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The Role of Agroforestry in Sustainable Land Management and Climate Resilience for enhancing Crop Production: A Literature Review

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

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Review Article

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ABSTRACT

Agroforestry has emerged as a fundamental strategy for sustainable land management and climate resilience, integrating trees with crops and livestock to enhance ecological and socioeconomic outcomes. This literature review examines the role of agroforestry in improving soil health,

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biodiversity, water management, and crop productivity while mitigating climate change through carbon sequestration. Key agroforestry systems, such as agrosilviculture, agrosilvopastoral, silvopastoral systems, and specialized systems, are explored for their benefits, including nitrogen fixation, erosion control, and microclimate regulation. Despite these advantages, challenges like policy gaps, land tenure insecurity, financial constraints, and limited technical knowledge hinder widespread adoption, particularly in Zambia. The study underscores the need for interdisciplinary research, policy integration, and capacity-building to scale up agroforestry practices. By addressing these barriers, agroforestry can significantly contribute to sustainable agriculture, food security, and climate adaptation, offering a resilient pathway for future land-use systems.

Keywords: Agroforestry; climate resilience; crop production; sustainable land management.

1. INTRODUCTION

Zambia is endowed with a substantial natural resource base for agriculture, covering 75 million hectares of land, 42 million of which has medium to high potential for agricultural production (Tembo et al., 2025). However, the sustainability of this agricultural potential is increasingly threatened by climate change and environmental degradation, necessitating innovative land-use strategies. Agroforestry has emerged as a vital approach, combining trees with crops and livestock to enhance ecological resilience and socioeconomic sustainability (Verma et al., 2021). By integrating trees into agricultural landscapes, agroforestry systems offer a complex solution to some of Zambia's most pressing challenges, including soil degradation, biodiversity loss, and climate vulnerability. The climate resilience benefits of agroforestry are well-documented. Studies demonstrate that agroforestry systems stabilize local ecosystems, reduce the risk of crop failure, and improve soil fertility through organic matter retention (Pancholi et al., 2023; Muyabe et al., 2024). These systems act as buffers against extreme weather events, such as droughts and floods, ensuring more stable agricultural yields over time (Verma et al., 2021). Furthermore, the ecological stability provided by agroforestry stems from its promotion of species diversity, which enhances functional redundancy and supports critical ecosystem services.

Beyond climate adaptation, agroforestry plays a key role in biodiversity conservation. Conventional agricultural practices often lead to habitat fragmentation and species loss, whereas agroforestry maintains ecological connectivity by integrating trees and natural vegetation into farming systems (Raihan, 2023). This diversity supports pollinators, beneficial insects, and soil microorganisms all of which are essential for long-term agricultural productivity. Additionally, agroforestry helps preserve indigenous plant species that may hold untapped potential for climate-resilient crop development (Katumo et al., 2022). From a socioeconomic perspective, agroforestry offers significant advantages for smallholder farmers, who form the backbone of Zambia's agricultural sector. Diversification of farm products including timber, fruit, nuts, and medicinal plants reduces economic vulnerability while improving food security and income stability (Mbabarira & Nahayo, 2020). Moreover, agroforestry systems create employment opportunities, stimulate rural economies, and reduce dependence on single-crop systems, thereby enhancing community resilience. Despite these benefits, the widespread adoption of agroforestry in Zambia faces several barriers. Key challenges include inadequate policy support, insecure land tenure, limited access to quality tree seedlings, and a lack of technical knowledge among farmers (Kiyani et al., 2017). Addressing these constraints is critical to unlocking agroforestry's full potential as a sustainable land-use strategy. This research critically evaluates agroforestry's role in strengthening climate resilience, protecting biodiversity, and promoting sustainable land management. By examining diverse agroforestry practices, assessing their ecological and socio-economic implications, and evaluating their effectiveness in climate change mitigation, this study aims to provide evidence-based recommendations for incorporating agroforestry into climate-smart agricultural strategies that support a sustainable and resilient future.

2. AGROFORESTRY SYSTEMS SUPPORTING CROP PRODUCTION

2.1 Major Agroforestry Practices

2.1.1 Agrosilviculture: Integrating trees with crops

Agrosilviculture involves growing trees alongside crops, creating a mutually beneficial system.

Trees provide shade, reduce wind erosion, and enhance soil fertility through organic matter decomposition. Specific species, such as *Gliricidia sepium* and *Faidherbia albida*, fix nitrogen in the soil, reducing dependence on synthetic fertilizers (Fungo et al., n.d.). A compelling example comes from sub-Saharan Africa, where maize farmers incorporate *Faidherbia albida* trees into their fields. These trees exhibit a unique phenological pattern shedding leaves during the wet growing season, which allows sufficient sunlight to reach crops while simultaneously enriching the soil with nutrient-rich organic matter. Research demonstrates that maize yields increase by 100-200% in fields with these trees compared to mono-cropped areas (Sida et al., 2018).

2.1.2 Silvopastoral systems: Integrating trees with livestock

Silvopastoral systems incorporate trees, pasture, and livestock to create more sustainable grazing environments. Trees provide shade for animals, reducing heat stress and improving overall health outcomes. They also contribute to enhanced forage quality through increased soil organic matter and improved water retention.

An exemplary case of successful Silvopastoral implementation can be observed in Brazil, where farmers have strategically integrated Eucalyptus trees into cattle pastures. These trees provide essential shelter for livestock, while their fallen leaves enrich the soil profile, leading to higher-quality pasture growth (Tsufac et al., 2021). Empirical studies have demonstrated that such integrated systems increase both meat and dairy production while simultaneously contributing to carbon sequestration.

2.1.3 Agrosilvopastoral systems: Combining trees, crops, and livestock

Agrosilvopastoral systems represent some of the most diverse and complex agroforestry models, integrating trees, crops, and livestock into a single, multifunctional farming system. This approach maximizes land productivity while minimizing environmental degradation (Tsufac et al., 2021).

In Cameroon, farmers have developed sophisticated Agrosilvopastoral systems that intercrop maize with nitrogen-fixing trees while allowing livestock to graze in the fields after harvest. This integrated method enhances soil fertility, reduces animal feed costs, and provides multiple revenue streams for farmers throughout the year (Tsufac et al., 2021). Such systems demonstrate particular resilience in regions prone to climate variability, ensuring food security even during adverse weather conditions.

2.2 Specialized Agroforestry Systems

2.2.1 Alley cropping and windbreaks

Alley cropping involves planting rows of trees or shrubs alongside crops, enhancing biodiversity and improving land productivity. This practice effectively reduces soil erosion, improves crop performance, and promotes biodiversity (Wolz & DeLucia, 2018). Windbreaks, composed of strategically planted rows of trees or shrubs, function as protective barriers against strong winds that can damage crops, erode topsoil, and reduce moisture retention. Research indicates they can improve crop yields by 5-10% by minimizing wind stress and evaporation, thereby creating more favourable growing microclimates (Smith et al., 2021).

2.2.2 Home gardens

Home gardens represent traditional agroforestry systems that integrate various plant species including fruits, vegetables, medicinal plants, and spices often combined with small livestock. These systems contribute significantly to household food security, nutrition, and income generation. They also play crucial roles in biodiversity conservation and climate change mitigation at the local level (Nair et al., 2022). The primary limitation of home gardens is their relatively small scale, which constrains their broader environmental impact compared to landscape-level agroforestry implementations.

2.2.3 Riparian buffers

Riparian buffers consist of vegetation strips planted along waterways to intercept pollutants, reduce erosion, and enhance water quality. These buffer zones play a crucial role in maintaining watershed health by trapping sediments, nutrients, and pesticides before they enter water bodies. They also provide habitat corridors for wildlife, promote biodiversity, and support pollinator populations, contributing to overall ecosystem resilience (Anderson & Udawatta, 2019). Studies have shown that properly designed riparian buffers can reduce nitrogen and phosphorus runoff by 50-90%, significantly improving downstream water quality.

Table 1. Major agroforestry systems

System	Components	Examples	Key Benefits
Agrosilviculture	Trees + Crops	Faidherbia albida with maize (Sub-Saharan Africa)	Shade provision, wind erosion reduction, nitrogen fixation, improved soil fertility
Silvopastoral	Trees + Pasture + Livestock	Eucalyptus in cattle pastures (Brazil)	Shade for livestock, enhanced forage quality, reduced heat stress, carbon sequestration
Agrosilvopastoral	Trees + Crops + Livestock	Maize with nitrogen-fixing trees + livestock (Cameroon)	Soil fertility enhancement, diversified income, reduced feed costs, climate resilience

Table 2. Specialized agroforestry systems

System	Components	Examples/Implementation	Key Benefits
Alley Cropping	Trees/shrubs + Crops	Rows between crops or as barriers	Reduces soil erosion, improves microclimate (5-10% yield increase)
Windbreaks	Protective tree barriers	Tree rows perpendicular to winds	Shields crops from wind stress, reduces evaporation
Home Gardens	Fruit trees + Vegetables + Livestock	Household-level diverse plantings	Food security, nutrition, income, biodiversity conservation
Riparian Buffers	Trees + Shrubs + Grasses	Planted along water bodies	50-90% reduction in N/P runoff, improves water quality, wildlife habitat
Contour Hedgerows	Trees/shrubs + Terraced crops	Follows hillside contours	Reduces erosion, enhances water retention, improves soil fertility
Multi-Strata	Canopy + Mid-story + Understory	Shaded coffee systems	Maximizes vertical space, enhances biodiversity, natural pest control

2.2.4 Contour hedgerows and multi-strata systems

Contour hedgerows involve planting rows of trees or shrubs along the natural contours of sloped landscapes to reduce soil erosion and enhance water retention. These hedgerows function as living barriers that slow water runoff, allowing sediments and nutrients to accumulate and improve soil fertility in terraced agricultural systems (Pattanayak & Mercer, 1998).

Multi-strata agroforestry systems are designed to replicate natural forest structures by incorporating multiple layers of vegetation, from canopy trees to understory crops. These systems enhance biodiversity, improve soil structure, and optimize vertical space for maximum land productivity. An exemplary multi-strata approach is the shaded coffee agroforestry system, where coffee plants grow beneath taller shade trees, creating favourable microclimates while supporting ecosystem services such as carbon sequestration and natural pest control (Nair et al., 2022).

3. AGROFORESTRY AND SUSTAINABLE CROP PRODUCTION

Agroforestry, the strategic integration of trees, shrubs, and crops within agricultural landscapes, significantly contributes to sustainable crop production by enhancing biodiversity, improving soil health, and increasing resilience to climate change. By incorporating trees into farming systems, agroforestry improves ecosystem services, mitigates soil degradation, and boosts agricultural productivity (Kumar et al., 2023). This section explores how agroforestry enhances soil health and fertility to promote sustainable crop production.

3.1 Building Resilient Soils: The Foundation of Crop Success

Soil health and fertility are fundamental to agricultural sustainability, and agroforestry systems improve these aspects through multiple interconnected mechanisms. The integration of trees with crops enhances microbial activity, maintains soil moisture, and reduces reliance on synthetic fertilizers, fostering long-term soil productivity (Kumar et al., 2023; Kaur et al., 2023).

Agroforestry enhances soil fertility by increasing organic matter inputs through leaf litter and root exudates, which enrich the soil and promote microbial activity that facilitates nutrient mineralization (Pardon et al., 2017). The decomposition of organic matter, particularly from leguminous species like *Gliricidia sepium* and *Sesbania sesban*, significantly increases soil nitrogen levels, reducing the need for chemical fertilizers while enhancing crop yields (Raza et al., 2023).

The strategic placement of trees helps control soil erosion by stabilizing soil with extensive root systems and reducing the impact of wind and water erosion (Kaur et al., 2023). Tree canopies intercept rainfall, minimizing surface runoff and promoting better water infiltration, while accumulated leaf litter forms a protective organic layer that improves moisture retention and soil structure (Howard et al., 2022). The researcher further indicates that agroforestry interventions can reduce soil loss by up to 50% in sloped agricultural landscapes.

Leguminous trees commonly used in agroforestry, such as *Faidherbia albida* and *Calliandra calothyrsus*, facilitate nitrogen fixation through symbiotic relationships with rhizobia bacteria, converting atmospheric nitrogen into plant-available forms (Kaur et al., 2023). This reduces dependency on synthetic nitrogen fertilizers, lowering production costs and environmental impacts. Additionally, trees act as "nutrient pumps," extracting nutrients from deeper soil layers and redistributing them through leaf litter decomposition, ensuring a steady supply of nutrients for crops (Raza et al., 2023).

3.2 Microclimate Regulation and Water Conservation: Creating Resilient Agricultural Systems

Agroforestry significantly enhances microclimate conditions and water resource management, creating more stable and resilient growing environments. Tree canopies provide shade that reduces soil temperature and evaporation, helping maintain soil moisture while contributing to increased humidity and reduced wind erosion (Kaushal et al., 2021). This microclimate regulation is particularly beneficial for crop resilience in regions experiencing climatic variability.

The extensive root systems of trees improve soil structure and promote water infiltration while reducing surface runoff, with studies showing that agroforestry can decrease runoff by up to 50% compared to conventional agricultural systems (Xie et al., 2020). This enhanced infiltration leads to better groundwater recharge and reduced soil erosion. The accumulated leaf litter and organic matter contribute to soil aggregation, further enhancing water-holding capacity throughout the soil profile.

Agroforestry systems demonstrate superior drought resilience through deep-rooted trees that access water from lower soil layers, helping sustain associated crops during dry periods (Thorup-Kristensen et al., 2020). The organic matter from tree litter creates a protective layer that reduces evaporation losses, ensuring long-term water conservation in drought-prone areas. These water management benefits have become increasingly important as climate change intensifies the frequency and severity of drought events globally (Zhang et al., 2023).

3.3 Pest, Disease and Biodiversity Management

3.3.1 Pest and disease management

Agroforestry systems contribute significantly to the natural control of agricultural pests and diseases, thereby reducing reliance on chemical pesticides. The incorporation of diverse plant species creates habitats for natural predators of pests, such as birds, insects, and other beneficial organisms, which help regulate pest populations (Pumariño et al., 2015).

The structural complexity of these systems can act as physical barriers, impeding the spread of pests and diseases across crops. Furthermore, the altered microclimate within agroforestry settings characterized by modified temperature, humidity, and light conditions can be less conducive to the proliferation of certain pests and pathogens.

A meta-analysis by (Pumariño et al., 2015) demonstrated that agroforestry practices are associated with reduced weed abundance and increased presence of natural enemies, highlighting their effectiveness in pest and disease management.

3.3.2 Enhancing pollinators and natural predators

The diversity inherent in agroforestry systems supports a wide array of pollinators and natural predators, which are essential for crop production and ecosystem health. By providing continuous floral resources and nesting habitats, these systems sustain pollinator populations throughout the growing season (Centeno-Alvarado et al., 2023).

The presence of various flowering plants attracts insect pollinators, thereby enhancing pollination services and potentially increasing crop yields. Moreover, the habitat complexity supports natural predators that control pest populations, contributing to a balanced and resilient agroecosystem. Studies have shown that agroforestry practices can lead to increased pollinator diversity and abundance, which is crucial given that approximately 35% of global food production depends on animal pollination (Katumo et al., 2022).

3.3.3 Promoting ecological balance in cropping systems

Agroforestry promotes ecological balance by enhancing biodiversity and fostering interactions among various species within cropping systems. The integration of trees and shrubs creates a heterogeneous landscape that supports a multitude of organisms, including beneficial insects, birds, and soil fauna (Mlambo et al., 2024).

This biodiversity contributes to ecosystem services such as pest regulation, pollination, and nutrient cycling, which are vital for sustainable agriculture. For example, the presence of diverse plant species can disrupt pest life cycles and reduce the incidence of outbreaks. Additionally, agroforestry systems can improve soil health by increasing organic matter and supporting earthworm populations, which enhance soil structure and fertility.

Further a meta-analysis by (Pumariño et al., 2015) indicates that temperate alley-cropping agroforestry systems improve pest control potential by promoting spider abundance and functional diversity, thereby enhancing ecological balance.

3.4 Agroforestry for Climate Resilience

3.4.1 Climate change mitigation: Carbon sequestration and greenhouse gas reduction

Agroforestry systems enhance carbon storage by sequestering CO_2 in biomass and soils while reducing greenhouse gas emissions through improved land management practices (Verma et al., 2021), (Tembo & Sarzhanov, 2013). Trees in these systems act as long-term carbon sinks, absorbing atmospheric CO_2 and storing it in trunks, branches, roots, and the soil.

These systems can reduce emissions by minimizing the need for external inputs such as synthetic fertilizers and by improving nutrient cycling efficiency (De Stefano & Jacobson, 2018). The integration of trees in agricultural landscapes provides both environmental and economic benefits while improving the resilience of cropping systems to climate variability (Hlaing et al., 2024).

Research by (Sivaranjani & Panwar, 2023) has shown that agroforestry systems can sequester between 12 to 228 Mg C ha^{-1}, with variations depending on the specific system type, geographic location, and management practices. This carbon sequestration potential represents a significant contribution to climate change mitigation efforts within the agricultural sector.

3.4.2 Climate adaptation: Protection from extreme weather events

Climate change adaptation in agriculture focuses on minimizing the adverse effects of extreme weather and climatic variability, safeguarding crop production and rural livelihoods. Agroforestry provides physical and ecological buffers that protect farmland from damaging conditions such as strong winds, high temperatures, and intense rainfall (Anderson et al., 2020).

Trees in agroforestry systems act as windbreaks, reduce soil erosion, and help stabilize microclimates, thereby lessening the impact of heavy rains and heat stress on crops (Smith et al., 2021). Shade from tree canopies moderates extreme heat, reducing evapotranspiration and improving conditions for understory crops during periods of high temperature.

The presence of diverse root systems enhances soil structure and increases water infiltration, which boosts resilience during heavy rainfall events and reduces runoff (Jia et al., 2024). Field studies by (Touch et al., 2024) have documented how smallholder farmers exposed to changing rainfall patterns are increasingly adopting agroforestry as an adaptive response to climate variability. Agroforestry also promotes biodiversity, which improves pest control and pollination services, contributing to stable crop yields under variable conditions. This enhanced resilience allows for more reliable food production and income stability in climate-stressed regions.

3.5 Sustainable Crop Productivity and Food Security

Agroforestry significantly contributes to improved crop productivity and food security, particularly in regions vulnerable to climate variability. By integrating trees with crops, these systems create favourable microclimatic conditions that buffer extreme temperatures and reduce evapotranspiration, leading to more stable yields under erratic weather patterns (Coulibaly et al., 2017).

Tree cover offers physical protection from wind and storms, while root systems enhance soil structure and prevent erosion, supporting sustained crop performance during climatic stress(Kaur et al., 2023). These protective functions become particularly important as extreme weather events increase in frequency and intensity.

Soil health improves through the addition of organic matter from tree litter, which increases fertility and moisture retention. This natural enrichment reduces the need for synthetic fertilizers, lowering input costs and minimizing environmental risks associated with their overuse (Coulibaly et al., 2017).

Farmers practicing agroforestry become less dependent on external inputs and more self-reliant, which is especially important in low-income and climate-exposed regions. Research by(Coulibaly et al., 2017) done in Malawi reported yield improvements of 15-30% in maize-based agroforestry systems compared to monoculture systems during drought years.

Agroforestry systems foster biodiversity, promoting natural pest control and improving pollination, which further supports crop yield stability and reduces reliance on chemical pesticides(Altieri & Nicholls, 2020). The diversification of farm outputs where trees provide fruit, fodder, or timber alongside annual crops adds economic stability and food variety, enhancing overall household food security (Waha et al., 2018).

(Altieri & Nicholls, 2020) in their study further emphasized that approaches combining traditional cropping with agroforestry enhance adaptive capacity and productivity across seasons. These systems help maintain yields even when rainfall is sparse or temperatures deviate from historical norms. By stabilizing production and income, agroforestry supports both household-level food access and broader rural development goals.

Hence, agroforestry strengthens the foundation of climate-resilient agriculture by promoting ecological sustainability, reducing synthetic input dependency, and increasing yield stability under changing climatic conditions (Pumariño et al., 2015). As climate change continues to pose challenges to conventional farming, the multifunctional benefits of agroforestry offer a practical path toward long-term food security and agricultural sustainability.

4. CHALLENGES AND OPPORTUNITIES

4.1 Barriers to Agroforestry Adoption

The adoption of agroforestry practices in Zambia faces several challenges, despite its numerous environmental and economic benefits. These barriers hinder the widespread implementation of agroforestry systems, limiting their potential in sustainable agriculture and climate change mitigation. Among the most significant obstacles are policy gaps, land tenure issues, financial constraints, and inadequate knowledge and technical capacity. These challenges have direct and indirect impacts on crop production, affecting soil fertility, water availability, and overall farm productivity.

4.1.1 Land tenure and financial constraints

I. Insecure Land Rights

Land tenure security is a critical factor in agroforestry adoption. In Zambia, many smallholder farmers do not have secure land tenure, which discourages investment in long-term agroforestry practices (Houndjo Kpoviwanou et al., 2024). Farmers who lack clear ownership rights or long-term leases on their land may be reluctant to plant trees, as they might not benefit from the long-term returns associated with agroforestry systems. Additionally, customary land tenure systems, which dominate rural Zambia, often lack formal legal recognition, increasing the risk of land disputes and discouraging long-term investments.

II. Limited Access to Capital

Establishing agroforestry systems requires initial investments in tree seedlings, fencing, labour, and maintenance before the trees begin to provide economic returns. Many smallholder farmers in Zambia lack access to credit facilities or financial support mechanisms that would enable them to transition to agroforestry (Verma et al., 2021). Additionally, agroforestry systems often take years to yield substantial economic benefits, which makes it difficult for farmers who rely on short-term agricultural returns to sustain their livelihoods during the transition period.

4.1.1.1 Impact of land tenure and financial constraints on crop production

The lack of investment in agroforestry also affects crop production. Without trees integrated into farming systems, soil erosion and nutrient depletion become prevalent, reducing soil fertility and ultimately decreasing crop yields. Trees in agroforestry systems contribute to nitrogen fixation, organic matter accumulation, and improved water retention, all of which are essential for sustaining crop productivity (Hlaing et al., 2024). The absence of these benefits results in lower crop resilience, particularly in regions with erratic rainfall and degraded soils.

4.1.2 Knowledge and technical gaps

I. Limited Awareness and Skills

A lack of knowledge and technical skills among farmers is another barrier to agroforestry adoption in Zambia. Many farmers are either unaware of agroforestry's benefits or do not possess the necessary skills to integrate trees into their farming systems effectively. The absence of well-structured extension services and training programs exacerbates this issue, leaving farmers without guidance on species selection, land management techniques, and sustainable agroforestry practices (de Castro & Futemma, 2021).

II. Mindset and Traditional Practices

Agroforestry requires a shift in traditional farming mindsets. Conventional agricultural systems in Zambia often prioritize monocropping and rapid turnover, whereas agroforestry demands a long-term perspective and integrated land-use planning (Kala, 2025). Without proper training and demonstration plots, farmers may be hesitant to adopt agroforestry due to the perceived complexity and uncertainty of the system.

4.1.2.1 Consequences of knowledge and technical gaps for agricultural productivity

The impact of this knowledge gap on crop production is significant. Farmers who are unaware of agroforestry's soil-enhancing benefits continue to rely on chemical fertilizers, which may degrade soil quality over time. Furthermore, the lack of knowledge on proper tree-crop combinations can result in poor implementation, where trees compete with crops for nutrients and water instead of providing mutual benefits (Kiyani et al., 2017). This inefficiency leads to suboptimal crop yields and decreased farm productivity over time.

4.1.3 Policy gaps and institutional support

I. Weak Policy Frameworks

One of the primary barriers to adopting agroforestry systems in Zambia is the presence of policy gaps that fail to support farmers in transitioning to these sustainable practices. Although agroforestry is recognized in national policies such as the Forest Policy and Climate Change Policy, there is a lack of clear implementation frameworks and incentives to encourage farmers to adopt the practice (Nair et al., 2022). Government policies often favour conventional agriculture through subsidies for monoculture crops and chemical inputs, while agroforestry remains underfunded and under-promoted.

II. Fragmented Institutional Efforts

Inadequate institutional support further hinders agroforestry adoption. Limited collaboration between government agencies, research institutions, and non-governmental organizations leads to fragmented efforts in promoting agroforestry. Without well-coordinated programs, farmers lack access to financial incentives, technical support, and extension services that are essential for successful agroforestry implementation (Gifawesen et al., 2020).

4.1.3.1 Effects of policy and institutional support gaps on agriculture

The policy gap also affects crop production by limiting farmers' access to sustainable farming alternatives. Without government-backed incentives for agroforestry, farmers continue to rely on conventional farming methods that contribute to soil degradation and declining crop yields. A stronger policy framework supporting agroforestry could improve soil health, enhance biodiversity, and increase farm resilience to climate change, thereby sustaining crop production in the long term (Raihan, 2023).

4.1.4 Market and value chain limitations

I. Underdeveloped Market Access and Value Chain Facilities

Even when farmers successfully adopt agroforestry, market access challenges can reduce their motivation to continue with the practice. In Zambia, many agroforestry products, such as timber, fruits, and medicinal plants, require well-developed value chains to ensure profitability. However, the lack of processing industries, storage facilities, and reliable transportation networks makes it difficult for farmers to market their agroforestry products competitively (Mbabarira & Nahayo, 2020). Moreover, fluctuating market prices and limited buyer awareness about agroforestry products further constrain farmers' ability to profit from these systems.

4.1.4.1 Long-term implications of limited markets and value chain on agriculture

Market challenges have an indirect effect on crop production. Farmers who struggle to profit from agroforestry may abandon the practice, leading to the loss of agroforestry's benefits for soil fertility and microclimate regulation. This shift can result in increased soil degradation, reduced moisture retention, and lower crop yields over time. Strengthening market access for agroforestry products could encourage more farmers to adopt these practices, leading to more resilient and productive agricultural systems (Köthke et al., 2022).

4.2 Key Findings

The study highlights that agroforestry significantly enhances sustainable crop production by improving soil health, conserving water, regulating microclimates, and promoting biodiversity. Integrating trees into farming systems increases soil fertility through organic matter accumulation, nitrogen fixation, and erosion control, while also enhancing water infiltration and retention. Agroforestry regulates temperature and humidity, creating favorable conditions for crops and enhancing resilience to drought and climate extremes. It supports pest and disease management by attracting natural predators and increasing pollinator diversity, reducing reliance on chemical inputs. Additionally, agroforestry contributes to climate change mitigation through carbon sequestration and supports farmers' adaptation to climate variability. However, to fully realize these benefits and scale up agroforestry practices in Zambia, strategic interventions are required. These include integrating agroforestry into national policies, providing farmer incentives, and strengthening research, extension services, and capacity building efforts. As a multifunctional land-use system, agroforestry holds great promise for improving yields, reducing input costs, promoting environmental sustainability, and addressing key challenges such as food security, environmental degradation, and poverty reduction.

5. RESEARCH GAPS AND FUTURE DIRECTIONS

5.1 Current Research Limitations

A critical analysis of the existing literature on agroforestry in Zambia reveals several research gaps that need addressing. Most studies have focused on the technical aspects of agroforestry systems, while socio-economic dimensions remain underexplored. In particular, there is limited research on gender dynamics in agroforestry adoption and management. Women often play critical roles in tree management and harvesting of tree products, yet their participation in decision-making and access to benefits are poorly documented in the Zambian context. Additionally, most agroforestry research in Zambia has concentrated on a few regions, primarily the Eastern and Southern Provinces, leaving other agroecological zones with minimal investigation. This geographic imbalance limits our understanding of how agroforestry systems can be adapted to diverse environmental conditions across the country.

5.2 Emerging Research Priorities in Zambian Agroforestry

Emerging research priorities for agroforestry in Zambia encompass three critical areas: climate resilience studies that quantify the adaptive capacity of various tree-crop combinations across different agroecological zones; economic valuation methodologies to assess ecosystem services like carbon sequestration and biodiversity conservation; and innovations in knowledge dissemination through digital extension, farmer networks, and integration of indigenous practices. These priorities require interdisciplinary collaboration among ecologists, economists, agronomists, and social scientists, ideally through partnerships between Zambian institutions, international organizations, and farmer groups to ensure research relevance and build local capacity. Such collaborative approaches would address the multifaceted challenges of agroforestry implementation while aligning with national priorities and international sustainability goals.

6. CONCLUSION

Agroforestry represents a transformative approach to sustainable land management, offering multifaceted benefits for crop production, environmental conservation, and climate resilience. By enhancing soil fertility, regulating microclimates, and supporting biodiversity, agroforestry systems provide a robust alternative to conventional agriculture, particularly in regions vulnerable to climate change. However, the full potential of agroforestry is constrained by socioeconomic and institutional challenges, including insecure land tenure, financial limitations, and inadequate policy support. To overcome these barriers, coordinated efforts are needed to integrate agroforestry into national agricultural policies, provide targeted incentives for farmers, and strengthen research and extension services. Future studies should focus on climate adaptation strategies, economic valuation of ecosystem services, and innovative knowledge dissemination methods. By prioritizing these actions, agroforestry can play a central role in achieving sustainable development goals, ensuring food security, and building resilient agricultural systems for future generations.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author(s) hereby declare that no generative AI technologies, including but not limited to Large Language Models (e.g., ChatGPT, COPILOT) or text-to-image generators, have been utilized in the writing, editing, or preparation of this manuscript. All content, including textual and visual elements, has been created and reviewed solely by the authors, ensuring complete originality and compliance with academic standards.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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