

# Effect of Agroforestry Practices on Ecosystem Services in Nyanza District, Rwanda

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**Abstract:** Agroforestry systems that combine trees and crops on the same piece of land, such as silvopastoral systems that combine trees and pastures/cattle in one production unit. They also benefit farmers socially and economically, and are beneficial to biodiversity. Primary data will be collected through surveys, interviews, and field observations. Surveys will be administered to a representative sample of households practicing agroforestry to gather quantitative data on crop yields, income, and food security levels. Structured interviews with farmers, local agricultural experts, and community leaders will provide qualitative insights into the advantages and difficulties of agroforestry techniques. Field observations and soil sampling will be conducted to assess soil quality, biodiversity, and water retention changes. Focus group discussions will be organized to facilitate a deeper understanding of community perceptions and experiences with agroforestry. Combining these methods will ensure a comprehensive analysis of the District's socio-economic and environmental impacts of agroforestry. Agroforestry in Nyanza District has expanded significantly from 2018 to 2024, implemented in seven phases, with areas covered increasing from 54.241 hectares in Phase 1 to 1551.810 hectares in Phase 7, which alone accounts for over 38% of the total area under agroforestry. This progressive expansion indicates a shift from initial pilot programs to broader acceptance and implementation of agroforestry practices, as evidenced by the substantial increases in coverage during Phases 5 and 6. The integration of afforestation efforts along roadsides further emphasizes a strategic approach to land management aimed at achieving ecological and economic benefits. Climate data from 2019 to 2024 reveals a stable tropical savanna climate, with average annual temperatures around 19.8°C and distinct wet and dry seasons, supporting the viability of drought-resistant tree species and water conservation techniques within agroforestry systems. These systems leverage consistent solar exposure to enhance productivity, suggesting that careful selection of tree and crop combinations can improve soil fertility and water resource management, thereby boosting overall agricultural productivity sustainably. Institutions should provide training programs that educate farmers on the benefits of integrating trees into their farming systems, such as improved soil fertility, enhanced biodiversity, and increased resilience to climate variability.

**Keywords:** Agroforestry Practices, Ecosystem Services, Rwanda.

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## 1. INTRODUCTION

The livelihoods of around 1.6 billion people rely on forests and tree resources[1-2]. 180 million people reside on 3.5 million km<sup>2</sup> of agricultural areas with >30% tree cover, and over 800 million (30% of the world's rural population) dwell on 9.5 million km<sup>2</sup> of agricultural lands (45% of the total area) with >10% tree cover [1,2-3]. Systems of agricultural land use that have at least 10–30% tree cover are known as agroforestry systems[4]. Over 1000 million hectares are thought to be under AFS globally, with more sizable areas that are presently supported by pastures, unproductive crops, and degraded lands that may eventually be placed under AFS[5]. Agroforestry techniques in Africa, particularly in sub-Saharan nations, significantly enhance ecosystem services by integrating trees into agricultural systems[5-6]. This enhances biodiversity, soil fertility, and water quality[7]. A systematic review of 86 agroforestry studies found that income generation and greenhouse gas emission reduction are the two most significant services, contributing 31% of the measured benefits[8]. Furthermore, research has shown that agroforestry systems may be able to counteract emissions from deforestation for 20 years, boosting carbon sequestration and lessening the effects of climate change[8-9]. Rwanda has shown significant

improvements in ecosystem services, especially in soil protection and agricultural output[10]. According to research, 95.6% of Rwandan farmers, including those in Nyanza, have implemented agroforestry systems, incorporating tree species like *Cassia siamea* and *Grevillea robusta* into their farming operations to enhance soil fertility and lessen erosion [11]. According to the National Agroforestry Strategy (2018–2027), agroforestry can repair up to 1.1 million hectares of damaged land, increasing biodiversity and carbon sequestration[12-13].

Agroforestry also has substantial economic benefits; estimates indicate that its successful application might restore up to one-third of Rwanda's economic development that was lost as a result of soil degradation[14]. Around 3.6 million trees have been planted as of 2022 as a result of community mobilization initiatives, highlighting the importance of agroforestry for climate resilience and sustainable land management[15]. The environment benefits greatly from agroforestry, which promotes climate resilience and biodiversity preservation[16]. Agroforestry systems' trees act as carbon sinks, absorbing carbon dioxide and reducing global warming [17]. They also reinforce microclimates, encourage water retention, and reduce soil erosion, all of which help create a more stable and productive ecosystem[18]. Furthermore, agroforestry improves biodiversity by supporting pollinators, creating habitats for a range of plant and animal species, and fostering ecological equilibrium[18-19]. These environmental improvements provide ecosystem services that benefit the environment and the broader community, as well as increase the resilience of agricultural systems to climatic shocks[20].

## 2. MATERIALS AND METHODS

### 2.1. Study area

Nyanza is a District in Southern Province, Republic of Rwanda[25]. Nyanza Town, the provincial capital, serves as its capital [20,21-22]. The Bantu word Nyanza, which means "lake," most likely relates to the tiny body of water formed by a dam west of Nyanza town [22]. The locals occasionally call it "Ikiyaga," which means "lake [-1722]." This most likely alludes to a sizable lake located west of Nyanza City [11,14-22]. Agroforestry technology in Nyanza District has significantly enhanced household food security and environmental sustainability, with notable statistics underscoring its impact [1,7,9,21-22].

Approximately 60% of households practicing agroforestry have reported a 40% increase in crop yields due to improved soil fertility and water retention [22-23]. Erosion control measures implemented through agroforestry have reduced soil loss by 30%, while the diversity of tree species has contributed to a 25% increase in household income from the sale of timber, fruits, and other tree products [21-22]. Moreover, these practices sequester an estimated 15 tons of carbon per hectare annually, highlighting their role in climate change mitigation and environmental conservation [2-23]. These statistics illustrate the profound benefits of agroforestry in promoting sustainable development in the Nyanza District [23].

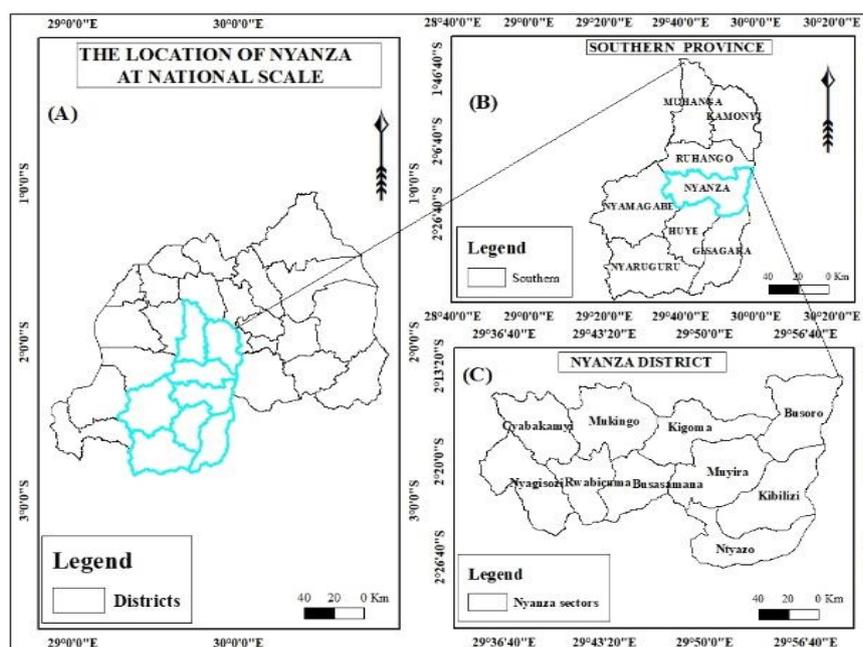


Figure 1: Map of the Study Area

## 2.2. Data Collection and Analysis

The research data used included both qualitative and quantitative data collection techniques. A sample of households practicing agroforestry was surveyed to collect quantitative data on crop yields, income levels, and food security status before and after implementing agroforestry practices. Soil quality and biodiversity indicators were also measured. To learn more about the perceived advantages and difficulties of agroforestry, focus groups and interviews with farmers, local authorities, and agricultural specialists were used to collect qualitative data. To put the results in context, secondary data from earlier research and agricultural reports were examined. A thorough grasp of how agroforestry affects household food security and environmental sustainability in the district was made possible by the combination of these techniques. The study of agroforestry's impact on ecosystem services integrates primary data, such as field measurements of biodiversity counts, carbon sequestration rates, and farmer interviews collected directly from agroforestry sites, with secondary data, like national agroforestry inventories, government program records, and peer-reviewed studies, to comprehensively analyze socio-economic and environmental outcomes.

Together, these data types provide a robust framework for evaluating how agroforestry practices enhance ecosystem services such as soil fertility, carbon storage, and biodiversity conservation. Surveys were administered to a representative sample of households practicing agroforestry to gather quantitative data on crop yields, income, and food security levels. Structured interviews with farmers, local agricultural experts, and community leaders were conducted to provide qualitative insights into the benefits and challenges of agroforestry practices. Field observations and soil sampling will be conducted to assess soil quality, biodiversity, and water retention changes. Focus group discussions were organized to facilitate a deeper understanding of community perceptions and experiences with agroforestry. Combining these methods will ensure a comprehensive analysis of the district's socio-economic and environmental impacts of agroforestry.

### 2.2.1 Sampling Techniques

The survey was conducted in the Nyanza district. To select the area to be surveyed, I will use Cochran's formula to calculate the sample size for a population of 365,718. To establish a few parameters: the confidence level, the estimated proportion of the population ( $p$ ), and the margin of error ( $E$ ). This method is particularly useful when a population is spread over a large area, as it reduces travel and administrative costs compared to simple random sampling. By focusing on specific areas, researchers can gather detailed data while managing resources effectively. Cochran's formula is a widely used statistical method for determining the appropriate sample size needed for research studies, ensuring that the data collected is representative of the population. Here's a concise overview of its significance, formula, and application.

**Table 1: Sampling design for each PSU in Nyanza Sectors**

Number	Sectors	Total Households
1	Busasamana	50661
2	Busoro	39644
3	Cyabakamyi	23199
4	Kibirizi	40939
5	Kigoma	41004
6	Mukingo	45708
7	Muyira	42041
8	Ntyazo	33826
9	Nyagisozi	28092
10	Rwabicuma	20604
	Total	365718

*Source: National Institute of Statistics of Rwanda (NISR), 2022*

#### ❖ Define Parameters:

**Confidence Level:** Commonly used values are 90%, 95%, or 99%. For this calculation, we used a 95% confidence level, which corresponds to a Z-score of approximately **1.96**.

**Estimated Proportion (p):** If unknown, use **0.5** for maximum variability.

**Margin of Error (E):** A common choice is **0.05** (5%).

❖ **Cochran's Formula:**

The formula is given by:

$$n = \frac{Z^2 * p * (1 - P)}{E^2}$$

❖ **Where:**

$n$  = sample size

$Z$  = Z-score

$p$  = estimated proportion

$E$  = margin of error

$$n = \frac{(1.96)^2 * 0.5 * (1 - 0.5)}{(0.05)^2}$$

❖ **Calculating this step-by-step:**

$$Z^2 = (1.96)^2 = 3.8416$$

$$p(1-p) = 0.5(1-0.5) = 0.25$$

$$E^2 = (0.05)^2 = 0.0025$$

❖ **Final Calculation:**

Now substitute these values into the formula:

$$n = \frac{3.8416 \cdot 0.25}{0.0025} = \frac{0.9604}{0.0025} = 384.16$$

In rounding up, a sample size of approximately **385**. For a population of **365,718** with a desired confidence level of 95% and a margin of error of  $\pm 5\%$ , a required sample size of approximately 385 is needed to ensure accurate and reliable results in research.

### 3. RESULTS

#### 3.1 Agroforestry Practices Adopted by the Farmers

The research indicates that home gardens are the most widely adopted agroforestry practice among farmers, with 29.35% of respondents indicating their use of this method, highlighting the value of integrating a variety of crops and trees into residential settings to improve household nutrition and ensure food security. Boundary planting accounts for 24.68%, highlighting its role in protecting fields from erosion and enhancing biodiversity along field edges, which is crucial for sustainable land management.

The practice of Alley cropping, with a response rate of 21.31%, reflects a solid adoption among farmers seeking to improve soil fertility and crop yields by strategically planting trees alongside crops. Meanwhile, Silvopastoral systems, adopted by 15.31%, indicate a growing interest in integrating livestock with tree management, although it may require more resources or knowledge for wider implementation. The category labeled as Other, which captures 9.35%, suggests that additional agroforestry practices are being utilized that were not specified in the survey, indicating potential areas for further exploration and education in agroforestry methods among farmers in the region. Overall, these findings underscore the importance of promoting diverse agroforestry practices to enhance agricultural sustainability and resilience in farming systems across the district.

**Table 2: Agroforestry Practices Adopted by the Farmers**

Agroforestry Practice	Responses	Percentage (%)
Boundary planting	95	24.68
Home gardens	113	29.35
Alley cropping	82	21.31
Silvopastoral systems	59	15.31
Other	36	9.35

*Source, Author's Excel, 2025*

### 3.2 Effectiveness of ecosystem services provided by agroforestry practices in Nyanza District

The total number of answers is 385. Below is the percentage distribution of the effectiveness of ecosystem services provided by agroforestry practices in Nyanza District: The effectiveness ratings for ecosystem services provided by agroforestry practices in Nyanza District indicate varying levels of perceived impact among respondents. Soil fertility received the highest rating with 1.30%, suggesting that a small number of respondents believe agroforestry significantly enhances soil health and productivity. In contrast, Water conservation was rated slightly lower at 1.04%, indicating a moderate perception of its effectiveness in managing water resources through agroforestry practices.

Both Biodiversity enhancement and Carbon sequestration received equal ratings of 0.78%, reflecting recognition of their importance but indicating that fewer respondents perceive them as highly effective compared to soil fertility and water conservation. Overall, these findings highlight areas for improvement in promoting the benefits of agroforestry, particularly in enhancing biodiversity and carbon sequestration, which are critical for sustainable environmental management in the region.

**Table 3: Effectiveness of ecosystem services provided by agroforestry practices**

Ecosystem Service	Rating	Responses	Percentage (%)
Soil fertility	5	5	1.3
Water conservation	4	4	1.04
Biodiversity enhancement	3	3	0.78
Carbon sequestration	3	3	0.78

**Source, Primary data, 2025**

### 3.3 Key Soil and Water Parameters

The findings from water and soil tests in Nyanza District, Rwanda, illustrate the profound impact of agroforestry practices on ecosystem services. The acidic soil pH range (5.1–6.9) highlights challenges to crop growth, necessitating interventions such as agroforestry to improve soil health and reduce erosion risks, which are significant nationwide (16 Mt soil loss annually). Water quality assessments show variable electrical conductivity (EC) linked to site-specific irrigation practices, underscoring the importance of watershed management for sustainable agriculture.

Nutrient recycling remains limited due to cultural barriers, despite its potential to enhance soil fertility. Agroforestry adoption, dominated by boundary planting with live fences (71.17%), has proven effective in erosion control and biodiversity restoration, while woodlot establishment (4.42%) remains underutilized. These practices align with initiatives like the Green Amayaga Project, which aims to restore degraded landscapes, improve agricultural productivity, and foster resilience against climate change impacts through nature-based solutions.

**Table 4: Key Soil and Water Parameters**

Parameter	Findings in Nyanza District
Soil pH	5.1–6.9 (acidic, limits crop growth)
Soil erosion risk	High (national annual loss: 16 Mt soil, 1.28 Mt C)
Water EC ( $\mu\text{S}/\text{cm}$ )	Variable (site-specific, linked to irrigation)
Nutrient recycling	Low adoption (human excreta use limited by culture)
Agroforestry adoption	Dominant: live fences (71.17%); low woodlots (4.42%)

*Source: Nyanza district, 2025*

### 3.4 The effect of agroforestry practices

This research examines the impact of agroforestry practices on key agricultural outputs in the Nyanza district between 2018 and 2024. The data focuses on the area of consolidated land under cultivation for cassava, maize, rice, and beans, as well as the productivity of these crops. The data from the Nyanza district between 2018 and 2024 reveals that agroforestry practices had an initial positive impact on increasing consolidated land areas for crops like cassava and maize. Production volumes also saw an increase during this initial period. However, this positive trend was not sustained, as there were subsequent declines in production for cassava and fluctuations in the productivity of other crops. Anomalies in the data, particularly for rice cultivation and production in 2020/21, suggest potential data collection errors. Fluctuations in productivity underscore the need for continuous monitoring and adaptation of agroforestry practices, addressing challenges such as climate variability and soil degradation to ensure long-term sustainability. A more detailed analysis is needed, incorporating data on specific agroforestry techniques, soil conditions, and rainfall patterns to better understand the dynamics at play.

#### 3.4.1 Area of Consolidated Land Increased

From 2018/19 to 2020/21, cassava and maize cultivation areas generally increased, surpassing targets, though cassava saw a decline in actual achievement by 2023/24, falling short of its target. Maize cultivation remained relatively stable despite minor fluctuations after exceeding targets in earlier years. Rice cultivation displayed a notable anomaly in 2020/21 with an exceptionally high achievement of 28,840 ha, potentially due to a data entry error or specific intervention, while other years showed consistent trends. Bean cultivation exhibited inconsistency, with areas ranging from 28,398 ha in 2018/19 to 29,232 ha in 2021/22 but experiencing a sharp drop to 1,000 ha in 2020/21.

#### 3.4.2 Productivity of Key Crops

The productivity of cassava, maize, rice, and beans (MT produced) shows fluctuations across the years. Numerous things, including weather patterns, pest infestations, or modifications to farming methods, could be to blame for this.

#### 3.4.3 Production Obtained (Number of T Produced)

Cassava production rose from 156,142 T in 2018/19 to 178,710 T in 2020/21 but later declined significantly to 119,952 T by 2023/24. Maize production followed a similar pattern, increasing from 13,296.24 T in 2018/19 to 14,421.6 T in 2019/20 before declining to 13,497 T by 2023/24. Rice production displayed the most notable deviation, with a sharp increase to 163,523 T in 2020/21, likely linked to the expanded cultivation area that year. Bean production mirrored maize's trend, showing an initial rise followed by a decline over the years.

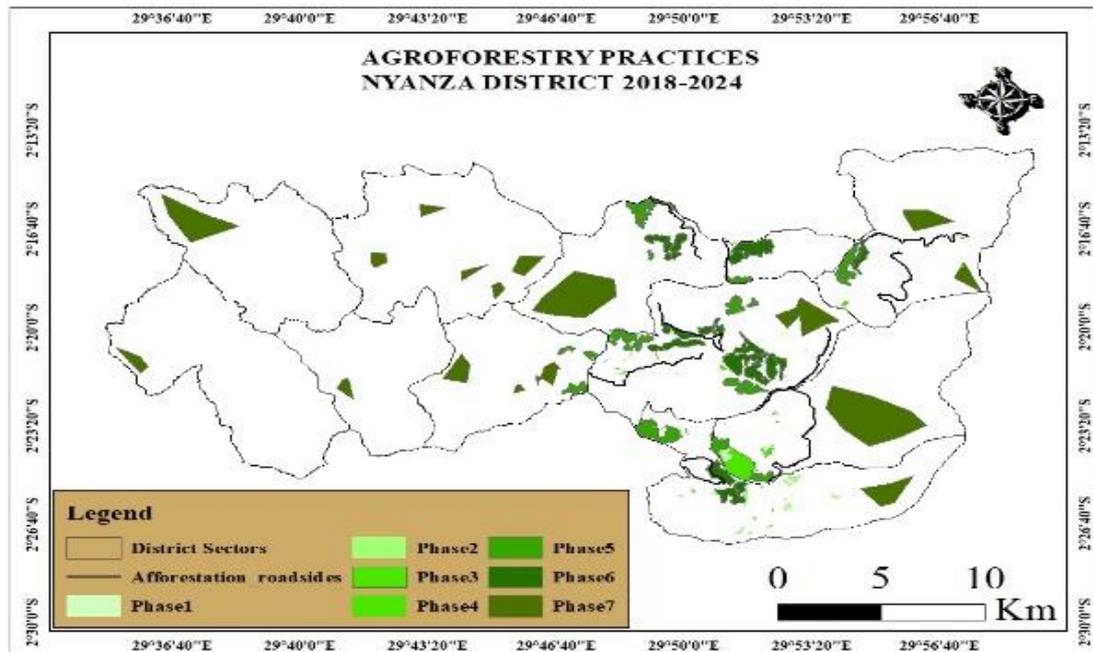
While agroforestry practices in the Nyanza district may have initially contributed to increased cultivated areas and crop productivity, subsequent declines in cassava production and fluctuations in other crops suggest external factors or the need for refinement of implemented strategies. Noteworthy data inconsistencies, particularly regarding rice cultivation and production in 2020/21, necessitate further investigation for accuracy. Therefore, to ensure long-term sustainability and productivity, continuous monitoring, adaptation of practices, and a more detailed analysis incorporating agroforestry techniques, soil conditions, and rainfall patterns are recommended to inform adjustments to the current agroforestry strategies.

**Table 5: The Effect of Productivity from Agroforestry Practices 2018- 2024**

S/N	Hillar	Sector	Outcome	Output	DSD Indicator	Target for	Actual										
						2018/19	achievement by 2019/20	2019/20	achievement by 2020/21	2020/21	achievement by 2021/22	2021/22	achievement by 2022/23	2022/23	achievement by 2023/24	2023/24	
			Area of non-forest land increased	In Contour planted			5,870		6,930.0		6,900		7,000		7,000		
									3,756		4,905.0		3,700		3,916		3,821
									1,045		1,040.0		28,840		1,180		1,172
									28,140		28,998.0		1,000		29,232		30,645
			Increased agriculture production and productivity	Standard of MF Production for Cereals, Mize, rice and Beans			20	20.6	20.5	20.8	27	25.9	21.0	22.0	27	20.2	
									3	3.5	3.0	3.6	3.2	3.6	3.3	3.3	3.2
									5.5	6.1	5.6	5.8	5.3	5.3	5.7	5.5	5.7
									1.3	1.5	1.4	1.3	1.3	1.12	1.20	1.30	1.30
			TFBOD/EPD/epda	DASSATA			156142		170364		178700		147004		162302		
									1339034		144010		15908		126213		126093
									432225		4032		143222		440		46004
									416473		340734		3138		336764		34782

**3.5 Agroforestry practices in Nyanza District 2018-2024**

The expansion of agroforestry practices in the Nyanza District is expected to significantly impact ecosystem services. Agroforestry enhances carbon sequestration, improves soil fertility and water management, and promotes biodiversity by creating diverse habitats. The increased tree cover helps in erosion control, reducing land degradation, and improving agricultural productivity. Additionally, these methods give local communities access to timber, fruits, and other non-timber forest products, which boosts their resilience to climate change and promotes sustainable livelihoods.



**Figure 2: Agroforestry in Nyanza District 2018- 2024**

Source: Nyanza District data,2025

Agroforestry in Nyanza District has seen substantial expansion from 2018 to 2024, with efforts divided into seven phases. Phase 1 covered 54.241 ha, Phase 2 expanded to 73.742 ha, Phase 3 reached 227.196 ha, Phase 4 involved 110.748 ha, Phase 5 encompassed 1012.533 ha, Phase 6 extended to 1269.991 ha, and Phase 7 included 1551.810 ha. These phases, as illustrated in the provided GIS map, demonstrate a widespread implementation of agroforestry practices across the district, with afforestation efforts also focusing along roadsides. The results indicate a progressive and substantial expansion of agroforestry initiatives in the Nyanza District between 2018 and 2024, implemented across seven distinct phases. The initial phases (1-4) covered relatively smaller areas, likely representing pilot programs or initial adoption stages.

Phases 5 and 6 marked a significant increase in coverage, indicating broader acceptance and implementation of agroforestry practices. Notably, Phase 7 represents the largest single expansion, accounting for over 38% of the total area under agroforestry, suggesting a strong commitment to scaling up these practices. The overall trend, also illustrated by the GIS map showcasing roadside afforestation efforts, highlights a strategic and increasingly comprehensive approach to integrating agroforestry practices as a central land management strategy in the District, aimed at achieving widespread and sustainable ecological and economic benefits. The rising percentages across phases underscore the growing emphasis on agroforestry as a key component of the district's environmental and agricultural policies.

**Table 6: Area in ha and % of agroforestry land in Nyanza district 2018-2024**

Phase	Area (ha)	Percentage of Total Area (%)
Phase 1	54.241	1.34
Phase 2	73.742	1.82
Phase 3	227.196	5.61
Phase 4	110.748	2.73
Phase 5	1012.533	25
Phase 6	1269.991	31.35
Phase 7	1551.81	38.15

**Source: Primary data; Survey in the Natural Resource Department on the Nyanza District, February 2025**

### 3.6 Relationship Between Agroforestry Practices and Ecosystem Services

The total number of responses is 385. Below is the percentage distribution of benefits associated with agroforestry practices: Table 12 illustrates the percentage distribution of benefits associated with agroforestry practices. Increased crop yield is the most significant benefit, accounting for 43.90% of responses, indicating that farmers prioritize agroforestry for its ability to enhance agricultural productivity. Improved soil health follows with 25.19%, reflecting its role in maintaining soil quality and fertility. Enhanced biodiversity accounts for 20.52%, highlighting the ecological advantages of agroforestry in supporting diverse species. Finally, Better water retention is the least selected benefit at 10.39%, suggesting that while agroforestry helps manage water resources, it is not as prominent as other benefits.

**Table 7: Relationship Between Agroforestry Practices and Ecosystem Services**

Benefit	Responses	Percentage (%)
Increased crop yield	169	43.9
Improved soil health	97	25.19
Better water retention	40	10.39
Enhanced biodiversity	79	20.52

**Source: Primary data, 2025**

## 4. CONCLUSION

In Rwanda's Southern Province, particularly in the Nyanza District, agroforestry techniques have demonstrated a great deal of promise for improving smallholder farmers' environmental sustainability and food security. According to the report, the majority of farmers have embraced boundary-planting agroforestry, which involves carefully placing trees around their properties. This approach supplies necessary resources like fuelwood and stakes in addition to raising demand for food and forest products. Diversifying production through the incorporation of trees into farming systems is essential for enhancing livelihoods and preparing for climatic variability.

Moreover, the farmers reported gaining valuable knowledge on tree planting techniques, spacing, and management skills, which are imperative for successful agroforestry implementation. To further enhance the benefits of agroforestry, the Rwandan government and stakeholders actively promote tree farming initiatives. Such efforts would help mitigate deforestation and land degradation caused by the over-extraction of firewood and timber from natural forests. By providing

incentives for tree planting, the government can encourage farmers to cultivate trees for personal use while contributing to the restoration of degraded environments. This dual approach not only supports local communities in meeting their needs but also fosters ecosystem services that are vital for sustainable agricultural practices in regions like Nyanza District.

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