



The role of agroforestry in enhancing farm sustainability and biodiversity

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Abstract

Agroforestry represents a multifunctional approach that integrates trees, crops, and sometimes livestock to create productive agricultural systems. It holds considerable promise for enhancing the long-term sustainability of farms by improving soil health, optimizing resource use, and providing resilience against environmental stressors. In addition to its benefits for agricultural productivity, agroforestry practices are recognized for fostering increased biodiversity, as they offer habitats and food sources for a wide variety of species. This essay examines both the ways in which agroforestry supports sustainable farming practices and the mechanisms by which it contributes to broader ecological diversity. The discussion culminates with an exploration of strategies for integrating agroforestry into contemporary agricultural systems, underscoring its practical relevance for the future of agriculture.

Keywords: Agroforestry, sustainability, biodiversity, soil fertility and ecosystem services

Introduction

Agroforestry is defined as the intentional integration of woody perennials such as trees and shrubs with crops and occasionally livestock within the same land management system. As agricultural challenges related to environmental degradation and declining soil productivity have intensified, agroforestry has garnered increasing attention for its capacity to address these issues through ecologically rooted approaches. This method is distinguished by its emphasis on interdependence among plant species, resulting in agricultural landscapes that are both productive and resilient. The present essay addresses the dual focus of agroforestry's influence on farm sustainability and its role in promoting biodiversity, providing a detailed exploration of each dimension. By examining these critical aspects, the discussion seeks to clarify why agroforestry is increasingly recognized as an integral component of modern, sustainable agriculture and highlights its ability to meet the evolving demands of food production and environmental stewardship.

The Concept and Principles of Agroforestry

Agroforestry is characterized by the intentional combination of trees, crops, and sometimes livestock within a unified land management approach, facilitating interactions that benefit both productivity and ecological health. Central to its principles is the spatial and temporal arrangement of plant species so that their differences in resource requirements result in improved land use efficiency. This integration not only boosts overall biomass production but also addresses environmental concerns such as carbon sequestration and soil preservation (Raj *et al.*, 2019) ^[12]. Through its incorporation of diverse biological components, agroforestry ensures sustained crop yields while providing essential services like fuelwood, timber, and nutritional resources, particularly in regions facing food and resource insecurity. By following structured practices that optimize the coexistence of multiple species, agroforestry establishes a system that maintains soil fertility, enhances economic

opportunity, and supports long-term sustainable agriculture (Raj *et al.*, 2019) ^[12].

Additionally, the historical development of agroforestry demonstrates its longstanding foundation in indigenous agricultural practices across various continents. Ancient farming communities in Africa, Asia, and the Americas implemented integrated systems combining trees, crops, and animals to maintain productivity and ecosystem stability. These traditional methods included practices such as alley cropping, shifting cultivation, and silvopasture, which relied on the natural complementarity among different biological components to secure food resources and ecological health. Over centuries, these locally adapted strategies enabled farmers to address environmental challenges, such as soil erosion and nutrient depletion, while ensuring the regular availability of essential resources for their communities (Raj *et al.*, 2022) ^[11]. As a consequence, the enduring relevance of these traditional agroforestry approaches has inspired modern adaptations that promote both agricultural sustainability and the restoration of degraded landscapes, bridging ancient wisdom with current scientific principles.

Furthermore, agroforestry encompasses a range of system types, each offering distinct structural and functional characteristics adapted to varying environmental and agricultural needs. Alley cropping involves the cultivation of crops between rows of trees or shrubs, promoting efficient nutrient cycling and protecting soil from erosion through the presence of perennial vegetative cover (Pantera *et al.*, 2021) ^[9]. Silvopasture combines trees with livestock grazing on the same land, providing animal shelter, improved forage quality, and diversified income streams. Forest farming incorporates shade-tolerant crops cultivated under a managed forest canopy, allowing for the sustainable production of non-timber products such as medicinal plants or mushrooms alongside timber resources. Windbreaks and riparian buffers, composed of strategically planted trees and shrubs, serve to reduce wind erosion and protect waterways, further contributing to habitat creation and environmental

management while enhancing overall farm resilience (Pantera *et al.*, 2021) ^[9].

Agroforestry and Farm Sustainability

Sustainable agriculture seeks to ensure the long-term viability of farming systems by maintaining or improving productivity, conserving natural resources, and reducing environmental impacts. In the context of modern agriculture, farm sustainability is foundational because it directly influences food security, farmer livelihoods, and ecological integrity in the face of climatic and socio-economic pressures. Ensuring sustainable practices involves more than simply maximizing yields; it requires integrated approaches that support soil health, water management, and biodiversity while balancing economic and ecological priorities. Agroforestry contributes directly to these objectives by functioning as a nature-based solution, as it integrates ecological, agricultural, and socio-economic

considerations to address challenges such as resource depletion and land degradation (Plieninger *et al.*, 2020) ^[10]. As global agricultural systems adapt to increasing demands and changing environmental conditions, the pursuit of sustainable farming remains a central imperative, making the incorporation of agroforestry methods especially pertinent within current and future landscape management strategies. The table-1 explains how agroforestry strengthens farm sustainability by improving soil fertility, enhancing water management, and promoting efficient nutrient cycling. Trees enrich the soil with organic matter, reduce erosion, and increase moisture retention, making farming more resilient to climate stress. Agroforestry also reduces dependence on chemical fertilizers, supports climate change mitigation by storing carbon, and provides farmers with multiple income sources like fruits, timber, and fodder. Together, these benefits make agricultural systems more productive, cost-effective, and environmentally sustainable.

Table 1: Role of Agroforestry in Enhancing Farm Sustainability

Aspect of Sustainability	Agroforestry Contribution
Soil Health Improvement	Enhances soil organic matter, increases nutrient cycling, improves structure, and reduces erosion.
Water Management	Increases water infiltration, reduces runoff, boosts soil moisture retention, and protects water bodies.
Efficient Nutrient Cycling	Deep-rooted trees bring up nutrients; leaf litter enriches soil, reducing fertilizer dependence.
Economic Benefits	Diversifies income (timber, fruits, fodder), lowers input costs, and improves farmer resilience.
Climate Change Mitigation	Sequesters carbon, reduces greenhouse gas emissions, and supports climate-resilient agriculture.
Social & Community Benefits	Improves food security, supports rural livelihoods, preserves traditional knowledge, and fosters local participation.

In particular, agroforestry is regarded as a valuable method for improving soil health due to its multifaceted effects on soil structure, fertility, and erosion control. Incorporating trees and shrubs into agricultural systems enhances the physical properties of soil by increasing organic matter and promoting better aggregation, which improves aeration and water infiltration. These systems also contribute to greater nutrient cycling; roots of diverse species access different soil layers, thereby redistributing essential minerals and maintaining soil fertility (Fahad *et al.*, 2022) ^[4]. Furthermore, agroforestry provides ground cover that shields soil from the impact of rainfall and wind, reducing the risk of surface runoff and erosion while stabilizing soil during extreme weather events. By integrating these management practices, agroforestry not only sustains productive capacity but also preserves the long-term environmental function of agricultural landscapes (Fahad *et al.*, 2022) ^[4].

Moreover, agroforestry systems play a crucial part in improving water management within agricultural landscapes by enhancing water retention, minimizing runoff, and safeguarding water resources. The strategic placement of trees and shrubs in these systems encourages deeper root penetration, which facilitates greater water infiltration and helps the soil retain moisture for extended periods. This increased retention reduces surface runoff, thereby lessening the likelihood of nutrient leaching and topsoil loss during periods of heavy rainfall and mitigating downstream flooding events (Eddy & Yang, 2022) ^[3]. Trees and perennial plants also serve as natural buffers, filtering sediments and agricultural pollutants before they reach nearby lakes, rivers, or groundwater reserves. As a result, agroforestry supports the sustained availability of high-quality water for both agricultural production and surrounding ecosystems by combining soil conservation with resource protection (Eddy & Yang, 2022) ^[3].

Additionally, agroforestry improves nutrient cycling by fostering interactions among tree roots, crops, and soil microorganisms, leading to more efficient redistribution of essential minerals within the ecosystem. The integration of deep-rooted woody species with annual crops enables the uptake of nutrients from subsoil layers, which are subsequently deposited on the surface through leaf litter and root turnover. This process enriches the topsoil with organic matter and nutrients, creating a self-renewing cycle that sustains fertility without continuous external inputs. As a result, agroforestry systems can significantly diminish the dependence on synthetic chemical fertilizers, thus reducing associated costs and minimizing environmental risks linked to nutrient runoff or contamination (Jose, 2019) ^[5]. By promoting natural soil enrichment and resource recycling, these practices contribute to a more balanced and ecologically responsible approach to farm management, complementing the previous strategies for water conservation and soil protection within sustainable agriculture.

Furthermore, the economic advantages provided by agroforestry systems are as compelling as their ecological and agronomic contributions. By combining crops, trees, and sometimes livestock, agricultural producers can access diverse income streams, thereby reducing their dependence on a single commodity and enhancing economic stability. Agroforestry enables farmers to capitalize on marketable products such as timber, fruit, and biomass while simultaneously gaining value from ecosystem services, including carbon storage and reduced environmental remediation costs (Kay *et al.*, 2019) ^[6]. This diversified revenue framework mitigates the risks associated with market price volatility and adverse climate conditions, enabling farmers to better withstand disruptions that might otherwise threaten their livelihoods. The integration of these multiple income sources and protective ecosystem functions

highlights why adopting agroforestry can be a practical strategy for long-term financial security and resilience in agricultural enterprises (Kay *et al.*, 2019) ^[6].

In addition, agroforestry contributes to climate change mitigation by facilitating the sequestration of atmospheric carbon and curbing greenhouse gas emissions. The integration of trees and shrubs into farming landscapes allows these woody perennials to capture and store substantial amounts of carbon dioxide through photosynthetic processes within their biomass and root systems. This natural storage of carbon reduces the atmospheric concentration of greenhouse gases, directly addressing the principal driver of anthropogenic climate change (Awazi & Tchamba, 2019) ^[1]. Furthermore, agroforestry systems diminish reliance on external inputs such as synthetic fertilizers, as improved nutrient cycling and soil fertility lower the need for these energy-intensive products. Collectively, these mechanisms not only reduce the overall carbon footprint associated with agriculture but also support climate-resilient production systems, reinforcing the environmental and economic case for adopting agroforestry methods (Awazi & Tchamba, 2019) ^[1].

Similarly, agroforestry provides tangible social and community benefits, particularly through its contributions to food security and the support of rural livelihoods. By diversifying on-farm production with a range of edible species and marketable products, agroforestry systems bolster household food availability while enabling surplus production for local or regional trade. The incorporation of trees and perennial crops into rural landscapes also supports community well-being by promoting gender inclusion and fostering opportunities for local participation in decision-making processes (Mukhlis *et al.*, 2022) ^[7]. Beyond individual farms, agroforestry has the capacity to stimulate cultural activities and reinforce traditional agricultural knowledge, thereby strengthening the social fabric of rural communities. Through the empowerment of local actors and the enhancement of nutritional access, these approaches directly address the broader dimensions of sustainable development and community resilience, complementing their ecological and economic contributions to sustainable agriculture (Mukhlis *et al.*, 2022) ^[7].

Therefore, agroforestry emerges as a holistic approach to farming by integrating multifaceted sustainability advantages that extend across ecological, economic, and social dimensions. Its capacity to support soil fertility, enhance water management, and foster efficient nutrient cycling

directly boosts agricultural productivity, which is particularly evident in systems practiced by smallholder farmers (Castle *et al.*, 2021) ^[2]. Additionally, the diversification of income sources through agroforestry reduces economic vulnerability, as it offers both immediate and long-term financial opportunities from a range of outputs. Environmental benefits, such as improved ecosystem services and soil preservation, further reinforce agroforestry’s position as a system that addresses not only resource conservation but also climate mitigation. By harmonizing productive, resource-conserving, and socially responsive strategies, agroforestry stands out as an integrated model that sustains farm viability while meeting pressing agricultural and environmental challenges in a balanced manner (Castle *et al.*, 2021) ^[2].

Agroforestry and Biodiversity Enhancement

Biodiversity is widely recognized as essential for maintaining the balance and resilience of agricultural ecosystems, directly supporting the stability and productivity of farm landscapes. Agroforestry systems contribute to on-farm biodiversity by introducing diverse vegetation layers, which create a variety of ecological niches and microhabitats for flora and fauna. These layered arrangements foster greater species richness compared to monoculture fields, supporting a wider range of animals, plants, and microorganisms through the continuous presence of woody perennials and understory vegetation (Udawatta *et al.*, 2019) ^[14]. Research indicates that the spatial diversity and favorable microclimatic conditions associated with trees and shrubs in agroforestry not only attract pollinators and natural pest predators but also improve soil microbial activity, further sustaining ecosystem processes vital to both agriculture and conservation. By establishing these intricate habitat networks, agroforestry becomes instrumental in enriching farm biodiversity and enhancing the ecological function of production landscapes (Udawatta *et al.*, 2019) ^[14]. The table-2 highlights how agroforestry boosts biodiversity by creating diverse vegetation layers that support a wide range of plants, animals, and soil organisms. Trees and shrubs provide habitats for birds, insects, and small animals while improving plant diversity through multi-strata arrangements. These systems attract pollinators, strengthen natural pest control, and help conserve native and endangered species by offering stable habitats. By promoting ecological interactions and creating more complex landscapes than monocultures, agroforestry significantly improves ecosystem health and resilience.

Table 2: Role of Agroforestry in Biodiversity Enhancement

Biodiversity Component	Agroforestry Contribution
Plant Diversity	Integrates multiple tree, shrub, and crop species, creating multilayered vegetation structures.
Animal & Insect Diversity	Provides habitats for birds, pollinators, beneficial insects, and soil organisms.
Pollination Support	Offers continuous floral resources and microhabitats that sustain pollinator populations.
Natural Pest Predation	Attracts predators like birds and beneficial insects, reducing dependence on pesticides.
Native Species Conservation	Mimics natural habitats, protecting endangered and indigenous flora and fauna.
Ecological Interactions & Stability	Promotes mutualistic relationships (e.g., nitrogen-fixing plants), improving ecosystem resilience.

Specifically, agroforestry amplifies plant diversity by purposefully integrating several species of trees, shrubs, and crops across the farm landscape. This approach replaces uniform monocultures with assemblies of varying perennial and annual species, resulting in a multilayered structure that supports both ecological function and resilience. Through

combinations of species with different growth habits and ecological functions, agroforestry systems generate overlapping strata above and below ground, which further heightens the diversity and genetic variability within managed farmland (Nair *et al.*, 2021) ^[8]. Notably, multistrata agroforestry arrangements—including those

found in tropical regions—demonstrate superior capacity to maintain both aboveground and belowground diversity when compared to conventional agriculture. By embedding a range of species within agricultural spaces, agroforestry not only restores plant complexity formerly found in natural forests but also enhances the conservation and circulation of genetic resources lost in simplified, single-crop systems (Nair *et al.*, 2021) ^[8].

Moreover, agroforestry exerts a strong influence on animal biodiversity by providing habitats and resources for a diverse array of bird, insect, and soil-dwelling species. The structural complexity of agroforestry systems, characterized by multiple layers of vegetation and the presence of perennial plants, facilitates increased populations of avian and insect wildlife throughout agricultural landscapes. Birds, in particular, benefit from the availability of food, shelter, and nesting sites within tree-dominated areas, while insect populations—including pollinators and natural pest predators—find supportive environments due to diverse floral species and a stable microclimate. These settings also foster greater abundance and activity of beneficial soil organisms, such as bacteria, fungi, and invertebrates, which are crucial for nutrient cycling and soil fertility (Udawatta *et al.*, 2021) ^[15]. Thus, by integrating a mixture of plant species and perennial vegetation, agroforestry creates multifunctional habitats that support the persistence and vitality of animal communities otherwise diminished in monocropped systems (Udawatta *et al.*, 2021) ^[15].

Additionally, agroforestry systems play a crucial role in sustaining pollinator populations and supporting natural pest predators through the deliberate incorporation of diversified plant species and varied vegetation layers. The structural and floral diversity within these systems offers continuous resources, such as nectar, pollen, shelter, and nesting habitats, which are essential for attracting and maintaining healthy communities of bees, butterflies, predatory insects, and birds. By enabling year-round foraging and refuge opportunities, agroforestry landscapes facilitate greater abundance and stability of beneficial organisms, leading to more regular pollination services and biological pest control. This ecological balance directly decreases the dependence on chemical pesticides, as natural enemy populations are more effective in regulating pest outbreaks within multifaceted environments as compared to monoculture fields (Santos *et al.*, 2019) ^[13]. Across diverse agricultural regions, such interactions have resulted in improved productivity and ecosystem health, demonstrating the value of agroforestry in strengthening both pollination and pest management outcomes while minimizing synthetic input usage.

Furthermore, agroforestry plays a critical role in the conservation of native species and the protection of endangered flora and fauna by sustaining complex habitat networks embedded within agricultural landscapes. The diversified and perennial vegetation in agroforestry systems offers spatial heterogeneity that mimics natural habitats, supporting the persistence and recruitment of indigenous plant and animal species, many of which are vulnerable to extinction in highly simplified monoculture environments. This structural complexity provides refuge and resources, such as food and nesting sites, enabling native wildlife—including rare birds, reptiles, and insects—to thrive amidst agricultural production systems (Udawatta *et al.*, 2021) ^[15]. Additionally, the favorable microclimatic conditions

generated by canopy cover and litter accumulation promote the recovery and regeneration of threatened plants, contributing to broader ecosystem restoration. By actively supporting the spatial distribution and abundance of both floral and faunal diversity, agroforestry emerges as an effective land management tool for safeguarding regional biodiversity and mitigating the decline of endangered species (Udawatta *et al.*, 2021) ^[15].

In fact, agroforestry generates a web of ecological interactions and synergies that play a vital role in fostering functional agricultural systems. The deliberate arrangement of multiple plant species in proximity creates opportunities for mutualistic relationships, such as nitrogen-fixing legumes improving soil fertility for neighboring crops and trees. Animal species, including pollinators and natural pest predators, benefit from the diversified habitats and food resources provided by these mixed-vegetation environments, which in turn support enhanced pollination and biological pest control. Furthermore, the integration of livestock or wildlife within agroforestry systems can promote nutrient cycling and vegetation management, reinforcing the ecological stability of the farm landscape (Raj *et al.*, 2019) ^[12]. Through these interconnected relationships between plants and animals, agroforestry not only boosts productivity and resource use efficiency but also strengthens the resilience and sustainability of agricultural ecosystems (Raj *et al.*, 2019) ^[12].

However, despite the advantages associated with agroforestry for biodiversity enhancement, significant challenges and limitations must be acknowledged. The complexity of managing multiple species with diverse ecological requirements, growth habits, and interactions often increases operational demands and necessitates specialized knowledge from practitioners. This heightened management complexity can create barriers for implementation, especially among smallholders or in regions where technical support and extension services are limited (Plieninger *et al.*, 2020) ^[10]. Furthermore, agroforestry systems may pose ecological risks if non-native or potentially invasive species are introduced without careful oversight, thereby threatening native biodiversity and undermining intended conservation outcomes. Addressing these limitations requires comprehensive planning, awareness of local ecological contexts, and integration of stakeholder expertise to ensure that agroforestry contributes positively to both agricultural productivity and regional biodiversity conservation (Plieninger *et al.*, 2020) ^[10].

Overall, agroforestry enhances biodiversity not only within individual farms but also across entire landscapes, resulting in greater ecosystem stability and resilience. By incorporating a variety of plant species and maintaining vegetation structure at multiple levels, these systems support increased diversity among flora, fauna, and soil microorganisms while establishing high-density biological communities near tree stands (Udawatta *et al.*, 2019) ^[14]. This expanded diversity underpins vital ecosystem services, such as pollination, pest regulation, and nutrient cycling, which are critical for both agricultural production and broader ecological health. Consequently, agroforestry's heterogeneous environments buffer farming operations against environmental perturbations, bolstering their capacity to adapt to climatic variability or pest outbreaks. These functions, deeply rooted in the spatial arrangement

and microclimatic benefits provided by trees, demonstrate how agroforestry systems serve as effective mechanisms for conserving biodiversity and supporting resilient agricultural landscapes (Udawatta *et al.*, 2019) ^[14].

Integrating Agroforestry into Modern Agricultural Practices

Consequently, effective strategies for integrating agroforestry into modern agricultural practices must consider policy frameworks, educational outreach, and targeted incentives for farmers. Policy support is fundamental, as government interventions can offer guidance, infrastructure, and financial mechanisms that encourage the adoption of agroforestry models suited to varying ecological conditions (Raj *et al.*, 2022) ^[11]. Comprehensive educational programs—delivered through extension services, farmer field schools, or digital resources—are also crucial for equipping practitioners with the scientific knowledge and technical skills necessary for successful implementation and long-term management. Furthermore, providing incentives such as financial subsidies, access to credit, or preferential market opportunities can motivate land managers to adopt diversified systems that enhance environmental and socioeconomic outcomes. These concerted strategies, supported by scientifically informed management practices, substantially increase the likelihood of widespread agroforestry adoption and maximize its contribution to climate mitigation, food security, and biodiversity conservation within contemporary farm settings (Raj *et al.*, 2022) ^[11].

Conclusion

In summary, agroforestry stands as a proven approach for improving farm sustainability and enhancing biodiversity within agricultural systems. Through the integration of trees, crops, and sometimes livestock, agroforestry supports soil fertility, water management, and nutrient cycling, which collectively underpin long-term agricultural productivity. Equally, the structural and species diversity provided by these systems fosters greater biological richness, supporting a range of plant, animal, and microbial communities that contribute essential ecosystem functions such as pollination and pest regulation. These dual benefits position agroforestry as a practical framework for addressing contemporary agricultural challenges, including climate change, resource scarcity, and the loss of ecological complexity. Looking ahead, mainstreaming agroforestry principles within broader agricultural policy and practice will be vital for advancing sustainable food production and conserving biodiversity amid global environmental change.

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