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Research Article

# Sustainability in Harnessing Agroforestry for Climate Change Mitigation and Development - Climate Change Mitigation Practices for Agroforestry and Conservation of Agriculture for Restoration of Degraded Agro Ecosystems in the Gambia

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## Abstract

Agroforestry, a land management system that integrates trees, crops, and livestock, has emerged as a promising strategy for climate change mitigation and sustainable development. This journal article explores the potential of agroforestry in sequestering carbon, conserving biodiversity, improving soil health, and enhancing livelihoods. Drawing on recent approaches to agroforestry on pilot in selected communities in the Gambia, this article highlights the multifaceted benefits of agroforestry and provides insights into its role in building resilience to climate change, improve mitigation and fostering environmental sustainability. Policy recommendations and future research directions are also discussed to promote the adoption of agroforestry as a viable solution to address the challenges posed by climate change.

## Introduction

The need to address climate change and achieve sustainable development goals has led to growing interest in agroforestry as a nature-based solution. Agroforestry offers a holistic approach that combines agricultural production with environmental conservation, making it a valuable strategy for mitigating climate change impacts. The impact of climate change in the Gambia has directly impacted on agricultural and livelihood systems by degrading forest and agricultural landscapes. This affected both human, domestic and wildlife in the greater environment and existing ecosystems. Degradation in agricultural and forest landscapes has far reaching impact on crop productivity especially in the rural areas where subsistence farming is the economic backstay and main livelihood means for most of the population.

Due to low crop productivity, people turn to the forest to extract forest resources for timber, fuelwood and wildlife as a source of additional income. Consequently, the forest got degraded thus aggravating extreme climate change negates. The main causes of degradation in farmlands in Lower River Region (LRR) are intensive use of land (55.8%), erosion and flooding (7.9%), salt intrusion (4.2%) (Source: Agroforestry for agricultural land restoration, ICRAFT 2021).

This journal article explores the transformative potential approach through agroforestry and forest restoration as conservation practices in regenerating and promoting ecosystem resilience. The goal is to introduce an agricultural conservation practice that equips farmers with new ideas and technology towards increasing crop productivity and production while preserving and protecting the environment from adverse effects of climate change. The aim is to enhance community participation and build their capacity in mitigating and building resilience to climate change. The technical field approaches are aimed at enhancing carbon sequestration and improving livelihoods for smallholder farmers, enriching the soil through smart agricultural practices. Reflecting on agroforestry activities carried out in selected communities in the Gambia, this article shares experiences on achievements and suggested way forward.

## Definition of Agroforestry

Agroforestry is a land management system that combines agriculture and forestry practices in a sustainable way. It involves growing trees and shrubs with crops and/or livestock on the same piece of land. Agroforestry systems can provide multiple benefits such as increased biodiversity, improved soil health, carbon sequestration, and diversified sources of income for farmers. It is a holistic approach to land use that promotes environmental conservation and food security.

## Benefits of Agroforestry

Apart from being a suitable land management practice, agroforestry has numerous interlinked benefits for farmers, specialized commercial markets, and even end consumers of produce. Its benefits are summarized in the paragraphs below.

## Soil and Water preservation

Trees grown in the farmlands and elsewhere dose not only enrich soil fertility but can also protect soil and water erosion and evaporation. With more nitrogen fixing trees on the farmlands, the fertility of the soil increases, soil becomes more porous allowing siltation rather erosion to occur. With more trees, rainfall is expected to increase enhancing growing different types of crops thus increase in food production. Trees also provide a good habitat for wildlife. Most wildlife depends on trees for food from nuts, fruits, leaves and even roots of certain species.

In addition, trees provide a home for wildlife. Humans and wildlife are interdependent for livelihood systems. Apart from enriching human dietary, wildlife attracts tourists which in turn generates income especially in community manage forests. Economic benefits: Trees can provide a source of wood products such as lumber veneer logs, and fuelwood, and crops grown between trees can provide an annual food and income for households. Agroforestry serves as diverse source of food for humans, domestic animals and wildlife. Agroforestry can create and provide a healthier place to live and work (Source: USDA National Resource Conservation, USDA National Agroforestry Center).

## Problem Statement

Despite its proven benefits in carbon sequestration, biodiversity conservation, and sustainable land management, agroforestry faces several challenges that hinder its widespread adoption and integration into mainstream agricultural practices. Agriculture (mostly crop farming and livestock) is the main livelihood systems for about 70% of rural Gambian population. It employs close to 45% of the country's population. Agricultural systems in the Gambia are facing numerous challenges as follows:

Agriculture has been going on for centuries, and with growing population trend increase pressure is observed on available arable land, hence degrading the land resources with little or any successful efforts to restore soil fertility in the degrading farmlands and forest covers.

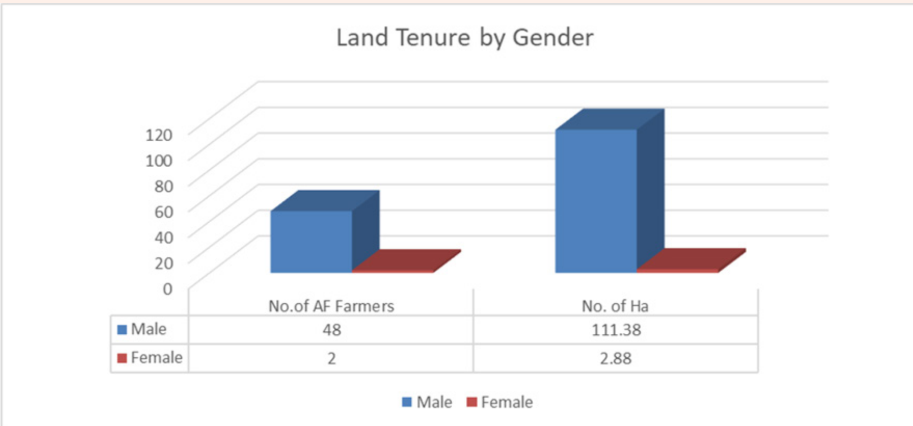
The results of the baseline study conducted by Large-Scale Ecosystem Based Adaptation Project (EbA) found that 81% of the households were actively engaged in agricultural activities in the last 10 years or more. Most of the agricultural lands were poor in plant nutrients showing clear erosion signs. The findings also show that 72% of the households surveyed confirmed their land is degrading. The table below analyze the causes and extent of degradation and factors responsible in the EbA project implementation sites in the Gambia.

Source: ICRAFT report on Agroforestry for agricultural land restoration.
**Table 1**: causes of farm degradation in project intervention regions.

| Intervention Regions | Use of land | Erosion & flood | Salt Intrusion | Tree Cover loss | Signs of erosion | Signs of degradation |
|---|---|---|---|---|---|---|
| CRRN | 94.30% | 67.54% | 4.80% | | 61.84% | 48% |
| CRRS | 15.18% | - | 3% | - | 47% | 42% |
| LRR | 55.80% | 7.90% | 4.20% | - | 71% | 51% |
| URR | - | 78.40% | - | 13.74% | 75% | 51% |

The crops that are widely grown such as ground nuts, rice, sorghum and millet are largely extractive, hence extensive nutrient mining happening in the agricultural landscapes. Source Baseline Study of EbA (Large – Scale Ecosystem Adaptation Project). There exist several persistent challenges to reviving and upscaling crop production to mitigate climate change impacts. These include inadequate awareness about benefits of agroforestry, limited access to resources, land tenure systems, market barriers and policy inconsistencies over the years. The land tenure system was observed as major constrain when male and female are compared. Traditionally. Men own and have control over land than women. The graph below illustrates male female participation in agroforestry due to land tenure systems.

Source: 2020 agroforestry planting report in selected communities.
**Figure 1:** Land Tenure by Gender.



Addressing these challenges requires a concerted effort by governments, NGOs, research institutions, civil society organizations and the private sector to promote awareness, provide targeted support to farmers, secure land rights, strengthen market linkages, and develop favorable policy frameworks that incentivize the adoption of agroforestry practices. By overcoming these barriers, agroforestry can play a more prominent role in sustainable agriculture, climate change mitigation, and rural livelihood improvement.

## Objectives for Agroforestry

1. Assess the impact of agroforestry practices on carbon sequestration and contribution to climate change mitigation.
2. Investigate the effects of agroforestry systems on soil health, promoting sustainable agricultural practices and mitigating climate change.
3. Evaluate the biodiversity conservation outcomes of different agroforestry models, including their effects on plant and animal diversity.
4. Analyze the socio-economic impacts of agroforestry on smallholder farmers, and its impact on rural development and poverty reduction.

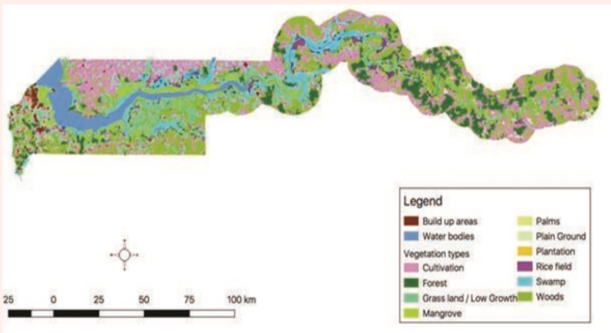
## Materials and Methods for Agroforestry Research

### Study Site Description

The Gambia is located on the West African coast and stretches over 320 km inland from west to east on either side of the River Gambia, varying in width from about 50 km near the mouth of the river to about 24 km upstream. The country is surrounded to the north, south and east by the Republic of Senegal and to the west with a short Atlantic Ocean coastline. The River Gambia runs the entire length of the country from the Fouta Djallon highlands in Guinea, Conakry to the Atlantic Ocean, dividing the country's land area of 11,295 square kilometers almost equally into two halves: The South Bank and the North Bank [1]. Major tributaries include the Sandougou, Nianija, Sofaniama, Miniminiyang, Baobolong and Bintang "bolongs" (creek in Mandinka). 8.

This article is mainly confined to the following agroforestry systems described as suitable to implementation sites (Figure 2).

**Figure 2:** Elevation map of The Gambia. Source: World Agroforestry Centre 2018.




## Agroforestry Systems

### Parkland agroforestry

It is an agroforestry system where multipurpose tree species are intentionally kept in the farms during land clearings for the trees to provide nutrients through biomass return to the soil and provide wood for the farm and households. The Sahel (Niger) and many West African countries practice this agroforestry system widely (Bayala et al 2015) (Figure 3) [2-7].

**Figure 3:** An agroforestry farmland before planting.

### Woodlot agroforestry

Gambia, like many other countries, is facing shortage of wood supply for both household and industrial use. One of the potential means of boosting the wood supply is by investing in tree growing interventions. Woodlot agroforestry is among the key interventions adopted to assist in this regard [8-14].

**Table 2**: Potential areas of land for woodlot establishment in the CFs where EbA protocol was done in Lower River Region (LRR

| Region | CF name | Potential woodlot plot no. as on map | Plot perimeter (m) | Plot area (ha) |
|---|---|---|---|---|
| LRR | Namba | Woodlot plot 1 | 2,119.74 | 20.41 |
| | Folanko soto | Woodlot plot 1 | 2,553.24 | 27.9 |
| | | Woodlot plot 2 | 2,531.16 | 25.59 |
| | | Woodlot plot 3 | 1,916.71 | 20.7 |

### Home garden agroforestry

Numerous households in the Gambia practice home garden systems though when compared to other countries in the sub region, the home gardens look very poor in composition of plant diversity due to limited water availability coupled with long dry season of 7 months minimum. The uniqueness of home gardens is that they are mostly managed by women who stay close to the house. A home garden provides numerous benefits e.g. vegetables, fruits, spices, etc. to the households.

### Fodder banks agroforestry and improved silvo-pasture

Livestock make up one of the biggest elements of livelihood in the Gambia. Fodder bank agroforestry is where fodder trees are grown in grazing lands, in farm boundaries, village boundaries and as part of soil conservation interventions. Tree species such as Faidherbia albida, Gliricidia sepium, Pterocarpus erinaceus and Pterocarpus lucens (Hamer et al 2007) were planted as part of the efforts to establish such fodder banks.

## Data Collection Methods

Conventional methods of data collection were used to generate raw data. These include questionnaires at household levels as well as Focus Group Discussions to generate quantity and quality information. Other methods were field surveys using GPS especially in the community forests to determine tree density, type and spacing between trees, shrubs etc. The methods generated data and information on Community Protected Areas (CPAs, Community Forests (CFs), Multi – Purpose Centers (MPCs) targeted as mitigation measures, for economic and agricultural production systems etc. This information was useful in designing the most appropriate agroforestry system for the area. The baseline survey also engaged local farmers, community members, extension agents, and policymakers through interviews, surveys, and participatory workshops to gather insights on the challenges and opportunities related to agroforestry adoption. Since the approach was participatory involving farmers approvals for conducting research on private or communal lands compliance with ethical guidelines was ensured.

By using the above materials and methods in agroforestry research, researchers were able to gather comprehensive data, analyze key variables, and draw meaningful conclusions to advance knowledge in sustainable land management and agroforestry concepts and practices.

## Theoretical Background on Agroforestry

Agroforestry is rooted in the principles of sustainable land management and integrated farming systems, drawing on agroecological concepts and traditional farming practices that harness the synergies between trees, crops, and livestock. Theoretical frameworks underpinning agroforestry highlighted its potential to enhance ecosystem services, promote biodiversity conservation, mitigate climate change, and improve livelihoods for rural communities.

### Agroecology

Agroforestry is aligned with the principles of agroecology, which emphasize the ecological relationships between plants, animals, humans, and their environment in agricultural systems. Agroecological approaches focus on enhancing biodiversity, nutrient cycling, and natural resource management to create resilient and productive farming landscapes.

### Resource Use Efficiency

Agroforestry systems are designed to optimize resource use efficiency by diversifying plant species, utilizing vertical and horizontal spatial arrangements, and enhancing nutrient cycling and water retention. These practices aim to improve overall productivity while minimizing negative environmental impacts.

### Ecosystem Services

Agroforestry contributes to the provision of multiple ecosystem services, including carbon sequestration, soil fertility improvement, water regulation, pest control, and habitat creation. By integrating trees into agricultural landscapes, agroforestry enhances the resilience of ecosystems and enhances their capacity to provide valuable services to society.

### Traditional Ecological Knowledge

Agroforestry builds upon traditional ecological knowledge and indigenous farming practices that have sustained communities for generations. By incorporating local wisdom and adaptive management strategies, agroforestry systems blend modern science with traditional practices to create sustainable and culturally relevant farming systems.

### Land Use Planning

Agroforestry integrates principles of land use planning and landscape management to optimize the spatial arrangement of trees, crops, and livestock within agroecosystems. By considering factors such as microclimatic conditions, soil fertility gradients, and ecological interactions, agroforestry design aims to maximize productivity and environmental benefits.

### Climate Change Mitigation

Agroforestry serves as a nature-based solution for climate change mitigation, as trees sequester carbon dioxide from the atmosphere, reduce greenhouse gas emissions, and enhance landscape resilience to climate variability. Theoretical frameworks in agroforestry emphasize the role of tree-based systems in mitigating climate change impacts and supporting adaptation to a changing climate.

By grounding agroforestry research and practice in these theoretical foundations, stakeholders can leverage the inherent ecological principles and sustainability concepts of agroforestry to promote resilient and productive agricultural systems that benefit both people and the planet.

## Design Proposals for Agroforestry Interventions

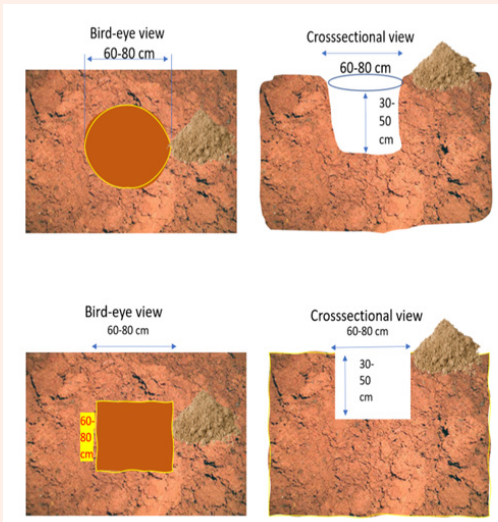
The proposed agroforestry design emphasizes the need for measures to address the moisture constraint by increasing rainwater capture and minimizing the losses of available moisture due to high temperature conditions. Among the many intervention options, the Zai pit system combined with agroforestry (Zai AF hereafter) borrowed from Niger in the Sahel region where it proved to be successful. Niger has similar conditions to that of the Gambia rural areas (Sawadogo et al 2001).

The Zai pit approach to agroforestry has positive results in providing micro-watersheds for supporting plant growth, transforming landscapes with little upfront investment, limited rainfall conditions. Easily adaptive to the weather conditions (Figure 4).

### Example of types of Zai Pits experimented

Source: ICRAF Training Materials for Large-scale ecosystem-based adaptation project (EbA) Gambia.

**Figure 4:** Types of Zai Pits.




## Results and Discussion on Agroforestry Research

### Results

Prior to planting an assessment was made to determine the total seedlings required by each farmer in each community. The table below was the outcome and actual of seedlings that were planted in the agroforestry farm lands during 2020 planting season.

Note: The indicated spacings may vary for a single species depending on the agroecology and the purpose for which the species are grown. The indicated spacings are the widely used ones.

**Table 3**: Tree species suitable for agroforestry interventions and their spacing.

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| Tree Species | Vernacular name/ local name | Recommended under a monocropping mode (m) | No. of seedlings required per ha |
|---|---|---|---|
| *Khaya senegalensis* | Jalo | 15*15 | 44 |
| *Ceiba pentandra* | Bantango | 15*15 | 44 |
| *Pterocarpus erinaceus* | Keno | 12*12 | 69 |
| *Cordyla pinnata* | Duto | 12*12 | 69 |
| *Borassus aethiopum* | Sibo | 5*5 | 400 |
| *Bombax costatum* | Bunkungho | 10*10 | 100 |
| *Parkia biglobosa* | Dawadawa/ Netto | 15*15 | 44 |
| *Antiaris africana* | Jaffo | 10*10 | 100 |
| *Faidherbia albida* | Cayki/ caski (Fula) | 10*10 | 100 |
| *Spondias mombin* | Wula kono ninkongho | 10*10 | 100 |
| *Cola cordifolia* | Taboo | 15*15 | 44 |
| *Daniella oliveri* | Santango | 10*10 | 100 |
| *Lonchocarpus laxiflorus* | Mbembo | 7*7 | 204 |
| *Parinari excelsa* | Mampato | 5*5 | 400 |
| *Parinari macrophylla* | Tamba | 7*7 | 204 |
| *Tamarindus indica* | Tamarind/ Timbingo | 10*10 | 100 |
| *Sclerocarya birrea* | Kuntang jawo | 12*12 | 69 |
| *Ziziphus mauritiana* | Tomborongo | 5*5 | 400 |
| *Saba senegalensis* | Kaba | 7*7 | 204 |
| *Adansonia digitata* | Baobab / Sito | 15*15 | 44 |
| *Detarium senegalense* | Tallo | 15*15 | 44 |
| *Prosopis africana* | Kembo | 10*10 | 100 |
| *Moringa oleifera* | Moringa/ Nebedayo | 5*5 | 400 |
| *Afzelia africana* | Lenko | 10*10 | 100 |
| *Rhizophora spp* | Mankwo | 1*1 | 10,000 |
| *Ficus spp* | Soto | 10*10 | 100 |
| *Mitragyna inermis* | Jungo | 10*10 | 100 |

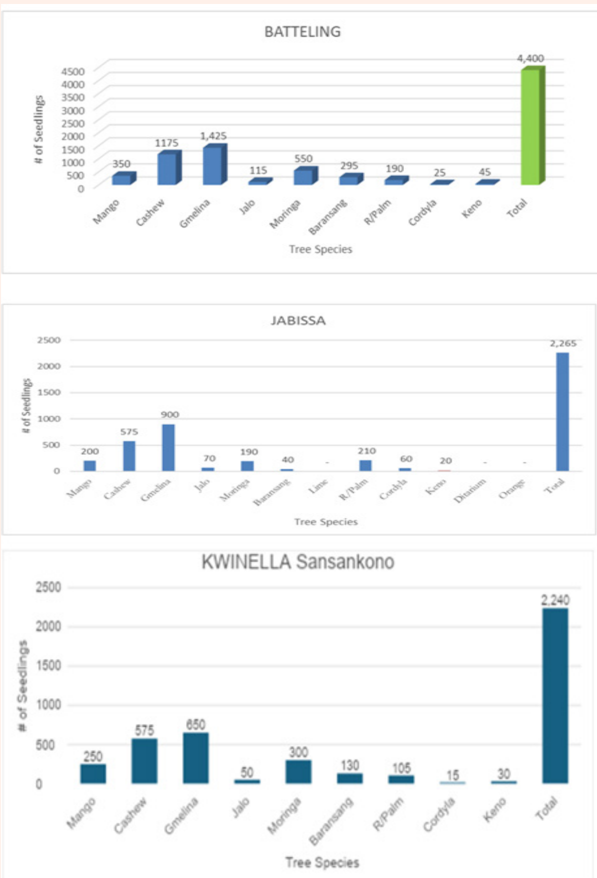
On the field training and demonstrations were critical to enabling farmers acquire the skills and knowledge in Zai AF approach. Below shows farmers measuring the spacing between plants on farmlands as part of field demonstration.

The farmers are measuring the spacing between plants on farmlands (a: spacing and b: Zai pit AF digging, on field demonstration) (Figure 5). The graphs below provide analytical data on types of tree species and quantity planted in selected intervention communities.

This pilot study has proven the hypothesis that agroforestry farming has high potentials of carbon sequestration thus qualifying the first objective of this research. It also improves soil health as more nitrogen fixing trees planted provides more organic matter and diversifies microbial activities in the soil thus meeting the second objective of the research (Figure 6). Naturally more trees imply conducive habitat for plants and animals. The presence of tree species in agroforestry systems created microhabitats that supported a variety of wildlife, contributing to enhanced biodiversity conservation in agricultural landscapes. Surveys and interviews with farmers revealed that agroforestry practices provided additional sources of income, diversified livelihood options, and increased resilience to climate variability. Farmers reported improved food security, enhanced crop yields, and enhanced socio-economic well-being because of integrating trees into their farming systems.

**Figure 5:** On Farm demonstration.


**Figure 6**: Types of tree species and quantity planted in selected intervention communities.




## Discussion

The results of our study highlight the significant potential of agroforestry as a sustainable land management practice with multiple benefits for humans and wildlife. The findings revealed that agroforestry systems play a crucial role in carbon sequestration, soil health improvement, biodiversity conservation, and socio-economic development, aligning with the principles of sustainable agriculture and ecosystem-based adaptation.

The increased carbon sequestration observed in agroforestry systems underscores the importance of integrating trees into agricultural landscapes to mitigate climate change impacts and enhance carbon storage capacity. The positive effects on soil health, including improved nutrient cycling and increased soil organic matter, suggest that agroforestry can contribute to soil fertility enhancement and sustainable land use practices.
Furthermore, the enhanced biodiversity conservation outcomes of agroforestry systems indicate the potential of tree-based farming systems to support ecosystem services, maintain habitat connectivity, and promote wildlife diversity in agricultural landscapes. The socio-economic impacts observed in our study highlight the importance of agroforestry in improving livelihoods, diversifying income sources, and enhancing resilience to environmental shocks. Overall, the results and discussion emphasize the critical role of agroforestry in promoting sustainable agriculture, climate change resilience, and rural development. By mainstreaming agroforestry practices and incorporating them into agricultural policies and programs, we can harness the full potential of tree-based farming systems to build more resilient and environmentally sustainable food systems for the future.

Over the years non-project implementation sites replicated the agroforestry approach through experimental design. Farm sizes where trees are planted were measured determining the tree species and spacing between trees. The new approach to agriculture took a well-designed study and implementation strategy most appropriate for replication.

## Conclusion

In conclusion, agroforestry stands out as a versatile and sustainable land management practice that offers multiple benefits for climate change mitigation and sustainable development. Through carbon sequestration, biodiversity conservation, and soil health improvement, agroforestry systems contribute to building climate resilience and enhancing ecosystem services. The evidence presented in this journal article underscores the importance of scaling up agroforestry practices to address the pressing challenges posed by climate change.

Policy support and investment in agroforestry initiatives are critical for maximizing its potential impact on climate change mitigation and adaptation. By integrating trees into agricultural landscapes, agroforestry not only helps farmers diversify their income streams but also promotes environmental sustainability and social equity. The case studies and research findings highlighted in this article demonstrate the transformative power of agroforestry in fostering a more resilient and sustainable future for agriculture and the environment. Moving forward, further research is needed to better understand the mechanisms underlying the success of agroforestry systems and to develop best practices for their implementation. By leveraging the multiple benefits of agroforestry, we can unlock its full potential as a nature-based solution for addressing the interconnected challenges of climate change, biodiversity loss, and food insecurity.

In conclusion, agroforestry offers a pathway towards a more sustainable and climate-resilient agriculture sector, paving the way for a future where human well-being and environmental health coexist harmoniously. Embracing agroforestry as a mitigation measure for climate change is not only an investment in our planet's future but also a commitment to ensuring a more equitable and thriving world for generations to come.

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List of Symbols

1. causes of farm degradation in project intervention regions
2. Elevation map of The Gambia
3. An agroforestry farmland before planting
4. Example of types of Zai Pits experimented
5. "Zai Pit" filed measuring and digging demonstration
6. Graphs showing actual number and types of trees planted in selected communities

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