**Agroforestry Systems for Enhancing Biodiversity and Soil Conservation in Agricultural Landscapes**

**Abstract**

Agroforestry is an integrative land-use system that enhances biodiversity, improves soil conservation, and mitigates climate change while sustaining agricultural productivity. By strategically combining trees, crops, and livestock, agroforestry systems provide critical ecosystem services, including carbon sequestration, nutrient cycling, soil stabilization, and water retention. Research indicates that agroforestry can increase soil organic carbon by 20–40%, reduce erosion by up to 80%, and enhance species richness by 50% compared to conventional agriculture. These systems also support pollinators, beneficial insects, and endangered species by creating ecological corridors and microhabitats. Despite its proven benefits, widespread adoption faces several challenges, including high initial investment costs, **resource competition**, land tenure insecurity, and a lack of policy incentives. Socioeconomic constraints such as limited access to credit and extension services further hinder implementation, particularly among smallholder farmers. Technical limitations include complex management requirements, potential pest interactions, and variability in system performance across different agroecological zones. To overcome these barriers, targeted policy interventions, financial incentives such as payments for ecosystem services, and farmer education programs are needed. Recent innovations in precision agroforestry, digital technologies, and climate-smart approaches offer promising avenues for optimizing agroforestry systems while increasing resilience to climate change. Scaling up adoption requires a multidisciplinary approach **integrating**scientific research, policy support, and community-driven initiatives to enhance global food systems while preserving natural ecosystems.

**Keywords:** *Agroforestry, Biodiversity, Soil Conservation, Carbon Sequestration, Sustainable Agriculture, Ecosystem Services*

**I. Introduction**

**A. Importance of Agroforestry**

***1. Agroforestry***

Agroforestry is a land management approach that deliberately integrates trees, crops, and livestock within the same land unit to optimize productivity, ecological balance, and sustainability (Keprate *etal.,* 2024). This practice combines the ecological benefits of forests with the productive benefits of agriculture, promoting diversified land use while maintaining environmental integrity. The Food and Agriculture Organization defines agroforestry as a "dynamic, ecologically based natural resource management system that diversifies and sustains production for increased social, economic, and environmental benefits." Agroforestry is not merely about planting trees on farms but involves strategic planning to create synergies between different components for enhanced ecosystem services (Torralba et al., 2016).

***2. Historical context and evolution of agroforestry practices***

Traditional agroforestry practices have existed for centuries, particularly in regions with long-standing agricultural traditions (Puri *et al.,* 2004). Ancient civilizations, such as those in Mesopotamia, Africa, and Mesoamerica, employed tree-based farming techniques to improve soil fertility, provide shade, and ensure sustainable yields. The earliest recorded examples of agroforestry systems include home gardens in Southeast Asia, the taungya system developed in Myanmar during British colonial rule, and shifting cultivation practices observed across tropical landscapes. Modern agroforestry gained recognition as a scientific discipline in the late 20th century, particularly after the establishment of the International Council for Research in Agroforestry (ICRAF), now known as the World Agroforestry Centre. Since then, extensive research has demonstrated that agroforestry systems enhance biodiversity, improve soil health, and mitigate climate change. Policies promoting agroforestry as a sustainable land-use practice have been increasingly integrated into national and international conservation strategies (Jose *et al.,* 2021). The agricultural systems based on monoculture are deemed to be more vulnerable compared to alternatives such as the cultivation of a mixture of crops and species, especially a mixture of trees and crops as in agroforestry (<https://climate-adapt.eea.europa.eu/es/metadata/case-studies/agroforestry-agriculture-of-the-future-the-case-of-montpellier>).

***3. Role of agroforestry in sustainable agriculture***

Sustainable agriculture aims to balance productivity with ecological health while ensuring food security for present and future generations. Agroforestry contributes significantly to sustainable agriculture by enhancing biodiversity, reducing soil erosion, improving soil fertility, and increasing carbon sequestration. Trees in agroforestry systems support beneficial organisms, including pollinators and natural pest predators, fostering a more resilient farming environment. Agroforestry also plays a crucial role in climate adaptation, as trees act as windbreaks, reducing crop damage, and their deep-root systems enhance soil water retention, minimizing drought stress. Research indicates that integrating trees with crops and livestock can increase overall land productivity by 30–50% compared to monoculture farming. Additionally, agroforestry reduces dependence on synthetic fertilizers and pesticides by naturally cycling nutrients and suppressing pests through ecological interactions (Zhu et al., 2020).

**B. Rationale for Agroforestry in Agricultural Landscapes**

***1. Challenges in conventional agriculture (e.g., biodiversity loss, soil degradation)***

Modern agricultural intensification, characterized by monoculture cropping and heavy reliance on chemical inputs, has led to severe biodiversity loss and environmental degradation (Crews *et al.,* 2018). Studies indicate that global agricultural expansion is responsible for approximately 80% of deforestation, threatening habitats and reducing genetic diversity. Pollinator populations, essential for crop productivity, have declined by nearly 40% due to habitat destruction and pesticide overuse. Soil degradation is another major concern, as conventional farming practices lead to increased soil erosion, nutrient depletion, and reduced microbial diversity. Globally, about 33% of land is moderately to highly degraded due to erosion, salinization, compaction, and chemical contamination. Intensive tillage disrupts soil structure, exacerbating carbon loss and reducing water retention capacity, making agricultural landscapes more vulnerable to climate extremes (Hussain *et.al.,* 2021).

***2. Need for sustainable alternatives***

Addressing the negative impacts of conventional agriculture requires a shift toward sustainable land-use systems that integrate ecological principles with food production. Agroforestry offers a viable solution by restoring ecosystem services, improving soil quality, and fostering biodiversity conservation while maintaining agricultural productivity (Fahad et al., 2022). The incorporation of trees into farming landscapes helps stabilize ecosystems, enhance nutrient cycling, and provide additional sources of income through non-timber forest products (Shanley *et al.,* 2015). Evidence suggests that agroforestry systems can significantly reduce soil erosion, with tree-based farming reducing topsoil loss by up to 75% compared to open-field agriculture. Additionally, agroforestry supports sustainable livelihoods by diversifying income sources, reducing economic vulnerability to market fluctuations, and providing ecosystem-based adaptation to climate change.

***3. Agroforestry as a multifunctional approach***

Agroforestry operates as a multifunctional land-use system, simultaneously delivering environmental, economic, and social benefits. Research highlights that agroforestry landscapes harbour up to 50% more biodiversity than monoculture farms, supporting a range of beneficial species, including birds, insects, and soil microorganisms. These landscapes act as ecological corridors, connecting fragmented habitats and promoting species movement, which is critical for genetic diversity and ecosystem resilience (Christie *et al.,* 2015). Soil conservation benefits of agroforestry extend beyond erosion control; the addition of organic matter through leaf litter and root biomass improves soil structure, enhances microbial activity, and boosts nutrient availability. Furthermore, agroforestry contributes to carbon sequestration, with studies estimating that well-managed agroforestry systems can sequester 0.29–15.21 Mg C ha⁻¹ year⁻¹, making them an effective strategy for mitigating climate change. From an economic perspective, agroforestry enhances farm resilience by providing diversified income streams through timber, fodder, fruits, nuts, and medicinal plants. Farmers practicing agroforestry report higher long-term economic stability due to reduced dependency on external agricultural inputs and improved land productivity.

**C. Objectives of the Review**

***1*. To explore the role of agroforestry in biodiversity enhancement**

Biodiversity is a key component of ecosystem stability and agricultural sustainability. This review aims to examine how agroforestry contributes to biodiversity conservation by providing habitat, food resources, and ecological connectivity for various species. It will assess how different agroforestry systems influence species richness, abundance, and ecosystem functionality compared to conventional agricultural landscapes.

**2. To examine agroforestry’s impact on soil conservation**

Soil health is fundamental to agricultural productivity and environmental sustainability (Kibblewhite *et al.,* 2008). This review will analyse the role of agroforestry in preventing soil degradation through erosion control, organic matter enrichment, and enhanced soil microbial activity. It will present empirical evidence from different agroforestry systems to highlight their effectiveness in improving soil quality and long-term land productivity.

**3. To identify research gaps and future directions**

Despite the recognized benefits of agroforestry, knowledge gaps remain regarding the optimization of system designs, species selection, and long-term ecological impacts. This review seeks to identify critical research needs, including the development of region-specific agroforestry models, the integration of advanced technologies for monitoring ecosystem services, and policy frameworks for large-scale adoption. By addressing these gaps, the review aims to provide insights for future agroforestry research and implementation strategies (Quandt *et al.,* 2023).

**II. Agroforestry Systems and Their Classification**

**A. Agroforestry systems**

**1. Structural and functional diversity**

Agroforestry systems are characterized by their structural and functional diversity, which distinguishes them from conventional agricultural and forestry systems. Structurally, agroforestry integrates multiple plant species, including trees, shrubs, and herbaceous crops, along with livestock in some cases, creating a vertically stratified ecosystem that mimic natural forests. This stratification increases resource-use efficiency by allowing different plants to utilize light, water, and nutrients at various soil depths and canopy layers. Functionally, agroforestry systems provide a range of ecological services, including biodiversity conservation, carbon sequestration, soil erosion control, and microclimate regulation. These systems enhance ecosystem stability by fostering interactions between different organisms, improving nutrient cycling, and increasing resilience to environmental disturbances. Studies have shown that well-managed agroforestry systems can support up to 50% more biodiversity compared to conventional agricultural fields.

**2. Classification based on components and ecological functions**

Agroforestry systems can be classified based on their components, interactions, and ecological functions (Nair *et al.,* 2021). The primary classification includes:

* **Structural classification:** Agroforestry systems are categorized based on the presence of trees, crops, and livestock. These include agrosilvicultural (crops + trees), silvopastoral (livestock + trees), and agrosilvopastoral (crops + trees + livestock) systems.
* **Functional classification:** Systems are divided based on their primary ecological roles, such as soil conservation, biodiversity enhancement, or microclimate modification.
* **Ecological classification:** Agroforestry systems are tailored to different ecological zones, including humid tropics, semi-arid regions, and temperate landscapes (Mahmud *et al.,* 2021).

**B. Major Types of Agroforestry Systems**

**1. Agrosilvicultural Systems (Crops + Trees)**

Agrosilvicultural systems integrate crops with trees to optimize land productivity while improving soil health and microclimate conditions. These systems provide multiple benefits, including enhanced biodiversity, carbon sequestration, and improved water retention.

***Alley cropping***

Alley cropping involves planting rows of trees or shrubs alongside annual crops to reduce soil erosion, increase organic matter, and enhance nutrient cycling (Garrett *et.al.,* 2021). Research has demonstrated that alley cropping can increase soil organic carbon by 15–20% over a period of 10–15 years. This system also promotes biological pest control by providing habitat for beneficial insects and birds.

***Windbreaks and shelterbelts***

Windbreaks and shelterbelts consist of strategically planted trees and shrubs along field edges to reduce wind speed, protect crops from desiccation, and minimize soil erosion. These systems have been found to increase crop yields by 10–25% in wind-prone regions by improving microclimatic conditions and reducing evapotranspiration losses. Studies have also indicated that windbreaks enhance soil organic matter and microbial activity by reducing soil erosion and increasing litter decomposition.

***Taungya system***

The taungya system is a traditional agroforestry practice where crops are cultivated in the early stages of forest plantation establishment, allowing farmers to benefit from short-term agricultural yields while trees mature (Nair *et al.,* 2021). This system is widely practiced in tropical regions and has been credited with enhancing soil fertility, reducing deforestation pressure, and improving land-use efficiency. A long-term study showed that taungya systems improve soil organic matter by 30–50% over two decades.

***2.* Silvopastoral Systems (Livestock + Trees)**

Silvopastoral systems integrate trees, pasture, and livestock in a way that optimizes forage production while maintaining ecological sustainability. These systems contribute to carbon sequestration, biodiversity conservation, and improved animal welfare by providing shade and forage.

***Silvopasture***

Silvopasture combines trees with grazing pastures to enhance livestock productivity and improve ecosystem resilience. Studies have shown that silvopastoral systems can reduce heat stress in livestock, leading to increased milk production in dairy cows by up to 20% in warm climates (Deniz *et.al.,* 2023). These systems also improve soil health by enhancing nutrient cycling and reducing compaction from grazing animals.

***Fodder banks***

Fodder banks involve the planting of leguminous trees and shrubs to provide high-quality feed for livestock, reducing dependence on external feed sources. Research indicates that well-managed fodder banks can improve livestock weight gain by 15–30% while enhancing soil fertility through nitrogen fixation.

***Home gardens with livestock integration***

Home gardens incorporating livestock create multifunctional landscapes that provide food, fodder, and fuel while maintaining ecological balance (Galhena *et al.,* 2013). These systems contribute to household food security and improve waste recycling by integrating animal manure into soil nutrient management practices. A study found that home gardens with livestock integration increase farm productivity by up to 40% compared to conventional monocultures.

**3. Agrosilvopastoral Systems (Crops + Livestock + Trees)**

Agrosilvopastoral systems represent the most integrated form of agroforestry, combining crops, livestock, and trees to create a self-sustaining farming system (Chappa *etal.,* 2024). These systems enhance nutrient cycling, improve farm resilience, and maximize land productivity.

***Integrated land-use systems***

Integrated land-use systems strategically combine crop cultivation, livestock rearing, and tree planting to create diversified farming landscapes that optimize land and resource use. Research has shown that such systems increase overall farm productivity by 30–50% compared to conventional monoculture farming.

***Multi-strata systems***

Multi-strata agroforestry systems mimic natural forests by incorporating multiple vertical layers of vegetation, including canopy trees, understory shrubs, and ground crops. These systems enhance biodiversity conservation, improve soil moisture retention, and provide year-round harvests of different products. Long-term studies indicate that multi-strata agroforestry can sequester up to 15.21 Mg C ha⁻¹ year⁻¹, making it an effective strategy for climate change mitigation.

**4. Other Agroforestry Practices**

***Riparian buffer strips***

Riparian buffer strips involve planting trees and vegetation along waterways to reduce soil erosion, filter agricultural runoff, and enhance biodiversity (Cole *et al.,* 2020). Studies have demonstrated that riparian buffers can reduce nitrogen runoff by up to 90% and sedimentation by 75%, significantly improving water quality in agricultural landscapes.

***Forest farming***

Forest farming integrates understory crops such as medicinal plants, mushrooms, and shade-tolerant vegetables within managed forested areas. This practice supports biodiversity conservation while providing economic benefits through non-timber forest products. Research suggests that forest farming can enhance farm incomes by 25–50% in regions with high-value medicinal plant markets.

**III. Agroforestry and Biodiversity Enhancement**

**A. Role of Agroforestry in Enhancing Biodiversity**

***1. Increased habitat diversity for flora and fauna***

Agroforestry creates heterogeneous landscapes that support a wide range of plant and animal species by integrating trees, shrubs, and herbaceous crops within agricultural systems (Udawatta *et al.,* 2019). This structural complexity increases vertical and horizontal habitat diversity, providing food, shelter, and breeding sites for diverse taxa. Studies indicate that agroforestry landscapes can support 50–80% of the biodiversity found in natural forests, making them crucial for conservation efforts in human-dominated ecosystems. Tree-based farming systems contribute to habitat restoration by providing microhabitats that are absent in monoculture farms. The presence of multiple vegetation layers attracts a variety of bird, insect, and mammal species, improving overall species richness. A study in Central America found that silvopastoral landscapes contained 30% more bird species compared to conventional pastures. Agroforestry also supports soil-dwelling organisms such as earthworms and beneficial microbes, which enhance nutrient cycling and soil structure (Singh *et al.,* 2024).

***2. Agroforestry as a refuge for pollinators and beneficial insects***

Declining pollinator populations pose a significant threat to global food security, as over 75% of leading food crops depend on pollination services. Agroforestry provides diverse floral resources and nesting sites, supporting pollinator diversity and abundance throughout the year. Research in tropical cacao agroforestry systems found that pollinator diversity was 40% higher compared to monoculture plantations, leading to increased fruit set and yield. Agroforestry also enhances natural pest control by attracting predatory insects, birds, and bats that help regulate pest populations. Studies show that shade-grown coffee agroforestry systems harbour significantly higher populations of insectivorous birds, reducing coffee borer beetle infestations by up to 50%. Similarly, windbreaks and hedgerows support spider and beetle species that predate on crop pests, reducing reliance on chemical pesticides.

**3. Impact on genetic diversity and conservation of native species**

The integration of native tree species in agroforestry systems plays a vital role in preserving genetic diversity and protecting rare plant varieties. Traditional agroforestry practices often incorporate locally adapted tree species that provide food, medicine, and timber while maintaining genetic reservoirs for future breeding programs (Dawson *et.al.,* 2013). Forest farming systems, which cultivate understory crops beneath a tree canopy, contribute to the conservation of shade-tolerant species such as medicinal plants, fungi, and orchids. Studies in the Amazon demonstrate that traditional agroforestry systems contain up to 200 plant species per hectare, preserving genetic resources that might otherwise be lost due to deforestation.

**B. Comparative Analysis: Agroforestry vs. Conventional Agriculture**

***1. Species richness and ecosystem services***

Conventional monoculture farming reduces species richness by simplifying landscapes, eliminating natural habitats, and increasing pesticide use. Agroforestry counteracts biodiversity loss by incorporating trees and perennials, which provide food, shelter, and microhabitats for various organisms (Cheruto *et.al.,* 2025). Studies have shown that agroforestry systems can support up to 70% more bird species than conventional farms, contributing to improved pest regulation and seed dispersal. Similarly, the presence of leguminous trees in agroforestry systems enhances soil microbial diversity, leading to better nutrient cycling and soil fertility.

***2. Landscape connectivity and ecological corridors***

Habitat fragmentation is a leading cause of biodiversity decline, as isolated patches disrupt migration routes and genetic exchange among wildlife populations (Lino *et.al.,* 2019). Agroforestry creates ecological corridors by connecting forest remnants, allowing species to move between habitats and maintain viable populations. A study in Costa Rica found that shade coffee plantations function as biodiversity corridors, enabling the movement of pollinators and seed-dispersing animals across fragmented landscapes. Similarly, silvopastoral systems in Latin America have been shown to enhance mammal diversity by providing alternative habitats for species that would otherwise be restricted to forests.

***3. Contribution to the conservation of endangered species***

Agroforestry provides critical habitat for endangered species by preserving native vegetation and reducing deforestation pressures. Research in the Atlantic Forest of Brazil found that agroforestry systems supported higher populations of endemic and threatened bird species compared to conventional farmlands. The use of agroforestry in cocoa and coffee production has helped conserve habitat for species such as the jaguar (*Panthera onca*), which relies on connected forest patches for hunting and migration. Similarly, agroforestry buffer zones around protected areas enhance conservation efforts by creating semi-natural landscapes that support species survival outside of reserves.

**C. Case Studies and Empirical Evidence**

***1. Agroforestry systems in tropical regions***

Tropical agroforestry systems contribute significantly to biodiversity conservation by maintaining diverse vegetation structures and ecological functions. A long-term study in Indonesia’s cacao agroforests found that bird and insect diversity was comparable to that of primary forests, highlighting the potential of agroforestry as a conservation strategy (Zakariya *etal.,* 2024). In the Amazon basin, traditional indigenous agroforestry systems sustain high biodiversity levels by integrating fruit trees, timber species, and medicinal plants into shifting cultivation practices. These systems support local livelihoods while preventing large-scale deforestation and habitat loss.

***2. Agroforestry’s role in temperate landscapes***

Temperate agroforestry systems, including hedgerows, windbreaks, and alley cropping, provide essential ecosystem services such as soil conservation, carbon sequestration, and biodiversity enhancement. Research in the United Kingdom demonstrated that farm hedgerows support over 1,500 insect species, including pollinators and natural pest predators. Studies in North America show that alley cropping with walnut and pecan trees increases bird diversity while improving soil health through organic matter accumulation (Tsonkova *et al.,* 2012). Riparian buffer strips in temperate agricultural landscapes enhance aquatic biodiversity by reducing sedimentation and nutrient runoff into water bodies. The socioeconomic changes of the twentieth century radically changed the landscapes and caused the abandonment of almost all previous agroforestry and silvopastoral practices. Currently, there are new opportunities for the implementation of mixed systems, in which the crop-trees will be orientated to have a socioeconomic impact and environmental benefits. Some initiatives in Europe are now looking for developments of this type (Rubio Torres, 2011).

***3. Success stories from different agroecological zones***

The implementation of agroforestry projects has yielded positive biodiversity outcomes across diverse ecosystems. In Africa, the *Faidherbia albida*-based agroforestry system has improved soil fertility, increased crop yields, and provided habitat for bird and insect species. A silvopastoral project in Colombia demonstrated that incorporating native trees into livestock systems increased butterfly and bird diversity while improving carbon sequestration. In Southeast Asia, rubber agroforestry systems have been shown to maintain high levels of amphibian and reptile diversity, surpassing conventional rubber monocultures in ecological value.

**IV. Agroforestry and Soil Conservation**

**A. Mechanisms of Soil Conservation in Agroforestry**

***1. Reduction of soil erosion through tree covers and root systems***

Soil erosion is a major environmental challenge, particularly in agricultural landscapes with intensive tillage and monoculture cropping (Crews *et al.,* 2018). Agroforestry plays a crucial role in controlling soil erosion by stabilizing the soil surface with tree roots and reducing the impact of raindrops through canopy interception. Studies have shown that tree-based systems can reduce soil erosion by 50–80% compared to conventional farming practices. Tree roots act as natural soil binders, preventing surface runoff from washing away topsoil. Deep-rooted species such as *Faidherbia albida* and *Gliricidia sepium* penetrate multiple soil layers, enhancing soil stability and reducing landslide risks in sloped landscapes. Research from Central America has demonstrated that agroforestry practices, particularly contour hedgerows, can decrease soil loss from 140 tons per hectare per year in open fields to less than 10 tons per hectare per year in tree-integrated systems. Agroforestry also minimizes wind erosion by acting as a natural windbreak. Trees and shrubs planted in shelterbelts slow wind speeds, protecting soil particles from being carried away. In arid and semi-arid regions, windbreaks have been found to reduce wind velocity by up to 60%, significantly decreasing the rate of topsoil loss.

***2. Enhancement of soil organic matter and microbial diversity***

Soil organic matter (SOM) is a key indicator of soil health, influencing nutrient availability, water retention, and microbial activity (Weil *et.al.,* 2004). Agroforestry systems contribute to the buildup of SOM by increasing litter deposition, root turnover, and decomposition rates. Research indicates that soils under agroforestry accumulate 20–30% more organic matter compared to those under conventional agriculture. Microbial diversity in agroforestry soils is significantly higher than in monoculture systems due to the presence of varied plant species, which support diverse microbial communities. Mycorrhizal fungi, which form symbiotic relationships with tree roots, enhance phosphorus uptake and improve plant resilience to drought and pests. Studies in tropical agroforestry systems have found that soil microbial biomass carbon is 40–50% higher than in monoculture farms, leading to improved nutrient cycling.

***3. Water retention and reduced runoff***

Water conservation is a critical aspect of sustainable agriculture, particularly in regions prone to drought and erratic rainfall (Rastogi *et al.,* 2024). Agroforestry improves soil water retention by enhancing infiltration rates, reducing runoff, and increasing the soil’s capacity to hold moisture. Tree roots create macropores in the soil, allowing water to percolate deeper and reducing surface water loss. Research has shown that agroforestry systems can improve soil infiltration rates by 25–60% compared to conventional cropping systems. A study in sub-Saharan Africa found that integrating *Faidherbia albida* into cropping systems increased soil moisture content by 15–20% during the dry season, extending the growing period for food crops. Agroforestry systems also reduce the risk of flash floods by slowing down surface water movement and decreasing peak runoff rates by up to 35%.

**B. Agroforestry’s Role in Soil Fertility Improvement**

***1. Nitrogen fixation through leguminous trees***

Nitrogen is one of the most critical nutrients for plant growth, yet it is often depleted in agricultural soils due to continuous cropping and synthetic fertilizer dependency (Mulvaney *et al.,* 2009). Agroforestry mitigates nitrogen depletion by incorporating leguminous trees such as *Acacia*, *Gliricidia sepium*, and *Leucaena leucocephala*, which fix atmospheric nitrogen through symbiotic relationships with Rhizobia bacteria. Research has shown that nitrogen-fixing trees in agroforestry systems can contribute between 30 and 250 kg of nitrogen per hectare annually, significantly reducing the need for synthetic fertilizers. A study in Malawi found that maize yields increased by 50–70% when intercropped with *Faidherbia albida*, a nitrogen-fixing species that sheds its leaves during the wet season, enriching the soil with organic nitrogen.

***2. Nutrient cycling and reduced dependence on chemical fertilizers***

Agroforestry enhances nutrient cycling by promoting deeper root penetration, which extracts nutrients from lower soil layers and redistributes them to the topsoil through leaf litter decomposition. Trees with deep root systems, such as *Sesbania sesban* and *Prosopis juliflora*, act as "nutrient pumps," mining phosphorus and potassium from subsoil layers and making them available for shallow-rooted crops. A long-term study in sub-Saharan Africa demonstrated that agroforestry-based farming reduced the need for chemical fertilizers by 40–60% while maintaining high crop yields. Agroforestry also prevents nutrient leaching, which is a common problem in conventional agriculture, particularly in areas with high rainfall.

***3. Prevention of soil compaction and improvement in soil structure***

Continuous ploughing and heavy machinery used in conventional agriculture often lead to soil compaction, reducing porosity and impeding root growth (Hamza *et al.,* 2005). Agroforestry mitigates soil compaction by maintaining permanent vegetation cover, reducing the frequency of mechanical disturbance, and enhancing root penetration. Research has shown that agroforestry practices improve soil aggregate stability, increasing water infiltration and reducing surface crust formation. A study in silvopastoral systems demonstrated that tree-covered areas had 30% higher soil porosity and lower bulk density compared to adjacent open pastures.

**C. Agroforestry for Climate Resilience and Carbon Sequestration**

***1. Role of trees in carbon sequestration***

Agroforestry systems contribute significantly to carbon sequestration by storing carbon in biomass and soil organic matter (Lorenz *et al.,* 2014). Studies estimate that well-managed agroforestry systems can sequester between 0.29 and 15.21 Mg C ha⁻¹ year⁻¹, depending on tree species, climate, and management practices.

***2. Mitigation of climate change impacts on soil degradation***

Soil degradation due to climate change is a growing concern, particularly in arid and semi-arid regions. Agroforestry helps mitigate these impacts by stabilizing soil, reducing temperature extremes, and maintaining moisture levels. A meta-analysis found that agroforestry reduced soil erosion by an average of 50% across various climatic zones.

***3. Adaptation strategies for farmers in vulnerable regions***

Farmers in regions prone to drought, floods, and soil degradation benefit from agroforestry as an adaptive strategy. Research in West Africa found that agroforestry-enhanced cropping systems increased farmers’ resilience to drought by improving soil moisture retention and nutrient availability (Kaushik *et al.,* 2020). Agroforestry also diversifies farm income by providing timber, fruits, and medicinal plants, reducing financial vulnerability to climate shocks.

**V. Challenges and Limitations of Agroforestry Implementation**

**A. Socioeconomic Barriers**

***1. High initial investment and slow return on investment***

Agroforestry requires substantial initial investments in tree seedlings, soil preparation, and infrastructure, which can be a major deterrent for small-scale farmers. Unlike conventional crops that provide returns within a single growing season, agroforestry systems take years to mature, delaying financial benefits. Studies indicate that tree-based farming systems require an investment period of 5–15 years before they start yielding significant economic returns. The delayed economic benefits make agroforestry less attractive compared to annual crops, particularly for farmers who rely on short-term income for their livelihoods (Current *et.al.,* 1985). Financial constraints further limit the ability of farmers to adopt agroforestry, as access to credit and microfinance remains insufficient in many regions. A study in Africa found that 70% of farmers cited high initial costs as the primary reason for not adopting agroforestry practices.

***2. Lack of awareness and extension services***

The successful adoption of agroforestry depends on farmers’ knowledge of its benefits and management practices. Many rural farmers have limited access to technical knowledge, making it difficult for them to transition from conventional farming systems to integrated tree-based agriculture. Research shows that in areas where agroforestry extension services are available, adoption rates increase by 40–60%. Despite the well-documented environmental and economic benefits, agroforestry education remains inadequate in agricultural extension programs. A survey conducted in sub-Saharan Africa revealed that only 30% of extension officers had received formal training in agroforestry, limiting their ability to guide farmers (Mwase *et al.,* 2015). Strengthening extension services and farmer-to-farmer knowledge-sharing networks is critical for increasing agroforestry adoption.

***3. Policy constraints and land tenure issues***

Unclear land tenure policies and insecure land rights discourage farmers from investing in long-term agroforestry systems. Tree-based farming requires long-term commitment, but in many regions, farmers do not own the land they cultivate, making them hesitant to plant trees that they may not benefit from in the future. Policies that prioritize monoculture and large-scale commercial farming over integrated farming systems further limit agroforestry adoption. A study in Southeast Asia found that rigid land-use classifications restricted farmers from legally integrating trees into agricultural lands, despite the known benefits of agroforestry. Revising land policies to recognize agroforestry as a legitimate land-use strategy can encourage wider implementation.

**B. Technical and Ecological Challenges**

***1. Competition for water, nutrients, and sunlight***

Agroforestry systems involve multiple plant species growing together, leading to competition for essential resources such as water, nutrients, and sunlight (Fahad *et al.,* 2022). Trees with extensive root systems may compete with crops for soil moisture, particularly in regions with low rainfall. Research shows that in semi-arid areas, agroforestry systems can reduce soil moisture availability for shallow-rooted crops by up to 30%. Competition for nutrients is another concern, especially when non-leguminous tree species are used. Some trees extract large amounts of nitrogen and phosphorus from the soil, potentially reducing the nutrient supply available for companion crops. Proper species selection and spacing are critical to mitigating these challenges. Studies suggest that integrating nitrogen-fixing trees such as *Gliricidia sepium* or *Faidherbia albida* can improve soil fertility while minimizing resource competition.

***2. Complexity in management and knowledge requirements***

Unlike monoculture farming, agroforestry requires knowledge of multiple plant species, their interactions, and long-term management strategies. Farmers must understand tree-crop-livestock interactions, pruning techniques, and optimal planting densities to maximize productivity while minimizing competition (Kuria *et al.,* 2014). Managing agroforestry plots can also be labor-intensive, requiring more effort in tree maintenance, harvesting, and processing of diversified products. A study in Latin America found that agroforestry farmers spent 20–30% more time on farm management compared to conventional farmers, which can discourage adoption among smallholders with limited labor resources.

***3. Risks associated with pests and diseases***

Agroforestry introduces multiple plant species into a single system, which can increase the risk of pest outbreaks if not properly managed (Altieri *et al.,* 2008). Certain tree species attract pests that can spill over to crops, affecting yields. For example, in cocoa agroforestry systems, shade trees can harbour fungal pathogens that reduce cocoa pod production. Conversely, agroforestry can also enhance biological pest control by increasing populations of natural predators such as birds, spiders, and predatory insects. Research indicates that well-designed agroforestry systems reduce the incidence of crop diseases by up to 30% due to improved microclimatic conditions and increased biodiversity.

**C. Strategies for Overcoming Challenges**

***1. Farmer education and capacity building***

Expanding farmer training programs and knowledge-sharing platforms is essential for overcoming technical barriers to agroforestry adoption. Extension services should incorporate agroforestry education into agricultural training, ensuring that farmers receive hands-on experience with tree-crop-livestock integration. Community-based training programs have proven effective in increasing agroforestry adoption. A study in Malawi found that peer-to-peer learning models increased the uptake of nitrogen-fixing trees by 60%, as farmers gained confidence in the benefits of the practice through demonstrations and shared experiences.

***2. Policy support and financial incentives***

Governments and international organizations can play a crucial role in promoting agroforestry through supportive policies and financial incentives (Place *et.al.,* 2012). Subsidies for tree seedlings, tax breaks for agroforestry practitioners, and payments for ecosystem services (PES) can encourage adoption among smallholder farmers. Successful policy interventions include Brazil’s Agroforestry Credit Program, which provides low-interest loans for farmers implementing tree-based agriculture. Similarly, Costa Rica’s PES scheme rewards farmers for maintaining agroforestry plots that contribute to carbon sequestration and biodiversity conservation.

***3. Integrating agroforestry into national and global conservation programs***

Recognizing agroforestry as a core strategy for achieving global environmental goals can facilitate widespread adoption. Agroforestry aligns with the objectives of international agreements such as the United Nations Convention on Biological Diversity (CBD) and the Paris Climate Agreement, making it a key solution for addressing deforestation, climate change, and land degradation. Agroforestry programs should be integrated into national reforestation initiatives and climate adaptation plans. The African Forest Landscape Restoration Initiative (AFR100) has already committed to restoring 100 million hectares of degraded land through agroforestry by 2030, demonstrating the scalability of tree-based systems in global conservation efforts.

**VI. Future Directions and Research Needs**

**A. Innovations in Agroforestry Practices**

***1. Precision agroforestry and digital technologies***

The integration of precision agriculture with agroforestry has the potential to revolutionize tree-based farming systems by optimizing resource use, enhancing productivity, and minimizing environmental impacts (Vinodhini *etal.,* 2023). Precision agroforestry employs remote sensing, Geographic Information Systems (GIS), drones, and artificial intelligence (AI) to monitor tree-crop-livestock interactions, soil health, and water availability in real time. Unmanned aerial vehicles (UAVs) and multispectral imaging have been used to assess canopy health, measure biomass accumulation, and identify nutrient deficiencies in agroforestry systems. These technologies improve decision-making for farmers by providing site-specific recommendations on tree spacing, intercropping arrangements, and irrigation management. A study in sub-Saharan Africa demonstrated that integrating remote sensing with agroforestry planning improved crop yields by 25% while reducing water use by 30%. AI-driven models are also being developed to predict the growth rates of different agroforestry tree species under varying climatic conditions. Machine learning applications can analyse large datasets from long-term agroforestry trials to optimize carbon sequestration strategies and enhance soil conservation practices.

***2. Agroforestry and permaculture integration***

Agroforestry and permaculture share common principles of sustainability, biodiversity conservation, and ecological balance. Integrating these two approaches can create resilient food production systems that require minimal external inputs while maximizing ecosystem services (Bommarco *et al.,* 2013). Permaculture emphasizes designing agricultural landscapes that mimic natural ecosystems, incorporating multiple plant layers, water harvesting techniques, and self-sustaining nutrient cycles. When combined with agroforestry, this approach enhances soil fertility, increases biodiversity, and improves food security in both tropical and temperate regions. Studies indicate that agroforestry-permaculture systems can reduce synthetic fertilizer use by 50–70% while maintaining or increasing yields. These systems also improve resilience to extreme weather events by diversifying income sources and enhancing soil moisture retention.

***3. Climate-smart agroforestry approaches***

Climate-smart agroforestry integrates tree-based farming with climate adaptation and mitigation strategies to improve resilience against climate change while enhancing food security and carbon sequestration. These approaches involve selecting drought-tolerant tree species, improving water management, and designing agroforestry landscapes that buffer against extreme weather events. Research suggests that climate-smart agroforestry can increase farm productivity by 30–50% in regions affected by climate variability (Awazi *etal.,* 2021). The use of resilient tree species such as *Faidherbia albida*, which sheds its leaves during the rainy season to support crop growth while providing shade in the dry season, has been successful in improving soil fertility and water retention. Agroforestry’s potential in carbon sequestration is well-documented, with estimates suggesting that tree-based farming systems can store between 0.29 and 15.21 Mg C ha⁻¹ year⁻¹, making them an essential component of climate change mitigation strategies. The implementation of carbon credit programs for agroforestry farmers could further incentivize climate-smart practices while promoting global sustainability goals (Tumushabe *etal.,* 2023).

**B. Need for Long-Term Monitoring and Research**

***1. Assessing long-term impacts on biodiversity and soil health***

Long-term studies are crucial to understanding the full ecological and economic benefits of agroforestry. Many existing agroforestry trials focus on short-term outcomes, leaving gaps in knowledge regarding soil health restoration, biodiversity enhancement, and ecosystem resilience over multiple decades. Research has shown that agroforestry systems contribute to soil organic carbon accumulation over time, but precise rates of sequestration depend on factors such as tree species, soil type, and management practices. A 20-year study in Latin America found that well-managed agroforestry plots stored up to 40% more soil organic carbon compared to conventional farming systems. Assessing biodiversity trends in agroforestry landscapes is equally important. Studies indicate that bird and insect diversity is 50–80% higher in agroforestry systems compared to monocultures. Establishing long-term biodiversity monitoring frameworks will provide valuable insights into species interactions and habitat conservation within tree-based farming systems.

***2. Developing region-specific agroforestry models***

Agroforestry practices must be tailored to specific agro-ecological zones, soil conditions, and socio-economic contexts to maximize their benefits (Mukhlis *et al.,* 2022). Research is needed to refine region-specific models that consider optimal tree-crop-livestock combinations, soil fertility management strategies, and climate adaptation techniques. Developing site-specific agroforestry recommendations requires participatory research involving farmers, scientists, and policymakers. Collaborative studies in Africa have demonstrated that farmer-led experimentation improves the success rate of agroforestry adoption by 30–50%. Integrating indigenous knowledge with scientific innovations can further enhance agroforestry’s applicability across diverse landscapes.

***3. Expanding research on agroforestry’s role in ecosystem services***

The contribution of agroforestry to ecosystem services such as water purification, pollination, and carbon sequestration is well-recognized, but more research is needed to quantify these benefits at different spatial scales. Studies have shown that agroforestry reduces nitrogen leaching by up to 90% compared to conventional agriculture, improving water quality in agricultural landscapes. Research on agroforestry’s role in climate adaptation and disaster risk reduction is also critical. Studies suggest that agroforestry buffers against extreme weather events by reducing surface runoff, preventing landslides, and stabilizing riverbanks (Hairiah *et al.,* 2020). Long-term data collection on these processes will support evidence-based policy-making for sustainable land-use planning.

**C. Policy and Institutional Support**

***1. Strengthening agroforestry policies at national and international levels***

Policy frameworks that integrate agroforestry into national agricultural and environmental strategies are essential for large-scale implementation. Many existing policies focus on forestry and agriculture as separate sectors, creating regulatory barriers for tree-based farming systems. National agroforestry action plans, such as those developed in Brazil and Kenya, have demonstrated the potential of policy-driven agroforestry promotion. Strengthening global commitments to agroforestry within agreements like the United Nations Framework Convention on Climate Change (UNFCCC) can further enhance adoption rates (Dhyani *et al.,* 2021).

***2. Incentivizing farmers through subsidies and payments for ecosystem services***

Economic incentives such as subsidies, tax reductions, and payments for ecosystem services (PES) can encourage farmers to adopt agroforestry. Costa Rica’s PES program compensates farmers for maintaining tree cover, leading to a 40% increase in agroforestry adoption. Expanding such initiatives globally could accelerate the transition to sustainable land-use systems.

***3. Integrating agroforestry into land-use planning and conservation programs***

Incorporating agroforestry into national land-use policies and conservation programs can enhance biodiversity conservation and reduce deforestation. Agroforestry buffer zones around protected areas help maintain ecological connectivity, supporting wildlife movement and genetic diversity (Schroth *etal.,* 2013).

**Conclusion**

Agroforestry plays a pivotal role in enhancing biodiversity, improving soil health, and promoting climate resilience in agricultural landscapes. By integrating trees with crops and livestock, agroforestry systems support ecosystem services such as carbon sequestration, nutrient cycling, and water retention while mitigating soil erosion and habitat loss. Research indicates that well-managed agroforestry can increase species richness by up to 50% and enhance soil organic carbon by 20–40%, contributing to long-term sustainability. Despite its benefits, adoption faces socioeconomic, technical, and policy barriers, including high initial costs, land tenure insecurity, and competition for resources. Addressing these challenges requires farmer education, financial incentives, and policy reforms that integrate agroforestry into national land-use strategies. Future research should focus on long-term ecosystem monitoring, climate-smart innovations, and precision agroforestry technologies to optimize productivity and resilience. Strengthening institutional support and global commitments will be essential for scaling agroforestry worldwide.

**Disclaimer (Artificial intelligence)**

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Details of the AI usage are given below:

1.

2.

3.

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