Review Article

Agroforestry Practices as a Keystone for Biodiversity Conservation: A review

Abstract

Agroforestry, the integration of trees and shrubs into agricultural systems, presents a sustainable land-use practice that enhances biodiversity conservation and ecosystem services. This review examines the historical development of agroforestry, its various types, and its role in promoting biodiversity and ecosystem health. Traditional agroforestry systems, such as home gardens and shifting cultivation, have long supported diverse species and sustainable land management. Modern agroforestry innovations, including climate-smart and precision agroforestry, further optimize resource use and resilience to climate change. Despite these benefits, the adoption of agroforestry faces significant socio-economic barriers, including limited financial resources, insecure land tenure, and cultural resistance. Policy and institutional constraints, such as fragmented governance and insufficient support for agroforestry, also impede its widespread implementation. Technical and knowledge gaps, particularly in region-specific practices and long-term ecological impacts, further challenge adoption. Environmental challenges, including climate change and soil degradation, add to the complexity of managing agroforestry systems. Nevertheless, agroforestry's contributions to habitat creation, genetic diversity, species richness, and ecosystem services like soil fertility, water regulation, carbon sequestration, and pest management underscore its importance. Future prospects for agroforestry involve innovations in practice, supportive policies, targeted research, and the active role of stakeholders, including farmers, extension services, NGOs, the private sector, and governments. Effective promotion and implementation require integrated efforts across these domains to overcome existing barriers. This review highlights the need for comprehensive policies, enhanced research and development, and multi-stakeholder collaboration to scale up agroforestry practices globally. As global environmental and climate crises intensify, agroforestry stands out as a viable strategy for creating resilient and sustainable agricultural landscapes, ultimately contributing to food security, rural livelihoods, and ecological health.

Keywords: *Agroforestry, Biodiversity, Ecosystems, Conservation, Soil health, Ecosystem services*

1.Introduction

Agroforestry is an integrated land-use management system where trees and shrubs are cultivated alongside crops and livestock within the same land area. This practice merges agricultural and forestry technologies to form more diverse, productive, profitable, and sustainable land-use systems [1]. The primary goal is to optimize the beneficial interactions among different components, such as trees, crops, and livestock, to enhance economic and environmental outcomes. Agroforestry systems encompass various practices, including agrisilviculture (combining crops and trees), silvopastoral systems (integrating trees and livestock), agrosilvopastoral systems (incorporating crops, trees, and livestock), as well as home gardens and alley cropping [2].Biodiversity conservation is critical for maintaining ecosystem health and stability. Biodiversity refers to the variety of life in a particular habitat or ecosystem, including genetic diversity within species, species diversity among species, and ecosystem diversity. High biodiversity is essential for the resilience of ecosystems to disturbances and stresses, such as climate change, pest outbreaks, and human activities. It supports vital ecosystem services, including food production, water purification, disease regulation, and climate regulation. Additionally, biodiversity provides genetic resources necessary for developing new crop varieties and medicines. Agroforestry significantly contributes to biodiversity conservation by creating habitats, enhancing genetic diversity, and supporting various species [3].The primary objective of this review is to comprehensively examine the role of agroforestry practices in biodiversity conservation. The review aims to:Explore the historical context and evolution of agroforestry practices, highlighting how they have traditionally integrated biodiversity conservation.Categorize and describe the different types of agroforestry systems and their specific contributions to biodiversity.Analyze the ecological benefits of agroforestry, focusing on habitat creation, genetic diversity enhancement, species richness promotion, and ecosystem services.Present case studies and examples from various regions to illustrate successful implementations of agroforestry for biodiversity conservation.Identify the challenges and limitations faced in the widespread adoption of agroforestry practices.Discuss future prospects and opportunities for advancing agroforestry practices, including innovations, policy recommendations, research needs, and the role of stakeholders.By addressing these objectives, this review seeks to provide a detailed understanding of how agroforestry practices serve as a keystone for biodiversity conservation and to offer insights into the ways these practices can be further promoted and optimized for ecological and economic benefits [4].

2. History

A. Traditional Agroforestry Systems

Traditional agroforestry systems have been practiced for centuries by indigenous and rural communities worldwide (Table-1). These systems often reflect a deep understanding of local ecological conditions and incorporate a variety of plants and animals in a way that promotes biodiversity and sustainability. One notable example is the home garden, prevalent in tropical regions of Asia, Africa, and Latin America. These gardens typically include a diverse mix of trees, shrubs, herbs, and vegetables, providing food, medicine, and other resources year-round. Another traditional practice is the shifting cultivation system, also known as swidden agriculture, where forested land is cleared, cultivated for a few years, and then left to regenerate [5]. This method maintains soil fertility and biodiversity by allowing forest ecosystems to recover.In the Sahel region of Africa, the parkland system is a traditional agroforestry practice where trees such as Faidherbiaalbida are maintained on farmlands. These trees contribute to soil fertility through nitrogen fixation and provide shade and fodder for livestock. Similarly, in Central America, the Quesungual Slash-and-Mulch Agroforestry System integrates trees with maize and bean crops, enhancing soil moisture and reducing erosion [6]. These traditional systems demonstrate the long-standing role of agroforestry in promoting biodiversity and sustainable land use.

Table:1 Traditional Agroforestry Systems (Source: [4], [5], [6])

System Type	Description	Region	Practices	Benefits	Challenges	Examples
Silvopasture	Integration of trees with pasture and livestock	Latin America, Africa	Grazing livestock under tree canopy, fodder tree planting	Improved forage quality, enhanced biodiversity, reduced soil erosion	Management complexity, initial establishment cost	Dehesa systems in Spain, Acacia-based systems in Africa
Agrosilviculture	Combination of crops and trees	Asia, Africa	Alley cropping, shifting cultivation with trees, tree plantations in crop fields	Soil fertility improvement, reduced need for chemical fertilizers, enhanced crop yields	Competition for resources, complex management	Jhum cultivation in Northeast India, Cocoa agroforestry in Ghana
Agrosilvopasture	Integration of crops, trees, and livestock	Europe, North America	Sequential cropping, multi-layered cropping with animals, tree-hedgerow systems	Diversified income, improved land use efficiency, soil conservation	High labor input, need for technical knowledge	Traditional oak silvopastures in the UK, Montado systems in Portugal
Home Gardens	Small-scale agroforestry systems around homes	Southeast Asia, Central America	Mixed cropping, fruit trees with vegetables, medicinal plants	Food security, nutritional benefits, income generation from surplus	Limited scalability, intensive labor	Home gardens in Kerala, India, Maya home gardens in Mexico
Taungya System	Combining forestry with seasonal agriculture	Southeast Asia, Africa	Growing annual crops during the early stages	Forest regeneration, temporary income from crops,	Land tenure issues, sustainability concerns	Taungya systems in Myanmar, Agroforestry in

			of forest establishment	reduced weeding costs		Zambia
Forest Farming	Cultivation of high-value crops under forest canopy	North America, Europe	Non-timber forest products (e.g., mushrooms, herbs), shade-tolerant crops	Diversification of forest products, enhanced forest health, sustainable income	Market access, ecological impact	Ginseng cultivation in Appalachia, Truffle production in Italy

B. Evolution of Agroforestry Practices

The evolution of agroforestry practices can be traced back to the increasing recognition of the limitations of conventional agricultural methods and the need for sustainable land management solutions (Table-2). During the mid-20th century, the Green Revolution introduced high-yield crop varieties and chemical inputs that significantly boosted agricultural productivity but often led to soil degradation, water scarcity, and biodiversity loss [7]. In response, researchers and practitioners began to explore agroforestry as a means to mitigate these negative impacts while sustaining agricultural productivity.In the 1970s, the establishment of the International Council for Research in Agroforestry (ICRAF), now known as the World Agroforestry Centre, marked a significant milestone in the development of agroforestry as a scientific discipline. ICRAF's research emphasized the ecological and economic benefits of integrating trees into agricultural landscapes, leading to the development of various agroforestry models and practices. The publication of "Agroforestry: A Decade of Development" in 1987 further highlighted the potential of agroforestry to address global challenges such as food security, climate change, and biodiversity conservation [8].The adoption of agroforestry has been facilitated by international policy frameworks and initiatives that recognize the importance of sustainable land management. The United Nations Convention to Combat Desertification (UNCCD) and the Convention on Biological Diversity (CBD) have both advocated for agroforestry as a strategy to combat land degradation and promote biodiversity. In recent decades, advances in agroecology and sustainable agriculture have further integrated agroforestry practices into broader land management strategies [9].

Table 2: Evolution of Agroforestry Practices (Source- [5], [7], [9])

Era	Period	Characteristics	Practices	Regions	Notable Developments
Prehistoric	Before 10,000	Early human societies	Gathering of wild fruits,	Africa, Asia,	Development of basic tools for

Era	BCE	relying on wild trees and plants for food, shelter, and medicine	nuts, and herbs; Basic management of natural vegetation	Americas	harvesting, initial domestication of plants
Ancient Era	10,000 BCE - 1,000 CE	Transition to settled agriculture with integration of trees into farming systems	Shifting cultivation, orchard establishment, use of tree legumes	Mesopotamia, Indus Valley, Mesoamerica	Development of early agroforestry systems such as home gardens, improved crop varieties
Medieval Era	1,000 CE - 1,500 CE	Expansion of agroforestry practices with increasing population and agricultural needs	Silvopastoral systems, alley cropping, Taungya system	Europe, Asia, Africa	Innovations in tree grafting and breeding, spread of agroforestry knowledge through trade routes
Colonial Era	1,500 CE - 1,900 CE	Introduction of new crops and trees through global exploration and colonization	Plantation agriculture, introduction of exotic species, mixed farming	Americas, Africa, Asia	Establishment of large-scale plantations, development of agricultural extension services
Modern Era	1,900 CE - Present	Integration of scientific research and technological advancements into agroforestry practices	Agroforestry research stations, genetic improvement of tree species, modern silvopasture	Global	Recognition of agroforestry's role in sustainable development, policy support, climate change mitigation strategies
Contemporary	2000 CE -	Focus on sustainability,	Agroecological approaches,	Global	Advances in remote sensing

Era	Present	climate resilience, and multifunctional landscapes	agroforestry for carbon sequestration, urban agroforestry		and GIS for agroforestry planning, increased funding for agroforestry projects, integration of traditional knowledge with modern practices

C. Integration of Biodiversity Conservation in Agroforestry

The integration of biodiversity conservation into agroforestry practices has become increasingly prominent as the ecological benefits of these systems have been recognized. Agroforestry contributes to biodiversity conservation by creating diverse habitats, enhancing genetic diversity, and supporting various species. Trees and shrubs in agroforestry systems provide habitat and food sources for a wide range of organisms, including birds, insects, and mammals, thereby increasing species richness and ecosystem complexity [10].Agroforestry practices also enhance genetic diversity by maintaining and promoting the use of traditional and indigenous tree species. This genetic diversity is crucial for the resilience of ecosystems and the adaptation of species to changing environmental conditions. For example, the use of diverse tree species in agroforestry systems can reduce the risk of pest and disease outbreaks, as a more varied plant community can interrupt pest life cycles and provide habitat for natural predators [11].Agroforestry systems contribute to the conservation of soil and water resources, which are essential for maintaining biodiversity. Trees and shrubs help prevent soil erosion, improve soil structure and fertility, and enhance water infiltration and retention. These benefits are particularly important in areas prone to land degradation and desertification, where maintaining soil health and water availability is critical for sustaining biodiversity.The role of agroforestry in biodiversity conservation has been increasingly recognized in global environmental policy. For instance, the Aichi Biodiversity Targets set by the CBD include the restoration and safeguarding of ecosystems that provide essential services, including those related to agroforestry. Similarly, the United Nations Sustainable Development Goals (SDGs) emphasize the importance of sustainable agriculture and land use practices, including agroforestry, for achieving environmental sustainability and biodiversity conservation [12].

3. Types of Agroforestry Practices

A. Agrisilviculture (Crops and Trees)

Agrisilviculture is one of the most common forms of agroforestry, combining the cultivation of crops and trees on the same land. This practice leverages the benefits of tree-crop interactions to enhance productivity and sustainability. Trees in agrisilviculture systems provide multiple benefits such as shade, windbreaks, and improved soil fertility through leaf litter and root interactions. For example, alley cropping is a popular agrisilviculture system where rows of trees or shrubs are alternated with rows of crops. This system not only protects the crops from wind and soil erosion but also enhances soil organic matter and nutrient cycling [13].One notable example of agrisilviculture is the cultivation of leguminous trees like *Leucaenaleucocephala* with cereal crops. These trees fix atmospheric nitrogen, enriching soil fertility and reducing the need for synthetic fertilizers. Additionally, trees like Faidherbiaalbida, commonly used in Sahelian parklands, shed their leaves during the rainy season when crops are growing, providing a natural mulch that conserves soil moisture and improves soil structure [14]. This system is especially beneficial in arid and semi-arid regions where soil fertility and moisture retention are critical for crop success.

B. Silvopastoral Systems (Trees and Livestock)

Silvopastoral systems integrate trees, forage plants, and livestock in a symbiotic relationship. These systems offer numerous ecological and economic benefits, including improved animal welfare, enhanced biodiversity, and sustainable land management. Trees in silvopastoral systems provide shade and shelter for livestock, reducing heat stress and improving animal health and productivity. Trees contribute to soil conservation and fertility through leaf litter and root systems, promoting forage growth and quality [15].An example of a silvopastoral system is the use of scattered trees in pastures, such as oak trees in the dehesa systems of Spain and Portugal. These trees offer shade and forage for livestock, while their acorns provide an additional food source for pigs and other animals. In tropical regions, the integration of fodder trees like *Gliricidiasepium*and *Moringaoleifera* with pastures provides high-protein fodder for livestock, improving weight gain and milk production [16]. Silvopastoral systems are particularly effective in preventing land degradation and enhancing the resilience of pastoral landscapes.

C. Agrosilvopastoral Systems (Crops, Trees, and Livestock)

Agrosilvopastoral systems combine crops, trees, and livestock in a comprehensive land-use system that maximizes the benefits of each component. This integrated approach promotes resource efficiency, enhances biodiversity, and provides multiple streams of income for farmers. In agrosilvopastoral systems, trees contribute to soil fertility and structure, crops provide food and income, and livestock offer manure for fertilization and additional income sources [17].A well-known example of agrosilvopastoral systems is the traditional shifting cultivation practiced in many parts of the tropics. In this system, farmers clear small patches of forest to plant a mix of crops and trees, while also maintaining livestock. After a few years of cultivation, the land is left fallow to allow natural regeneration, during which livestock can graze on the recovering vegetation. Another example is the use of multi-strata systems in the Amazon, where a variety of crops, trees, and animals are integrated to mimic the structure and function of natural forests. These systems not only enhance biodiversity but also provide resilience against environmental stresses and market fluctuations.

D. Home Gardens

Home gardens are small-scale agroforestry systems typically found in residential areas, where a diverse mix of trees, shrubs, herbs, and vegetables are cultivated for household use. These gardens are characterized by high species diversity and complex vertical structure, providing numerous ecological, economic, and social benefits. Home gardens enhance food security and nutrition by supplying a variety of fruits, vegetables, and medicinal plants year-round [18].In tropical regions, home gardens are a common feature, especially in countries like India, Indonesia, and Sri Lanka. These gardens often include a mix of fruit trees like mango, papaya, and banana, along with spice plants, medicinal herbs, and vegetables. Home gardens also play a crucial role in conserving plant genetic resources, as they often contain rare and traditional plant varieties not found in commercial agriculture [19]. Additionally, home gardens contribute to biodiversity conservation by creating microhabitats for various species and promoting ecological interactions within urban and peri-urban landscapes.

E. Other Agroforestry Systems

Beyond the primary categories, several other agroforestry systems contribute to sustainable land management and biodiversity conservation. These systems include riparian buffer strips, windbreaks, and improved fallows. Riparian buffer strips are vegetative areas along water bodies designed to intercept pollutants, reduce erosion, and provide habitat for wildlife. Trees and shrubs in these buffers stabilize stream banks, filter runoff, and enhance water quality [20].Windbreaks are rows of trees or shrubs planted to protect crops, soil, and livestock from wind damage. They reduce wind speed, prevent soil erosion, and create microclimates that enhance crop yields. Windbreaks also provide habitat for beneficial insects, birds, and other wildlife, contributing to biodiversity conservation [21].Improved fallows involve planting fast-growing trees or shrubs on fallow land to restore soil fertility and structure. These species, often nitrogen-fixing legumes, enhance soil organic matter, suppress weeds, and provide fodder, fuelwood, and other products during the fallow period [22]. Improved fallows are particularly beneficial in regions with degraded soils, helping to regenerate productive agricultural land.

4. Agroforestry and Biodiversity Conservation

A. Role of Agroforestry in Habitat Creation

Agroforestry plays a critical role in creating habitats that support a wide variety of flora and fauna. By integrating trees and shrubs with agricultural crops and livestock, agroforestry systems mimic natural ecosystems, providing diverse habitats that are often more complex and varied than those in conventional agricultural landscapes. Trees and shrubs offer nesting sites, food sources, and shelter for birds, insects, mammals, and other wildlife. For instance, the incorporation of native trees in agroforestry systems can significantly enhance habitat quality and availability for local wildlife, thereby promoting biodiversity conservation [23].Moreover, agroforestry practices such as hedgerows and riparian buffer strips create corridors that connect fragmented habitats, facilitating wildlife movement and gene flow across landscapes. This connectivity is crucial for maintaining viable populations of species that require large territories or specific habitat conditions. Agroforestry systems also contribute to the conservation of endangered species by providing alternative habitats in agricultural landscapes, thus reducing pressure on natural forests [24].

B. Enhancement of Genetic Diversity

Agroforestry enhances genetic diversity by incorporating a wide range of plant species, including trees, shrubs, and herbaceous plants, into agricultural systems. This diversity is crucial for the resilience and adaptability of ecosystems to environmental changes and stressors such as climate change, pests, and diseases. By maintaining and promoting traditional and indigenous tree species, agroforestry systems help conserve genetic resources that are often overlooked in conventional agriculture [25].For example, traditional agroforestry systems in the tropics, such as home gardens and multi-strata systems, often include a diverse array of fruit trees, medicinal plants, and other useful species that have been selected and cultivated by local communities over generations [26]. This in situ conservation of genetic resources is vital for preserving the adaptive potential of plant species and ensuring the availability of diverse genetic material for future breeding and improvement programs.Agroforestry also supports the cultivation of wild relatives of domesticated crops, which are important sources of genetic variation for traits such as disease resistance and drought tolerance. By integrating these wild relatives into agricultural landscapes, agroforestry systems contribute to the conservation of genetic diversity and enhance the resilience of agroecosystems.

C. Promotion of Species Richness

Agroforestry systems promote species richness by creating diverse and multi-layered habitats that support a wide range of plant and animal species. The structural complexity of agroforestry systems, with their mix of trees, shrubs, and crops, provides niches for different species, leading to higher levels of biodiversity compared to monoculture systems [27]. For example, agroforestry practices such as shade coffee and cacao systems in Central and South America have been shown to support high levels of biodiversity, including numerous bird and insect species.In addition to supporting above-ground biodiversity, agroforestry systems also enhance below-ground biodiversity by improving soil health and structure. The presence of trees and shrubs in agroforestry systems increases organic matter inputs to the soil, promoting the activity and diversity of soil organisms such as earthworms, fungi, and bacteria [28]. These soil organisms play critical roles in nutrient cycling, soil formation, and plant health, contributing to the overall biodiversity and functioning of agroecosystems.Agroforestry systems also foster beneficial interactions among species, such as pollination and pest control services provided by birds, bats, and insects. These interactions are essential for maintaining ecosystem stability and productivity, highlighting the role of agroforestry in promoting species richness and ecological balance [29].

D. Contribution to Ecosystem Services

Soil Fertility and Health

Agroforestry systems contribute significantly to soil fertility and health through various mechanisms. Trees and shrubs in agroforestry systems enhance soil organic matter by providing leaf litter and root biomass, which decompose and enrich the soil with nutrients. Nitrogen-fixing trees and shrubs, such as leguminous species, play a crucial role in improving soil fertility by converting atmospheric nitrogen into forms that plants can use [30]. This natural fertilization process reduces the need for synthetic fertilizers, promoting sustainable agriculture.Agroforestry practices also help improve soil structure and prevent erosion. Tree roots stabilize the soil, reducing surface runoff and erosion, while leaf litter protects the soil surface from the impact of raindrops . Improved soil structure enhances water infiltration and retention, benefiting crop growth and reducing the risk of drought [31].

Water Regulation

Trees and shrubs in agroforestry systems play a vital role in regulating water cycles. Their deep root systems help improve water infiltration and reduce surface runoff, enhancing groundwater recharge and reducing the risk of flooding. Agroforestry practices such as riparian buffer strips protect water bodies by filtering sediments, nutrients, and pollutants from agricultural runoff, thereby improving water quality [32].Trees in agroforestry systems contribute to local and regional hydrological cycles through transpiration, which increases atmospheric moisture and can influence rainfall patterns. By enhancing water regulation and quality, agroforestry systems provide essential ecosystem services that support agricultural productivity and environmental health.

Carbon Sequestration

Agroforestry systems are effective tools for carbon sequestration, capturing atmospheric carbon dioxide and storing it in biomass and soils. Trees and shrubs in agroforestry systems sequester carbon through photosynthesis, with significant amounts stored in their trunks, branches, leaves, and roots [33]. Additionally, agroforestry practices enhance soil carbon storage by increasing organic matter inputs and improving soil structure.The carbon sequestration potential of agroforestry systems varies depending on the species composition, management practices, and environmental conditions. However, studies have shown that agroforestry can sequester substantial amounts of carbon, contributing to climate change mitigation. By integrating trees into agricultural landscapes, agroforestry systems offer a sustainable approach to reducing greenhouse gas emissions and enhancing carbon storage.

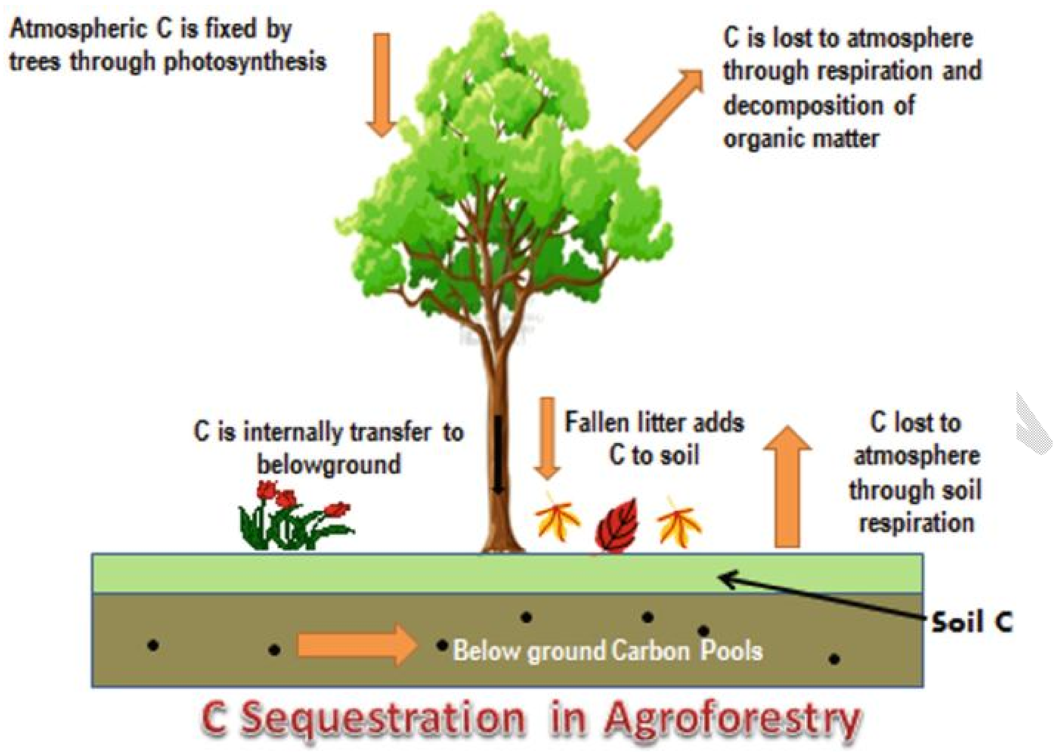

Fig: Carbon Sequestration Potential of Agroforestry Systems (**Source-** Springer)

Pest and Disease Management

Agroforestry systems contribute to pest and disease management through increased biodiversity and ecological interactions. The presence of diverse plant species in agroforestry systems creates habitats for natural enemies of pests, such as predators and parasitoids, which help control pest populations [34]. For example, birds and bats in agroforestry systems can reduce insect pests by preying on them, while beneficial insects such as ladybugs and wasps provide natural pest control services.Moreover, the diversity of plant species in agroforestry systems can disrupt pest life cycles and reduce the spread of diseases. Mixed cropping and the presence of non-host plants can create barriers that limit the movement and reproduction of pests and pathogens [35]. By enhancing natural pest and disease control mechanisms, agroforestry systems reduce the need for chemical pesticides and promote sustainable agricultural practices.

5. Case Studies and Examples

A. Agroforestry in Tropical Regions

Agroforestry practices in tropical regions are diverse and adapted to various ecological and socio-economic conditions. One prominent example is the shade-grown coffee systems in Central and South America. These systems integrate coffee plants with shade trees, which not only provide a suitable microclimate for coffee production but also support high levels of biodiversity. Studies have shown that shade-grown coffee plantations harbor a rich variety of bird species, insects, and other wildlife, contributing to biodiversity conservation and ecosystem health [36].Another example is the traditional home gardens of Kerala, India. These multi-layered agroforestry systems include a diverse mix of trees, shrubs, herbs, and crops, providing food, fuel, fodder, and other resources year-round. Home gardens in Kerala are known for their high species richness and play a crucial role in conserving plant genetic resources, including many traditional and indigenous species. The integration of various plant species in these gardens also enhances soil fertility, water retention, and pest management.In Africa, the Faidherbiaalbida parkland system is widely practiced in the Sahel region. Faidherbiaalbida is a leguminous tree that sheds its leaves during the rainy season, allowing crops to grow beneath it with minimal competition for light. This tree improves soil fertility through nitrogen fixation and provides fodder for livestock during the dry season. Studies have demonstrated that fields with Faidherbiaalbida trees have higher crop yields and better soil health compared to fields without these trees [37].

B. Agroforestry in Temperate Regions

Agroforestry in temperate regions includes practices such as alley cropping, silvopasture, and forest farming. Alley cropping involves planting rows of trees or shrubs between rows of crops. This practice can improve soil fertility, reduce erosion, and provide additional income from timber or non-timber forest products. For example, in the United States, black walnut trees are commonly grown in alley cropping systems with crops like corn or soybeans. These systems enhance soil health and provide valuable wood and nut products [38].Silvopastoral systems in temperate regions integrate trees with pastureland and livestock. In the dehesa system of Spain and Portugal, oak trees are scattered across pasturelands, providing shade and forage for livestock while producing acorns for pig feed. This system supports a variety of plant and animal species, contributing to biodiversity conservation and sustainable land management. Similarly, in the United Kingdom, silvopastoral systems with trees like ash and willow provide shade for livestock and improve pasture productivity [39].Forest farming, another temperate agroforestry practice, involves cultivating high-value crops such as mushrooms, medicinal plants, and herbs under the canopy of an existing forest. This practice enhances biodiversity by maintaining forest structure and composition while providing economic benefits to farmers. For instance, ginseng and goldenseal are commonly grown in forest farming systems in the Appalachian region of the United States, contributing to both biodiversity conservation and rural livelihoods [40].

C. Success Stories from Various Countries

Several countries have successfully implemented agroforestry practices, demonstrating their potential for biodiversity conservation and sustainable development. In Costa Rica, the development of payment for ecosystem services (PES) schemes has incentivized farmers to adopt agroforestry practices. These schemes compensate farmers for maintaining or enhancing ecosystem services such as carbon sequestration, biodiversity conservation, and water regulation.

The adoption of agroforestry practices under these schemes has led to increased tree cover, improved biodiversity, and enhanced livelihoods.In Kenya, the Green Belt Movement, founded by Nobel laureate Wangari Maathai, has promoted agroforestry as a means to combat deforestation, soil erosion, and poverty. The movement has encouraged communities to plant trees on farms and degraded lands, leading to improved soil fertility, water retention, and biodiversity. The success of the Green Belt Movement has inspired similar initiatives in other African countries, highlighting the role of agroforestry in sustainable land management and community development [41].In Brazil, the implementation of agroforestry systems in the Amazon region has shown promise in balancing agricultural production with forest conservation. The adoption of agroforestry practices such as multi-strata systems and agroforestry fallows has helped reduce deforestation and enhance biodiversity. These systems integrate a variety of crops, trees, and animals, mimicking the structure and function of natural forests while providing economic benefits to farmers [42].In Europe, the widespread adoption of agroforestry practices has been supported by policy frameworks and funding mechanisms. For example, the European Union's Common Agricultural Policy (CAP) includes measures to promote agroforestry as part of sustainable rural development. Countries like France and Spain have implemented agroforestry projects that integrate trees with crops and livestock, leading to improved soil health, water management, and biodiversity [43].

6. Challenges and Limitations

A. Socio-economic Barriers

Agroforestry practices, despite their numerous benefits, face significant socio-economic barriers that hinder their widespread adoption and implementation. One of the primary socio-economic barriers is the lack of access to financial resources. Smallholder farmers, who could benefit most from agroforestry, often lack the capital needed to invest in the establishment and maintenance of these systems. The initial costs of planting trees and shrubs, coupled with the delayed financial returns, pose a considerable challenge for farmers with limited financial means [44].Additionally, land tenure insecurity is a major obstacle. In many developing countries, unclear or disputed land tenure arrangements discourage farmers from investing in long-term agroforestry practices. Farmers without secure land rights are less likely to plant trees or engage in agroforestry systems that require several years to mature and yield benefits [45]. This issue is particularly acute in regions where customary land tenure systems prevail, and formal land rights are either weak or non-existent.Cultural and social factors also play a role in the adoption of agroforestry. In some communities, traditional agricultural practices are deeply ingrained, and there may be resistance to adopting new methods, even when they are more sustainable and beneficial in the long run. Social norms and values, as well as the influence of local leaders and extension services, can significantly impact farmers' willingness to embrace agroforestry [46].

B. Policy and Institutional Constraints

Policy and institutional constraints are another significant barrier to the adoption of agroforestry. In many countries, agricultural policies and land use regulations are not supportive of integrated land-use practices like agroforestry. Instead, they often favor monoculture cropping systems and conventional farming methods. This lack of supportive policies can discourage farmers from adopting agroforestry practices.There is often a lack of coordination between different government departments and agencies responsible for agriculture, forestry, and rural development. This fragmented approach can lead to conflicting policies and regulations that hinder the implementation of agroforestry systems. For example, forestry departments may impose restrictions on tree planting or harvesting that are not aligned with agricultural policies, creating confusion and disincentives for farmers [47].Institutional capacity is also a limiting factor. Many countries lack the institutional framework and resources needed to promote and support agroforestry. This includes the absence of dedicated agroforestry programs, insufficient training and extension services for farmers, and limited research and development initiatives focused on agroforestry practices.

C. Technical and Knowledge Gaps

Technical and knowledge gaps present significant challenges to the successful implementation of agroforestry. Many farmers lack the technical knowledge and skills required to design, establish, and manage agroforestry systems effectively. This includes understanding the interactions between different tree, crop, and livestock species, as well as the best practices for integrating these components in a way that maximizes benefits [48].The complexity of agroforestry systems, with their diverse components and interactions, can be daunting for farmers who are accustomed to simpler, monoculture systems. This complexity requires a higher level of management skill and knowledge, which is often lacking, particularly in regions with limited access to agricultural education and extension services.Research gaps also contribute to the challenges of implementing agroforestry. While significant progress has been made in understanding the benefits and potential of agroforestry, there is still a need for more localized research that addresses specific agroecological conditions and socio-economic contexts. This includes developing region-specific agroforestry models and practices, as well as conducting long-term studies to better understand the ecological and economic impacts of agroforestry systems [49].

D. Environmental Challenges

Environmental challenges can also limit the effectiveness and viability of agroforestry practices. Climate change, for instance, poses a significant threat to agroforestry systems. Changes in temperature, precipitation patterns, and the frequency of extreme weather events can affect the growth and productivity of trees, crops, and livestock. Droughts, floods, and storms can damage agroforestry systems, reduce yields, and undermine the long-term sustainability of these practices [50].Soil degradation and erosion are other environmental challenges that can impact agroforestry. In areas with severely degraded soils, establishing trees and shrubs can be difficult, and the benefits of agroforestry may take longer to materialize. Similarly, in regions prone to erosion, maintaining soil health and stability is critical, yet challenging.Pest and disease pressures can also be more complex in agroforestry systems, where the diversity of species can lead to a broader range of potential pests and diseases. Managing these threats requires careful planning and integrated pest management strategies, which can be more demanding than in simpler agricultural systems [51].Finally, biodiversity loss and habitat destruction pose significant environmental challenges. In many regions, natural forests and habitats are being converted to agricultural land, reducing the availability of native species that are crucial for the success of agroforestry systems. This loss of biodiversity can weaken ecosystem resilience and reduce the effectiveness of agroforestry practices in conserving biodiversity [52].

7. Future and Opportunities

A. Innovations in Agroforestry Practices

Innovations in agroforestry practices are critical for enhancing the sustainability and productivity of agricultural systems. One promising innovation is the development of climate-smart agroforestry practices. Climate-smart agroforestry involves the integration of trees into agricultural landscapes in ways that increase resilience to climate change while reducing greenhouse gas emissions. Techniques such as the use of drought-resistant tree species, improved tree-crop combinations, and water-efficient practices can help farmers adapt to changing climate conditions [53].Precision agroforestry is another emerging innovation, leveraging advancements in technology to optimize the management of agroforestry systems. Precision tools such as remote sensing, geographic information systems (GIS), and drones can be used to monitor tree health, soil conditions, and crop growth, allowing for more precise management interventions. These technologies can improve the efficiency of resource use and enhance the productivity of agroforestry systems [54].Agroforestry practices that enhance biodiversity and ecosystem services are also gaining attention. For example, the integration of multi-strata agroforestry systems, which include multiple layers of vegetation such as trees, shrubs, and ground cover plants, can significantly enhance biodiversity and provide a range of ecosystem services such as carbon sequestration, water regulation, and soil fertility. Additionally, the use of agroforestry in landscape restoration projects offers a sustainable approach to restoring degraded lands and improving ecosystem health [55].

B. Policy Recommendations

Effective policy frameworks are essential for promoting the adoption and scaling up of agroforestry practices. Governments should develop and implement policies that recognize and support the multifunctional benefits of agroforestry. This includes integrating agroforestry into national agricultural and forestry policies, providing financial incentives for farmers to adopt agroforestry practices, and creating favorable land tenure arrangements that encourage long-term investment in agroforestry.Policies that promote research and extension services for agroforestry are also crucial. Governments should invest in research to develop region-specific agroforestry models and best practices, as well as extension services to disseminate this knowledge to farmers. Training programs and capacity-building initiatives can help farmers acquire the skills and knowledge needed to implement and manage agroforestry systems effectively [56].International cooperation and policy alignment are also important. Global initiatives such as the United Nations Sustainable Development Goals (SDGs) and the Paris Agreement on climate change provide frameworks for integrating agroforestry into broader environmental and development agendas. Governments should work together to align policies and leverage international funding and support for agroforestry initiatives.

C. Research and Development Needs

Research and development (R&D) are critical for advancing agroforestry practices and addressing the challenges associated with their implementation. One key area of research is the development of improved tree species and varieties that are well-suited to different agroecological conditions. This includes breeding for traits such as drought tolerance, pest resistance, and fast growth, as well as developing methods for vegetative propagation and seed production [57].Research is also needed to better understand the ecological and socio-economic impacts of agroforestry systems. Long-term studies can provide valuable insights into the benefits and trade-offs of different agroforestry practices, as well as their impacts on biodiversity, soil health, water resources, and rural livelihoods. Socio-economic research can help identify the factors that influence the adoption of agroforestry practices and develop strategies to overcome barriers to adoption.Innovations in agroforestry management and technology also require R&D investment. This includes developing precision agroforestry tools and techniques, as well as exploring the potential of agroforestry in emerging fields such as bioenergy production and carbon markets [58]. Collaborative research efforts involving governments, universities, research institutions, and the private sector can help drive innovation and accelerate the development and adoption of agroforestry practices.

D. Role of Stakeholders in Promoting Agroforestry

The successful promotion and implementation of agroforestry practices require the active involvement of a wide range of stakeholders. Farmers are at the forefront of agroforestry, and their participation and engagement are essential. Providing farmers with the knowledge, skills, and resources needed to adopt and manage agroforestry systems is crucial. Farmer organizations and cooperatives can play a key role in facilitating knowledge exchange, collective action, and access to markets and financial services [59].Extension services and non-governmental organizations (NGOs) are important stakeholders in promoting agroforestry. Extension agents and NGOs can provide technical support, training, and capacity-building to farmers, as well as facilitate the dissemination of best practices and innovations. They can also advocate for supportive policies and create awareness about the benefits of agroforestry among policymakers and the general public.The private sector also has a significant role to play in promoting agroforestry. Agribusinesses, financial institutions, and technology providers can invest in agroforestry projects, develop agroforestry products and services, and create market opportunities for agroforestry products. Public-private partnerships can leverage the strengths of both sectors to promote the adoption and scaling up of agroforestry practices [60].Finally, governments and policymakers are critical stakeholders. They can create enabling environments for agroforestry through supportive policies, regulations, and incentives. Governments can also invest in R&D, extension services, and infrastructure to support the adoption and scaling up of agroforestry practices. International organizations and donors can provide funding and technical assistance to support national and regional agroforestry initiatives.

Conclusion

Agroforestry practices offer significant potential for biodiversity conservation and sustainable land management, addressing socio-economic, environmental, and technical challenges. By integrating trees, crops, and livestock, agroforestry systems enhance habitat creation, genetic diversity, species richness, and ecosystem services such as soil fertility, water regulation, carbon sequestration, and pest management. Despite the barriers to adoption, including socio-economic constraints, policy gaps, and technical knowledge deficiencies, innovative practices and supportive policies can drive the widespread implementation of agroforestry. Continued research, development, and stakeholder collaboration are essential to overcome these challenges and realize the full benefits of agroforestry. As global environmental and climate crises intensify, agroforestry presents a viable solution for resilient and sustainable agricultural landscapes, contributing to food security, rural livelihoods, and ecological health.

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 manuscripts.

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