disrupts pest cycles, reducing the incidence of outbreaks. For example, intercropping maize with trees like *Leucaena leucocephala* in Kenya has been shown to reduce stem borer infestations by 30-40% (Ogol et al., 1999). The presence of nectar-producing trees attracts pollinators, which enhance crop yields and improve overall farm productivity.

5.2.2 Reduction in pesticide use and promotion of sustainable agriculture

Agroforestry reduces the need for synthetic pesticides by promoting natural pest control mechanisms, which aligns with sustainable agricultural practices. A study in Indonesia demonstrated that incorporating *Gliricidia sepium* into cocoa farms reduced the need for pesticides by 50%, resulting in both environmental and economic benefits. This reduction in chemical inputs lowers production costs and reduces the negative impact of agriculture on soil health and biodiversity. The use of agroforestry in pest management supports sustainable agriculture by promoting soil health. Trees in these systems improve soil structure and fertility, which enhances plant resistance to diseases and pests. Integrating leguminous trees that fix nitrogen not only improves soil fertility but also reduces the vulnerability of crops to pests (Lebrazi & Fikri-Benbrahim, 2022).

5.3 Synergies with Regenerative Agriculture and Sustainable Development Goals (SDGs)

Agroforestry is synergistic with regenerative agriculture practices, as both aim to restore soil health, increase biodiversity, and enhance ecosystem resilience. The integration of agroforestry in regenerative agriculture systems leads to the restoration of degraded lands and the improvement of soil organic matter content by 20-30% over a period of 5-10 years. These practices contribute to the long-term sustainability of agricultural systems, which is essential for addressing global challenges such as food insecurity, climate change, and biodiversity loss (Wijerathna-Yapa & Pathirana, 2022).

5.3.1 Contribution to Sustainable Development Goals (SDGs)

Agroforestry supports multiple SDGs, including:

- SDG 2 (Zero Hunger): By increasing agricultural productivity, diversifying crops, and enhancing food security, agroforestry helps reduce hunger. In Malawi, smallholder farmers practising agroforestry reported a 30% increase in household food availability.
- SDG 13 (Climate Action): Agroforestry systems sequester carbon, reduce greenhouse gas emissions, and improve the resilience of farming systems to climate change. Agroforestry practices globally could contribute to reducing atmospheric CO_2 by up to 1.6 gigatons per year (Udawatta et al., 2022).

- SDG 15 (Life on Land): By promoting biodiversity, protecting soil health, and reducing land degradation, agroforestry contributes to the conservation and sustainable use of terrestrial ecosystems. For example, in the Amazon, integrating agroforestry practices with smallholder farms has helped restore 20,000 hectares of degraded land, preserving native species (Jarrett et al., 2017).

6. CHALLENGES AND BARRIERS TO AGROFORESTRY ADOPTION AND FUTURE

Despite its numerous benefits, the widespread adoption of agroforestry faces significant barriers. Understanding these challenges is essential for designing strategies to promote agroforestry as a sustainable agricultural practice.

6.1 Socio-cultural and Knowledge Barriers

6.1.1 Lack of awareness and traditional beliefs

In many rural areas, especially in developing countries, traditional beliefs and a lack of awareness about the benefits of agroforestry hinder its adoption. Smallholder farmers may be resistant to adopting agroforestry because they perceive it as a complex system that requires additional labour and expertise. According to a study in Ethiopia, 60% of farmers were unaware of the potential benefits of integrating trees with crops, leading to low adoption rates (Jerneck & Olsson, 2013). Furthermore, traditional farming practices are deeply rooted in cultural norms, making it difficult to convince farmers to switch to new, unfamiliar systems.

6.1.2 Knowledge gaps among farmers and extension services

The success of agroforestry systems relies heavily on technical knowledge related to species selection, management practices, and long-term planning. However, many farmers lack access to training and extension services that could help them implement agroforestry effectively. In Sub-Saharan Africa, over 70% of farmers reported insufficient knowledge about the proper management of agroforestry systems. Extension services are often underfunded or poorly trained, which limits their ability to support farmers. In India, only 20% of farmers received guidance on agroforestry practices from extension workers (Bukenya et al., 2008).

6.2 Policy and Institutional Constraints

6.2.1 Inadequate policy support and incentives

One of the major barriers to agroforestry adoption is the lack of supportive policies. In many countries, agricultural policies prioritize monoculture crops over integrated systems like agroforestry. For example, government subsidies in Brazil primarily support soybean and cattle production, leaving agroforestry initiatives underfunded. Land tenure insecurity discourages farmers from planting trees, which require several years to mature. Without clear land ownership, farmers are reluctant to invest in long-term agroforestry systems. While some countries have begun to recognize the importance of agroforestry, policy implementation remains weak. A study found that only 10% of national agricultural policies in Africa explicitly promote agroforestry (Place et al., 2013). Incentive programs that support tree planting, such as tax breaks or subsidies, are often limited or difficult to access for smallholder farmers.

6.2.2 Limited access to markets, credit, and technical assistance

Agroforestry products, such as timber, fruits, and non-timber forest products (NTFPs), often face challenges in reaching markets. In many regions, there is inadequate infrastructure for transporting and processing agroforestry products, which reduces their marketability. In Uganda, smallholder farmers reported that lack of market access reduced their incentives to invest in agroforestry (Gyau et al., 2014). Access to credit is another important barrier. Without financing, farmers cannot cover the initial costs of establishing agroforestry systems. Studies in India have shown that only 15% of smallholder farmers have access to formal credit facilities, limiting their ability to adopt agroforestry practices. Technical assistance is often unavailable, leaving farmers without the guidance needed to optimize agroforestry systems.

6.3 Economic and Financial Challenges

6.3.1 High Initial investment costs and delayed returns

Agroforestry systems often require a high initial investment in tree planting, fencing, and labour, which can be a significant barrier for resource-poor farmers. Unlike annual crops, which provide quick returns, trees may take several years to mature and generate income. According to a study in Southeast Asia, the average payback period for agroforestry systems ranges from 5 to 10 years (Phimmavong et al., 2019). This delay in returns can be a disincentive, especially for smallholder farmers who rely on immediate income for their livelihoods. The high upfront costs of establishing agroforestry systems can be prohibitive. In Latin America, smallholders need between $500 to $1,000 per hectare to establish silvopastoral systems, a cost that many farmers cannot afford without external support. Agroforestry systems require ongoing maintenance, such as pruning and pest management, which increases labour costs.

6.3.2 Perceived risks associated with adopting new systems

Farmers often perceive agroforestry as a risky investment due to the uncertainty of long-term benefits and the complexity of managing integrated systems. For example, in West Africa, farmers were hesitant to adopt agroforestry because of concerns about potential competition between trees and crops for water and nutrients, which could reduce yields (Sereke et al., 2016). The lack of reliable data on the economic returns of agroforestry systems exacerbates these perceptions, making it challenging to convince farmers of the long-term benefits.

6.4 Environmental and Ecological Concerns

6.4.1 Potential competition for water and nutrients between trees and crops

One of the main concerns associated with agroforestry is the potential competition between trees and crops for essential resources like water, light, and nutrients. In semi-arid regions, where water is scarce, integrating trees into croplands can reduce soil moisture availability for annual crops. A study in Kenya found that maize yields decreased by10-20% when grown too close to certain tree species (Omoyo et al., 2015). To mitigate this issue, proper species selection and management techniques are essential to minimize competition.

6.4.2 Invasive species management and ecosystem balance

Another environmental concern is the risk of introducing invasive species through agroforestry practices. Some fast-growing tree species, such as *Prosopis juliflora* and *Leucaena leucocephala*, have become invasive in certain regions, outcompeting native vegetation and altering ecosystems. Managing these species requires careful planning to avoid negative impacts on biodiversity and ecosystem services. Poorly managed agroforestry systems can lead to soil degradation if trees are not properly maintained (Acharya & Kafle, 2009).

6.5 Future

To overcome these challenges and promote the adoption of agroforestry, several strategies should be considered:

1. **Strengthening Extension Services and Training**: Expanding access to farmer training programs and extension services is crucial for building capacity and providing the knowledge needed to successfully implement agroforestry systems. Governments and NGOs should collaborate to deliver technical training on species selection, soil management, and sustainable harvesting practices (Pretty & Shah, 1997).
2. **Policy Reforms and Incentive Programs**: Policymakers should develop supportive frameworks that include subsidies, tax incentives, and grants for farmers adopting agroforestry. Land tenure reforms are also necessary to ensure secure property rights, encouraging farmers to invest in long-term agroforestry systems.
3. **Improving Market Access and Financial Support**: Developing infrastructure for processing and marketing agroforestry products can enhance profitability. Expanding access to microcredit and financial services can help farmers cover the initial costs of adopting agroforestry (Benjamin & Sauer, 2018).
4. **Research and Innovation**: More research is needed to optimize agroforestry systems for different agro-ecological zones. This includes studying the interactions between trees and crops, developing drought-resistant tree species, and identifying strategies to mitigate competition for water and nutrients.
5. **Promoting Agroforestry in Climate Action Plans**: Given its potential for

climate mitigation and adaptation, agroforestry should be integrated into national climate strategies and Sustainable Development Goals (SDGs). By doing so, countries can leverage agroforestry to enhance food security, restore degraded lands, and increase carbon sequestration (Sunderland & Rowland, 2019).

7. CONCLUSION

Agroforestry emerges as a sustainable land-use system with the potential to enhance agricultural resilience, improve rural livelihoods, and mitigate climate change. By integrating trees with crops and livestock, agroforestry provides multiple socio-economic and ecological benefits, including diversified income, food security, carbon sequestration, and ecosystem restoration. However, widespread adoption faces challenges such as socio-cultural resistance, limited policy support, high initial costs, and competition for resources. Addressing these barriers requires coordinated efforts from governments, NGOs, researchers, and local communities to provide adequate training, financial incentives, and supportive policies. Future strategies should focus on scaling up agroforestry practices, investing in research, and integrating agroforestry into national climate action plans. By leveraging agroforestry, countries can progress toward achieving the Sustainable Development Goals, enhancing food security, and building climate-resilient agricultural landscapes for a sustainable future.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Acharya, A. K., & Kafle, N. (2009). Land degradation issues in Nepal and its management through agroforestry. *Journal of Agriculture and Environment, 10*, 133–143.

Aili, A., Hailiang, X., Waheed, A., Bakayisire, F., & Yingying, X. (2024). Synergistic windbreak efficiency of desert vegetation and oasis shelter forests. *PLOS ONE, 19*(10), e0312876.

Altieri, M. A., Nicholls, C. I., Henao, A., & Lana, M. A. (2015). Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development, 35*(3), 869–890.

Amare, D., Wondie, M., Mekuria, W., & Darr, D. (2019). Agroforestry of smallholder farmers in Ethiopia: Practices and benefits. *Small-scale Forestry, 18,* 39-56.

Awazi, N. P., & Tchamba, N. M. (2019). Enhancing agricultural sustainability and productivity under changing climate conditions through improved agroforestry practices in smallholder farming systems in sub-Saharan Africa. *African Journal of Agricultural Research, 14*(7), 379-388.

B Teli, S. (2023). Millet-based agroforestry: A nature-positive farming to achieve climate-resilience and food security in India and Africa.

Benjamin, E. O., & Sauer, J. (2018). The cost-effectiveness of payments for ecosystem services: Smallholders and agroforestry in Africa. *Land Use Policy, 71*, 293–302.

Bisseleua, D. H. B., Missoup, A. D., & Vidal, S. (2009). Biodiversity conservation, ecosystem functioning, and economic incentives under cocoa agroforestry intensification. *Conservation Biology, 23*(5), 1176-1184.

Bryan, E., Akpalu, W., Yesuf, M., & Ringler, C. (2010). Global carbon markets: Opportunities for sub-Saharan Africa in agriculture and forestry. *Climate and Development, 2*(4), 309-331.

Bukenya, M., Bbale, W., & Buyinza, M. (2008). Assessment of the effectiveness of individual and group extension methods: A case study of Vi-Agroforestry Project in Uganda.

Clottey, V., Wairegi, L. W. I., Bationo, B. A., Mando, A., & Kanton, R. (2015). Sorghum- and millet-legume cropping systems.

Dagar, J. C., Ghosh, P. K., Mohanta, S. K., Singh, J. B., Vijay, D., & Kumar, R. V. (2017). Potentials for fodder production in degraded lands. In *Approaches towards fodder security in India* (pp. 333-364). New Delhi: Studera Press.

Dagar, J. C., Sileshi, G. W., & Akinnifesi, F. K. (2020). Agroforestry to enhance livelihood security in Africa: Research trends and emerging challenges. *Agroforestry for Degraded Landscapes: Recent Advances and Emerging Challenges-Vol. 1,* 71–134.

Dawson, I. K., Lengkeek, A., Weber, J. C., & Jamnadass, R. (2009). Managing genetic variation in tropical trees: Linking knowledge with action in agroforestry ecosystems for improved conservation and enhanced livelihoods. *Biodiversity and Conservation, 18,* 969-986.

Ekhuya, N. A. (2013). *Influence of trees on soil characteristics and maize productivity in small holder farms of western Kenya* (Doctoral dissertation, Jomo Kenyatta University of Agriculture and Technology).

Fahad, S., Chavan, S. B., Chichaghare, A. R., Uthappa, A. R., Kumar, M., Kakade, V., ... & Poczai, P. (2022). Agroforestry systems for soil health improvement and maintenance. *Sustainability, 14*(22), 14877.

Fahad, S., Chavan, S. B., Chichaghare, A. R., Uthappa, A. R., Kumar, M., Kakade, V., ... & Poczai, P. (2022). Agroforestry systems for soil health improvement and maintenance. *Sustainability, 14*(22), 14877.

Gil, J. D., Cohn, A. S., Duncan, J., Newton, P., & Vermeulen, S. (2017). The resilience of integrated agricultural systems to climate change. *Wiley Interdisciplinary Reviews: Climate Change, 8*(4), e461.

Gupta, S. R., Dagar, J. C., & Teketay, D. (2020). Agroforestry for rehabilitation of degraded landscapes: Achieving livelihood and environmental security. In *Agroforestry for Degraded Landscapes: Recent Advances and Emerging Challenges. 1*, 23-68.

Gyau, A., Franzel, S., Chiatoh, M., Nimino, G., & Owusu, K. (2014). Collective action to improve market access for smallholder producers of agroforestry products: Key lessons learned with insights from Cameroon's experience. *Current Opinion in Environmental Sustainability, 6*, 68–72.

Hossain, A., Krupnik, T. J., Timsina, J., Mahboob, M. G., Chaki, A. K., Farooq, M., ... & Hasanuzzaman, M. (2020). Agricultural land degradation: Processes and problems undermining future food security. In *Environment, climate, plant and vegetation growth* (pp. 17-61). Cham: Springer International Publishing.

Isenring, R. (2010). *Pesticides and the loss of biodiversity*. Pesticide Action Network Europe, *London*, *26*.

Jacobs, S. R., Webber, H., Niether, W., Grahmann, K., Lüttschwager, D., Schwartz, C., ... & Bellingrath-Kimura, S. D. (2022). Modification of the microclimate and water balance through the integration of trees into temperate cropping systems. *Agricultural and Forest Meteorology, 323,* 109065.

Jarrett, C., Cummins, I., & Logan-Hines, E. (2017). Adapting indigenous agroforestry systems for integrative landscape management and sustainable supply chain development in Napo, Ecuador. In *Integrating Landscapes: Agroforestry for Biodiversity Conservation and Food Sovereignty* (pp. 283–309).

Jerneck, A., & Olsson, L. (2013). More than trees! Understanding the agroforestry adoption gap in subsistence agriculture: Insights from narrative walks in Kenya. *Journal of Rural Studies, 32*, 114–125.

Kaushal, R., Mandal, D., Panwar, P., Kumar, P., Tomar, J. M. S., & Mehta, H. (2021). Soil and water conservation benefits of agroforestry. In *Forest Resources Resilience and Conflicts* (pp. 259–275). Elsevier.

Kiptot, E., & Franzel, S. (2012). Gender and agroforestry in Africa: A review of women's participation. *Agroforestry Systems, 84*, 35–58.

Lebrazi, S., & Fikri-Benbrahim, K. (2022). Potential of tree legumes in agroforestry systems and soil conservation. In *Advances in Legumes for Sustainable Intensification* (pp. 461–482). Academic Press.

Monteiro, A., Barreto-Mendes, L., Fanchone, A., Morgavi, D. P., Pedreira, B. C., Magalhães, C. A., ... & Eugène, M. (2024). Crop-livestock-forestry systems as a strategy for mitigating greenhouse gas emissions and enhancing the sustainability of forage-based livestock systems in the Amazon biome. *Science of the Total Environment, 906,* 167396.

Mosquera-Losada, M. R., McAdam, J. H., Romero-Franco, R., Santiago-Freijanes, J. J., & Rigueiro-Rodróguez, A. (2009). Definitions and components of agroforestry practices in Europe. *Agroforestry in Europe: Current Status and Future Prospects,* 3–19.

Neupane, D., Adhikari, P., Bhattarai, D., Rana, B., Ahmed, Z., Sharma, U., & Adhikari, D. (2022). Does climate change affect the yield of the top three cereals and food security in the world? *Earth, 3*(1), 45-71.

Nyaga, J., Barrios, E., Muthuri, C. W., Öborn, I., Matiru, V., & Sinclair, F. L. (2015). Evaluating factors influencing heterogeneity in agroforestry adoption and practices within smallholder farms in Rift Valley, Kenya. *Agriculture, Ecosystems & Environment, 212,* 106-118.

Ogol, C. K., Spence, J. R., & Keddie, A. (1999). Maize stem borer colonization, establishment, and crop damage levels in a maize-leucaena agroforestry system in Kenya. *Agriculture, Ecosystems & Environment, 76*(1), 1–15.

Omoyo, N. N., Wakhungu, J., & Oteng'i, S. (2015). Effects of climate variability on maize yield in the arid and semi-arid lands of lower eastern Kenya. *Agriculture & Food Security, 4*, 1–13.

Ortiz, J., Neira, P., Panichini, M., Curaqueo, G., Stolpe, N. B., Zagal, E., ... & Gupta, S. R. (2023). Silvopastoral systems on degraded lands for soil carbon sequestration and climate change mitigation. In *Agroforestry for Sustainable Intensification of Agriculture in Asia and Africa* (pp. 207-242).

Owuor, S. O., Butterbach-Bahl, K., Guzha, A. C., Rufino, M. C., Pelster, D. E., Díaz-Pinés, E., & Breuer, L. (2016). Groundwater recharge rates and surface runoff response to land use and land cover changes in semi-arid environments. *Ecological Processes, 5,* 1-21.

Paracchini, M. L., Justes, E., Wezel, A., Zingari, P. C., Kahane, R., Madsen, S., ... & Nègre, T. (2020). Agroecological practices supporting food production and reducing food insecurity in developing countries: A study on scientific literature in 17 countries.

Pent, G. J., Fike, J. H., Orefice, J. N., Sharrow, S. H., Brauer, D., & Clason, T. R. (2021). Silvopasture practices. In *North American Agroforestry* (pp. 127-162).

Peyre, A., Guidal, A., Wiersum, K. F., & Bongers, F. J. J. M. (2006). Dynamics of homegarden structure and function in Kerala, India. *Agroforestry Systems, 66,* 101-115.

Phimmavong, S., Maraseni, T. N., Keenan, R. J., & Cockfield, G. (2019). Financial returns from collaborative investment models of *Eucalyptus* agroforestry plantations in Lao PDR. *Land Use Policy, 87*, 104060.

Place, F., Ajayi, O. C., Torquebiau, E., Detlefsen Rivera, G., Gauthier, M., & Buttoud, G. (2013). Improved policies for facilitating the adoption of agroforestry. *Programa Agroambiental Mesoamericano (MAP), Fase I.*

Pretty, J. N., & Shah, P. (1997). Making soil and water conservation sustainable: From coercion and control to partnerships and participation. *Land Degradation & Development, 8*(1), 39–58.

Rivera, J. E., Villegas, G. O., Serna, L. P., & Chará, J. (2023). Cattle intensification based on silvopastoral systems with *Leucaena leucocephala* (Lam.) de Wit as a strategy to increase cattle production and mitigate greenhouse gas emissions in the Caribbean region of Colombia.

Sereke, F., Dobricki, M., Wilkes, J., Kaeser, A., Graves, A. R., Szerencsits, E., & Herzog, F. (2016). Swiss farmers don't adopt agroforestry because they fear for their reputation. *Agroforestry Systems, 90*, 385–394.

Sileshi, G. W., Akinnifesi, F. K., Mafongoya, P. L., Kuntashula, E., & Ajayi, O. C. (2020). Potential of *Gliricidia*-based agroforestry systems for resource-limited agro-ecosystems. In *Agroforestry for Degraded Landscapes: Recent Advances and Emerging Challenges-Vol. 1* (pp. 255-282).

Sileshi, G. W., Mafongoya, P. L., & Nath, A. J. (2020). Agroforestry systems for improving nutrient recycling and soil fertility on degraded lands. In *Agroforestry for Degraded Landscapes: Recent Advances and Emerging Challenges-Vol. 1* (pp. 225-253).

Sultana, R., & Bari, M. S. (2021). Livelihood improvement of farmers through agroforestry practices in Teesta and Jamuna River Basins. *AJRAF, 7*, 10–27.

Sunderland, T. C., & Rowland, D. (2019). Forests, land use, and challenges to climate stability and food security. In *Sustainable Food and Agriculture* (pp. 95–116). Academic Press.

Torralba, M., Fagerholm, N., Burgess, P. J., Moreno, G., & Plieninger, T. (2016). Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. *Agriculture, Ecosystems & Environment, 230*, 150–161.

Udawatta, R. P., Walter, D., & Jose, S. (2022). Carbon sequestration by forests and agroforests: A reality check for the United States. *Carbon Footprints, 1*(8).

Wanjira, E. O., & Muriuki, J. (2020). Review of the status of agroforestry practices in Kenya. *Background Study for Preparation of Kenya National Agroforestry Strategy (2021-2030).*

Wijerathna-Yapa, A., & Pathirana, R. (2022). Sustainable agro-food systems for addressing climate change and food security. *Agriculture, 12*(10), 1554.

Wunder, S., & Wertz-Kanounnikoff, S. (2009). Payments for ecosystem services: A new way of conserving biodiversity in forests. *Journal of Sustainable Forestry, 28*(3–5), 576–596.

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