

Journal of Agriculture & Environmental Sciences



Assessing the Effect of Landscape Restoration Interventions on Irish Potato Productivity in Nyabihu District: A Case of Selected Cooperatives

Diane Uwanyirigira & Dr. Eric Sibomana

ISSN: 2616-8456

Assessing the Effect of Landscape Restoration Interventions on Irish Potato Productivity in Nyabihu District: A Case of Selected Cooperatives

Diane Uwanyirigira¹, Dr. Eric Sibomana¹ (PhD)

¹*Faculty of Environmental Studies, University of Lay Adventists of Kigali, Kigali, Rwanda*

How to cite this article: Uwanyirigira, D. & Sibomana, E. (2026). *Assessing the Effect of Landscape Restoration Interventions on Irish Potato Productivity in Nyabihu District: A Case of Selected Cooperatives.* *Journal of Agriculture & Environmental Sciences*, 10(3), 33–50. <https://doi.org/10.53819/81018102t2615>

Abstract

Land degradation and soil erosion threaten agricultural productivity in Rwanda's Nyabihu District, particularly on steep slopes. This study assessed the effects of landscape restoration interventions on Irish potato productivity using a concurrent mixed-methods design. A sample of 177 smallholder farmers was selected from three cooperatives using Yamane's formula, representing 55.3% of 320 households at a 95% confidence level and $\pm 5\%$ margin of error. Quantitative data were analysed using descriptive statistics, t-tests, ANOVA, correlation, and multiple linear regression, while qualitative data from key informant interviews underwent thematic analysis. Results showed that 79.5% of farmers had adopted at least one restoration intervention: radical terraces, progressive terraces, or agroforestry. Adopters achieved an average yield of 19,654 kg/ha, compared with 10,054 kg/ha among non-adopters, nearly doubling productivity. Regression analysis revealed significant positive effects ($p < 0.001$) from radical terraces (+4,733 kg/ha; 37.1%), agroforestry (+4,049 kg/ha; 33.6%), and progressive terraces (+3,873 kg/ha; 31.0%). Control variables were statistically insignificant, indicating strong independent effects of restoration interventions. Qualitative findings confirmed improved soil stability, moisture retention, and yields, but identified labour intensity, inadequate maintenance, and ageing farmers as constraints. The study recommends integrated terracing and agroforestry, expanded farmer field schools for the 47.9% adopting only one intervention, and comprehensive support during the first three years after terrace construction to advance NST2's target of 50% crop production growth by 2029.

Keywords: *Nyabihu District, landscape restoration interventions, agricultural productivity, yield, and smallholder farmers.*

1. Introduction

Agriculture plays a fundamental role in global food security, economic development, employment creation, and rural livelihoods. It supports billions of people, particularly in developing countries where households depend on farming for food and income (World Bank, 2023). Among major food crops, Irish potato (*Solanum tuberosum*) is an important source of nutrition and income because of its high productivity and adaptability to diverse agroecological conditions. However, agricultural production is increasingly threatened by land degradation, declining soil fertility, climate variability, and unsustainable land management practices, which undermine long-term productivity and food security (FAO, 2022).

In Sub-Saharan Africa, these challenges are particularly severe in highland and mountainous regions, where steep slopes and intense rainfall accelerate soil erosion and nutrient loss. Continuous cultivation without adequate soil conservation measures further reduces soil quality and agricultural potential. Terracing, agroforestry, and other landscape restoration interventions are therefore promoted to reduce erosion, improve soil moisture retention, restore degraded land, and enhance agricultural productivity. Research on sustainable land management emphasizes the importance of integrating these practices to strengthen ecosystem resilience and support smallholder livelihoods (Winterbottom et al., 2013).

Rwanda faces considerable agricultural challenges because of its mountainous landscape, high population density, and limited arable land. Agriculture remains a major source of employment and contributes substantially to the national economy (MINAGRI, 2023). Nevertheless, cultivation on steep and erosion-prone slopes has increased pressure on agricultural resources, contributing to soil degradation and declining productivity. Irish potato is particularly important in Rwanda's highland regions, where it serves as both a staple food and a cash crop. Despite favorable climatic conditions in these areas, soil erosion and declining fertility can prevent farmers from achieving potential yields.

Nyabihu District is among the areas where these challenges are particularly pronounced. Its steep terrain, substantial rainfall, and intensive cultivation expose agricultural land to erosion and nutrient depletion. Irish potato production is an important livelihood activity in the district, particularly in Jenda, Mukamira, and Karago sectors. However, degraded soils and inadequate moisture retention constrain productivity, threatening household incomes and local food security. Landscape restoration interventions, including radical terraces, progressive terraces, and agroforestry, have been promoted to address these challenges by stabilizing slopes, conserving soil, and improving agricultural conditions.

Despite these efforts, evidence comparing the effects of individual restoration interventions on Irish potato productivity under Nyabihu's mountainous conditions remains limited. Understanding their relative contributions is essential for guiding investment, improving restoration strategies, and supporting evidence-based agricultural policies. Therefore, this study assesses the effects of radical terraces, progressive terraces, and agroforestry on Irish potato productivity in Jenda, Mukamira, and Karago sectors of Nyabihu District. The findings are intended to inform sustainable land management practices, strengthen smallholder agricultural productivity, and contribute to Rwanda's broader food security and agricultural development objectives.

1.2 Objectives of the Research

1.2.1 General objective

To assess the effect of landscape restoration interventions on Irish potato productivity among smallholder farmers in the selected three cooperatives of Nyabihu District, Western Province, Rwanda.

1.2.2. Specific objectives

- i. To assess the types of landscape restoration interventions implemented in Nyabihu District and assess the extent of their adoption.
- ii. To identify the current productivity of Irish potatoes in Nyabihu district.
- iii. To assess the relationship between restoration interventions and Irish potato productivity.
- iv. To assess the influence of intervening variables on the relationship between landscape restoration interventions and Irish potato productivity.

2. Research methods

2.1 Description of the study area

Nyabihu District is located in Rwanda's Western Province, in the Great Lakes region of East-Central Africa. It borders Rubavu, Musanze, Ngororero, and Rutsiro districts and covers approximately 532 km², divided into 12 administrative sectors (Nyabihu District, 2021). The district is characterized by a mountainous volcanic landscape, with elevations ranging from 1,500 to 2,500 metres above sea level. Approximately 70% of its land has slopes exceeding 30%, increasing susceptibility to soil erosion. Its dominant soils, including Andosols and Ferralsols, originate from volcanic materials and can support productive agriculture but are vulnerable to erosion and degradation when vegetation cover is removed. Annual rainfall ranges from 1,200 to 1,600 mm, with long and short rainy seasons that intensify erosion risks (RFA, 2020; NISR, 2022).

According to the 2022 census, Nyabihu had approximately 294,450 inhabitants, with a population density of 553 persons/km². Agriculture is the principal livelihood, with average farm sizes of approximately 0.5 hectares. Major crops include Irish potatoes, maize, beans, wheat, and vegetables. The district's proximity to Gishwati-Mukura National Park further emphasizes the need to balance agricultural production with environmental conservation. These characteristics make Nyabihu particularly suitable for assessing how landscape restoration interventions influence Irish potato productivity.

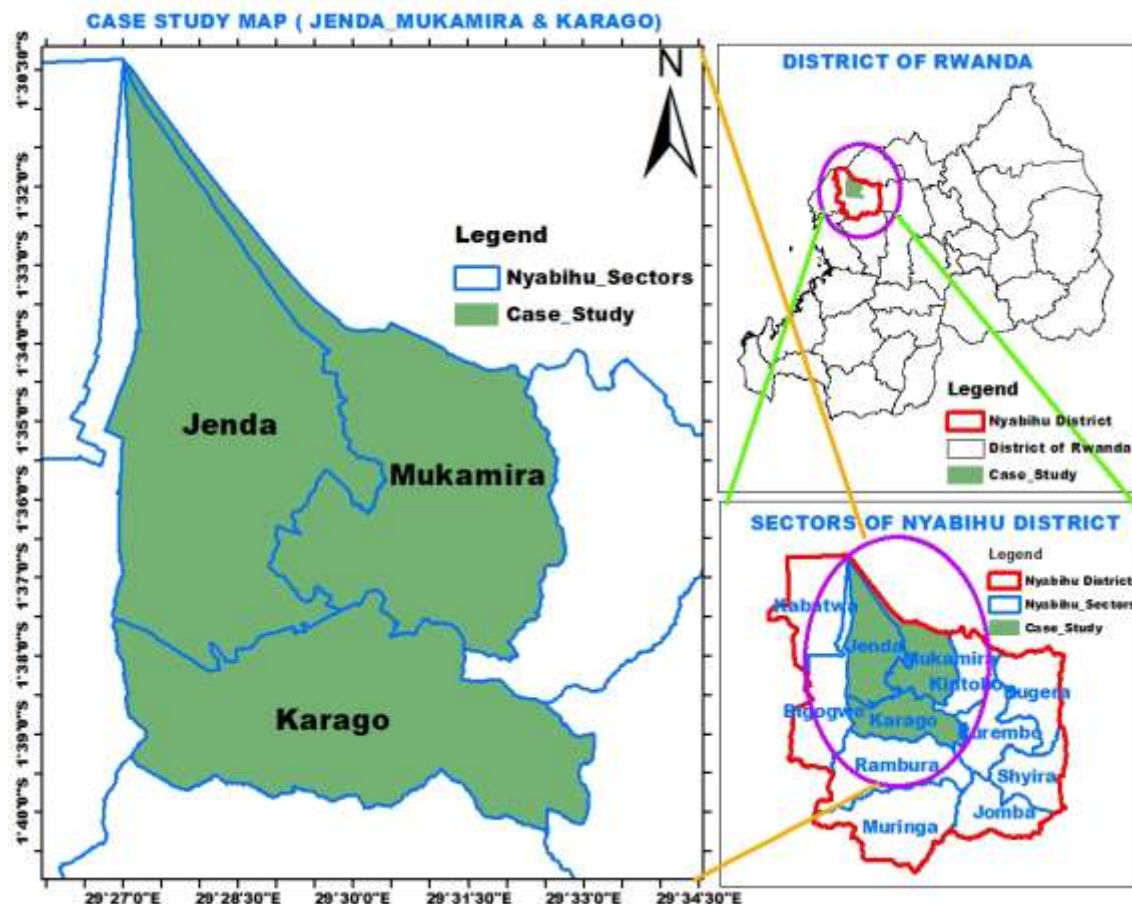


Figure 3.1.Map of Nyabihu District, Western Province, Rwanda
Source: Researcher's Computation, 2026

2.2 Research design and data collection methods

The study adopted a concurrent triangulation mixed-methods design, combining quantitative and qualitative approaches to assess the effects of landscape restoration interventions on Irish potato productivity in Nyabihu District. A descriptive and correlational design was used to describe restoration practices and examine their relationships with potato yields. A cross-sectional approach enabled data collection at a single point in time, supplemented by retrospective productivity information and secondary records.

The target population comprised 320 smallholder farming households belonging to three cooperatives in Jenda, Mukamira, and Karago sectors. The household head or principal agricultural decision-maker was the unit of analysis. Additionally, ten key informants, including district agricultural officers, sector agronomists, extension agents, and cooperative leaders, provided institutional perspectives on restoration interventions and agricultural productivity.

The sample size was determined using Yamane's (1967) formula, with a 5% margin of error, resulting in 177 households, representing 55.3% of the target population. Proportionate stratified sampling allocated 67 households to COAIPO, 55 to KOAIKAGA, and 55 to Nyabihu Potato Cooperative. Systematic random sampling was subsequently

used to select households from cooperative membership registers. The ten key informants were selected purposively based on their knowledge and experience.

Data were collected through household surveys, key informant interviews, and documentary review. A structured questionnaire captured household characteristics, restoration practices, farm sizes, potato yields, agricultural inputs, and implementation challenges. Face-to-face interviews were conducted with 177 households by the researcher and two trained enumerators. Semi-structured interviews explored restoration effectiveness, implementation barriers, and recommendations among ten key informants. Secondary information was obtained from cooperative records, district reports, RAB, NISR, MINAGRI, and relevant publications.

Data quality was enhanced through supervisor review, instrument pre-testing, enumerator training, standardized data collection procedures, and informed consent. Content validity was assessed using the Content Validity Index (CVI), reported as 0.857. Cronbach's alpha was used to assess questionnaire reliability; however, the calculated coefficient should be reported to demonstrate the instrument's reliability. Finally, household survey responses were compared with key informant interviews and secondary records to improve the consistency and credibility of the findings.

2.3 Data analysis and processing

Quantitative data were entered and cleaned in Microsoft Excel before being analyzed using IBM SPSS Statistics Version 26. Descriptive statistics, including frequencies, percentages, means, and standard deviations, summarized household characteristics, adoption of landscape restoration interventions (LRIs), and Irish potato productivity. Pearson's chi-square tests examined associations between categorical variables, while independent-samples t-tests compared yields between adopters and non-adopters. One-way ANOVA with Tukey's post-hoc test assessed yield differences across sectors and intervention types. Pearson correlation and multiple linear regression examined relationships between restoration interventions and potato yields, controlling for relevant household, institutional, and biophysical factors.

Qualitative data from key informant interviews were recorded in notebooks, transcribed verbatim, and analyzed using Braun and Clarke's (2006) six-phase thematic analysis framework. The process involved familiarization, initial coding, theme development, theme review, theme definition, and report preparation (Bowen, 2009). NVivo 14 was used to organize and manage the coding process.

Quantitative and qualitative findings were integrated during interpretation using convergent triangulation. A joint display matrix, guided by Creswell and Creswell (2018), compared statistical results with qualitative evidence, identifying areas of convergence, divergence, and complementarity across the research objectives.

The study followed UNILAK Research Ethics Committee guidelines and applicable ethical standards. Ethical approval was obtained from UNILAK, and clearance was sought from Nyabihu District. Participants provided informed consent after receiving explanations of the study's purpose, procedures, risks, benefits, and voluntary nature. Consent information was read aloud in Kinyarwanda where necessary. Confidentiality was protected through

anonymization, secure storage of questionnaires, and password-protected electronic files with encrypted backups. Data retention was planned for at least five years. Findings were intended to be shared with relevant communities and authorities.

The study sampled 177 of the 320 target households because of time and accessibility constraints associated with Nyabihu's mountainous terrain. Self-reported yields and intervention adoption may have introduced recall and reporting bias, which were mitigated by focusing on recent agricultural seasons, training enumerators, and triangulating survey responses with interviews and cooperative records. Since the study focused on cooperative members, non-cooperative farmers were excluded. Furthermore, its cross-sectional design limited causal conclusions. Retrospective information and key informant interviews provided additional context for interpreting relationships between restoration interventions and Irish potato productivity.

3. Results

3.1 Demographic Characteristics of Respondents

The study involved 177 respondents from three cooperatives: COAIPO in Karago (67; 37.85%), KOAIKAGA in Jenda (55; 31.07%), and Nyabihu Potato Cooperative in Mukamira (55; 31.07%). Males constituted 130 (73.45%) respondents, while females accounted for 47 (26.55%). Regarding marital status, 125 (70.62%) were married, 31 (17.52%) widowed, 14 (7.91%) single, and 7 (3.95%) divorced. Educationally, 58 (32.77%) had incomplete primary education, 50 (28.25%) completed primary education, 34 (19.21%) had incomplete secondary education, 16 (9.04%) completed secondary education, 10 (5.65%) had no formal education, and 9 (5.08%) had technical or vocational training. Overall, respondents were predominantly male and married, with mostly primary-level education, characteristics relevant to understanding adoption of landscape restoration interventions. Additionally, 10 key informants were purposively selected: 3 cooperative leaders, 3 sector agronomists, 2 district agronomists from Nyabihu District's Agriculture and Natural Resources Management Unit, and 2 extension agents from the VCRP implementing project.

Table 3.1: Demographic Characteristics of Respondents

Category	Sub-category	Count (N=177)	Percentage (%)
Cooperative Distribution	COAIPO (Karago)	67	37.85%
	KOAIKAGA (Jenda)	55	31.07%
	Nyabihu Potato Cooperative (Mukamira)	55	31.07%
Gender	Female	47	26.55%
	Male	130	73.45%
Marital Status	Divorced	7	3.95%
	Married	125	70.62%
	Single	14	7.91%
	Widowed	31	17.52%
Education Level	No formal education	10	5.65%
	Primary complete (P6)	50	28.25%
	Some primary (incomplete)	58	32.77%
	Secondary complete (S6)	16	9.04%
	Some secondary (incomplete)	34	19.21%
	Technical/vocational	9	5.08%
Grand Total		177	100.00%

Source: Primary Data, 2026.

3.1.1 Cooperative Institutional Context in the Three Study Sectors

The cooperative structures operating in the three sectors constitute the primary institutional platform through which LRIs are promoted, financed, and monitored. In the Karago sector, COAIPO (Cooperatives des Agriculteurs pour l'intensification de la pomme de terre), one cooperative operated with 120 registered and active members at the time of data collection, of whom 34% were female and 66% male, reflecting a predominantly male membership composition. The cooperative grows on land with both radical terraces and progressive terraces, tree planting, and agroforestry interventions, and members receive annual profit shares, assistance with Mutuelle de Sante premiums, enrolment in the Ejo Heza savings scheme, and collective marketing support. Member ages ranged predominantly from 35 to 65 years, with a considerable proportion exceeding 65, a factor with implications for labour-intensive terrace maintenance. Cooperative structures in Mukamira and Karago sectors operate under the same number of 100 active members, and the survey sample distribution is summarised in Table 3: COAIPO contributed 67 farmers (37.8%) from Karago sector, KOAIKAGA contributed 55 farmers (31.07%) from Jenda sector, and the Nyabihu potato cooperative contributed 55 farmers (31.07%) from Mukamira sector.

Table 3.2 Distribution of Survey Respondents by Cooperative and Sector.

Cooperative	Sector	Frequency (n)	Percent (%)
COAIPO	Karago	67	37.8
KOAIKAGA	Jenda	55	31.07
Nyabihu potato cooperative	Mukamira	55	31.07
Total		177	100.0

Source: Primary Data, 2026 Season A.

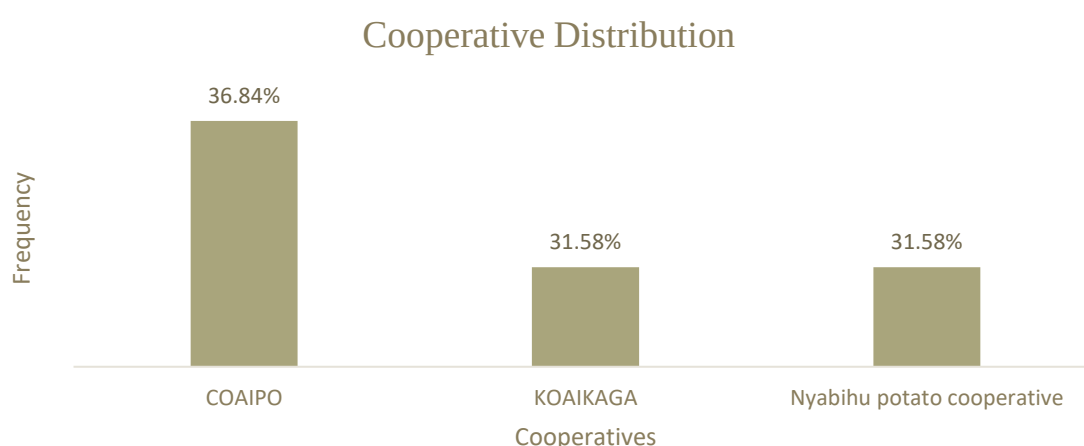


Figure 3.1 Cooperative Distribution

3.2.2 Adoption of Landscape Restoration Interventions

The main LRIs implemented are radical terraces, progressive terraces, and agroforestry.

The household survey revealed that 79.5% of farmers (136 out of 177) reported having adopted at least one restoration intervention among the three. Table 3 shows the adoption rates for individual practices: agroforestry was the most common (46.8%), followed by radical terraces (35.1%) and progressive terraces (31.0%). An adoption score (0–3) created by summing the three binary indicators (presented in Table 4.1 showed that the majority of farmers (47.9%) adopted only one practice, 29.8% adopted two, and only 1.8% adopted all three in different farmland. This indicates that while single-intervention adoption is widespread, integrated adoption of multiple practices remains limited.

Table 3.3 : Composite Adoption Score (Number of Interventions Adopted)

Number of interventions	Frequency (n)	Percent (%)	Cumulative (%)
0	35	20.5	20.5
1	82	48.0	68.5
2	51	29.8	98.2
3	7	1.8	100.0
Total	177	100.0	—

Note: Score = sum of Radical Terraces, Progressive Terraces, and Agroforestry.

Source: Primary Data, 2026 Season A.

Significant differences in adoption patterns across cooperatives were found (chi-square tests, $p < 0.001$ for all three interventions). Table 5 details these differences: COAIPO had the highest radical terrace adoption (58.3%), KOAIKAGA had the highest agroforestry adoption (66.7%), and the Nyabihu cooperative had the highest progressive terrace adoption (50.9%). These differences likely reflect varying extension emphases, leadership priorities, or biophysical conditions. Among farmers who adopted terraces, the average terrace area was 0.42 hectares (range 0.1–0.8 ha). Among agroforestry adopters, the average number of trees was 47 per hectare (range 7–99), indicating moderate but variable intensity of adoption.

Table 3.4 : Adoption of Interventions by Cooperative (%)

Cooperative	Radical terraces (%)	Progressive terraces (%)	Agroforestry (%)
COAIPO	58.3	30.2	33.3
KOAIKAGA	14.8	18.5	66.7
Nyabihu potato cooperative	31.5	50.0	42.6
Chi-square p-value	0.000	0.001	0.001

Source: Source: Primary Data, 2026 Season A.

Percentages are within-cooperative proportions.

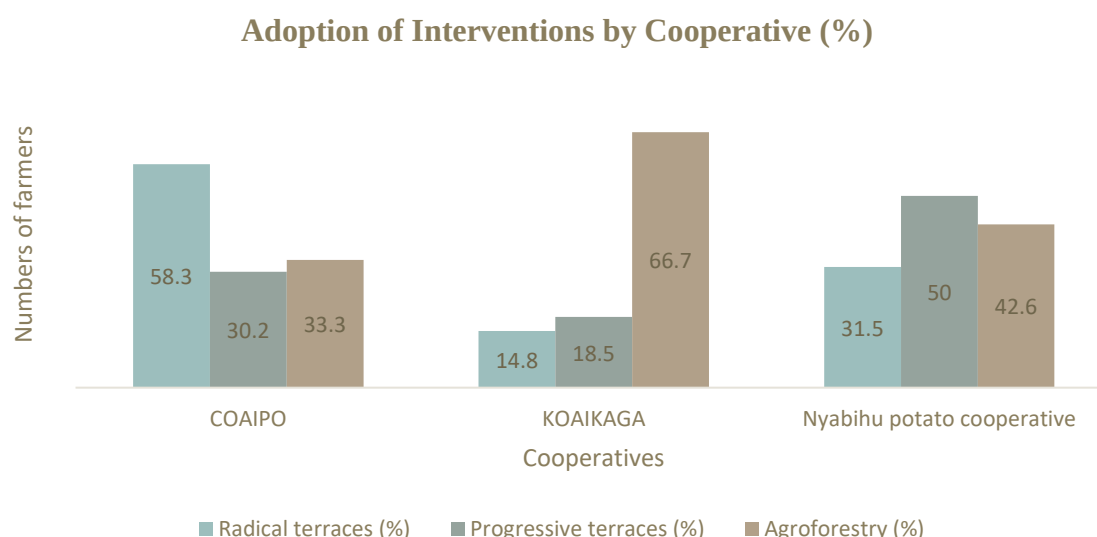


Figure 3.2: Adoption of intervention by Cooperatives

3.2.3 Secondary Data on Irish potato Production Trends (Cooperative production records from 2021 to 2026)

According to Cooperative records from 2021 to 2026 season A, the Jenda Sector Agronomist, a total of 3,344 hectares were under Irish potato cultivation during 2026 Season A. Most farmers cultivate plots of 0.5 ha or less, with 10 ares (0.1 ha) as a common reference unit, and the majority practice two seasons per year (Seasons A and B), with a minority growing three seasons by rotation with other crops, such as beans, peas, and maize.

Production records from the COAIPO cooperative document a clear upward trajectory. Total annual production was in 2021 at 585,708 kg, 632,006 kg in 2022 then declined between 2023 and 2024 (to 468,400 kg in 2023 and 584,631 kg in 2024), a period that may reflect the transitional costs of terrace construction, during which productivity can temporarily decrease as land is reshaped. A strong recovery occurred in 2025, with 976,350 kg, and the 2026 season A figure of 652,127 kg is the highest single-season production recorded in the dataset, suggesting accelerating productivity gains as terraces mature and construction area under radical terraces increases, without forgetting that agronomic practices improve, specifically, the use of certified seeds. Site-level quarterly data from Cyamabuye (2021–2026) and Bugoro Yarasine (2021–2023) confirm a positive productivity trajectory, with particularly sharp increases in 2025–2026.

3.10. Qualitative Findings from Key Informant Interviews (KIIs)

The qualitative findings are based on thematic analysis of interviews conducted with district agricultural officers, sector agronomists, extension agents, and cooperative leaders in Nyabihu District. Four major themes emerged: (1) effectiveness of landscape restoration interventions, (2) institutional and extension support systems, (3) farmer adoption constraints, and (4) environmental and biophysical influences on productivity.

3.10.1 Effectiveness of Landscape Restoration Interventions

Key informants consistently reported that landscape restoration interventions, such as radical terraces, progressive terraces, and agroforestry, have significantly improved soil stability, water retention, and Irish potato yields. Most respondents emphasized that radical terraces had the strongest observable impact, particularly in highly sloped areas. One sector agronomist noted:

"Before terraces, most farms were losing soil every rainy season. After radical terracing, we now see clear improvement in moisture retention and yields increasing year after year, and farmers are no longer losing their crops due to high runoff."

A cooperative leader similarly observed:

"Farmers who adopted terraces and combined them with good agronomic practices are harvesting almost double compared to those without any intervention. We are glad that the government is putting in much effort to control soil erosion"

These qualitative observations align closely with the quantitative results, showing that adopters of restoration practices achieve yields of 19,654 kg/ha compared to 10,054 kg/ha

for non-adopters (Table 7).

3.10.2 Institutional and Extension Support Systems

A second major theme was the importance of institutional support in promoting the adoption and maintenance of LRIs. Informants highlighted the role of extension services, cooperatives, and government programmes in training farmers and facilitating input access. One district agricultural officer stated:

"The success of these interventions depends heavily on continuous extension follow-up. Without technical support, some farmers fail to maintain terraces properly and have access to fertilizer in time."

An extension agent added:

"Cooperatives are very important because they organise farmers, distribute inputs, and ensure that maintenance of restoration practices is applied collectively rather than individually."

However, informants noted inconsistencies in extension coverage across sectors, which may partly explain the significant differences in adoption patterns observed in Table 5 (chi-square $p < 0.001$).

3.10.3 Farmer Adoption Constraints

Despite high overall adoption rates (79.5%), informants identified several barriers limiting full and integrated adoption of all three interventions. Labour shortages, ageing farmer populations, and limited financial capacity were most frequently mentioned. A sector agronomist explained:

"Terracing is labor-intensive. Older farmers struggle to maintain them, and younger people are often less engaged in farming."

A cooperative leader added:

"Most of the farmers have adopted at least one practice like agroforestry, but cannot afford to combine it with terraces due to costs and labour demands. And they are always waiting for government initiatives."

These constraints help explain the survey finding that only 1.8% of farmers adopt all three interventions simultaneously in their land, and are consistent with the small but significant negative correlation between farmer age and yield ($r = -0.266$, $p < 0.001$).

3.10.4 Environmental and Biophysical Influences

Informants also emphasized the strong influence of environmental conditions on the effectiveness of LRIs. Steep slopes, heavy rainfall, and erosion risks were frequently cited as key challenges shaping agricultural productivity in the district. One district officer noted:

"Nyabihu is naturally very fragile due to its steep slopes. Without terraces, farming here would not be sustainable at all."

Another informant stated:

"Rainfall is both a blessing and a challenge. It supports crops, but without proper land management it accelerates soil erosion and before terracing the farmers use to lose the whole season."

These observations reinforce the quantitative evidence showing that LRIs are particularly effective in improving productivity under high-risk agro-ecological conditions, and support the agronomist's testimony of a near twenty-eight-fold yield increase following terrace construction with full protocol adherence.

3.3. Discussion of Findings

The study found that 79.5% of farmers (141 out of 177) had adopted at least one landscape restoration intervention, reflecting substantial uptake of soil conservation practices in Nyabihu District. However, only 1.8% ($n = 6$) reportedly adopted all three interventions: radical terraces, progressive terraces, and agroforestry. This gap suggests that adoption of individual practices is more common than integrated implementation, consistent with Rogers' (2003) diffusion theory and Branca et al.'s (2021) discussion of resource constraints affecting sustainable land management. Adoption also varied significantly across cooperatives ($p < 0.001$): COAIPO recorded the highest radical terrace adoption (58.3%), KOAIKAGA led in agroforestry (66.7%), and Nyabihu Potato Cooperative had the highest progressive terrace adoption (50.0%). These differences highlight the influence of institutional and local conditions, consistent with Nabahungu et al. (2025).

A major finding was the productivity difference between adopters and non-adopters. Adopters achieved an average yield of 19,654 kg/ha (19.65 t/ha), compared with 10,054 kg/ha (10.05 t/ha) among non-adopters—an increase of approximately 95.6%. The adopters' average also exceeded the reported national average of 8.7 t/ha (NISR, 2025), while RAB (2025) reported yields of up to 22 t/ha under well-managed terraced conditions. These comparisons suggest the productivity potential of restoration practices, although differences in conditions and management should be considered when comparing yields.

Regression analysis further showed that all three interventions were significantly associated with higher yields ($p < 0.001$), controlling for fertiliser use, farm size, education, and institutional support. Radical terraces increased yield by 4,733 kg/ha, agroforestry by 4,049 kg/ha, and progressive terraces by 3,873 kg/ha. These results align with studies reporting productivity benefits from terracing (Kagabo et al., 2020; Tamburini et al., 2024), soil and water conservation (Winowiecki et al., 2021), and agroforestry (Kuyah et al., 2019; Muchane et al., 2020). Fertiliser use, farm size, education, and institutional support were not statistically significant ($p > 0.05$), possibly reflecting contextual or measurement limitations rather than their general irrelevance (Clay & Zimmerer, 2020; Minh et al., 2021; Niyonzima et al., 2022).

Qualitative interviews reinforced the quantitative results, with informants reporting improved yields following terracing and persistent erosion among non-adopters. One agronomist described yields increasing from below 700 kg/ha to over 20,000 kg/ha after terrace construction. However, labour shortages, ageing farmers, and financial constraints hindered integrated adoption. Overall, the findings support continued investment in terracing, agroforestry, and farmer support, consistent with Rwanda's NST2 priorities (GoR, 2024). Cooperative-specific extension, labour support, and improved maintenance assistance could help expand integrated restoration and sustain productivity gains.

4. Conclusion

This study concludes that landscape restoration interventions significantly improve Irish potato productivity in Nyabihu District, Rwanda. Among the 177 surveyed farmers, 79.5% had adopted at least one intervention, with agroforestry being the most common. Farmers adopting restoration practices achieved an average yield of 19,654 kg/ha, compared with 10,054 kg/ha among non-adopters. Regression analysis confirmed significant yield gains from radical terraces (+4,733 kg/ha), agroforestry (+4,049 kg/ha), and progressive terraces (+3,873 kg/ha), with the model explaining 63% of yield variation. However, integrated adoption remains limited, as only 1.8% of farmers reportedly implemented all three interventions. These findings support expanding restoration programmes alongside certified seed, manure, crop protection, continuous extension, and maintenance support. Addressing labour constraints, particularly among older farmers, is also essential. Scaling integrated restoration packages can strengthen soil conservation, improve farm productivity and livelihoods, and contribute to Rwanda's NST2 target of increasing crop production by 50% by 2029.

3.2.4. Primary Survey Data on Current Productivity

Table 3.3 and 4.6 presents descriptive statistics of Irish potato yield. The survey recorded an average yield of 17,689 kg/ha (median 19,353 kg/ha, standard deviation 3,974 kg/ha, range 8,167–20,985 kg/ha). The negative skew (-1.42) indicates that most farmers achieve yields near the upper end of the distribution. When disaggregated by restoration status (Table 7), farmers who adopted any intervention achieved an average of 19,654 kg/ha compared to only 10,054 kg/ha for non-adopters. A difference of 9,600 kg/ha, representing a near-doubling of productivity. One-way ANOVA revealed no statistically significant differences in yield across cooperatives or sectors ($F(2,168) = 0.35$, $p = 0.704$), with mean yields ranging from 17,318 kg/ha (KOAIKAGA/Jenda) to 17,915 kg/ha (Nyabihu/Mukamira) as shown in Table 8 This indicates comparable growing conditions and management levels across the study area.

Table 3.5: Descriptive Statistics of Irish Potato Yield (kg/ha)

Statistic	Value
Mean	17,689
Median	19,353
Standard deviation	3,974
Minimum	8,167
Maximum	20,985
Skewness	-1.42
25th percentile	18,438
75th percentile	20,066

N = 177 farmers.

Source: Source: Primary Data, 2026 Season A.

Table 3.6 : Yield (kg/ha) by Restoration Status – Independent t-test

<i>Restoration status</i>	<i>N</i>	<i>Mean</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>
No	37	10,054	1,148	8,167	12,286
Yes	140	19,654	745	17,351	20,985
Difference (No – Yes)	—	-9,600	—	—	—
Test statistic	Value				
t-value	-60.20				
Degrees of freedom	169				
p-value	0.000				
Cohen's d	-9.92				

Equal variances assumed. Effect size indicates a very large difference.

Table 3.7 : Mean Yield (kg/ha) by Cooperative and Sector ANOVA

Cooperative	Sector	N	Mean yield	SD
COAIPO	Karago	67	17,814	4,232
KOAIKAGA	Jenda	55	17,318	3,926
Nyabihu potato cooperative	Mukamira	55	17,915	3,754

ANOVA Result: $F(2,168) = 0.35$, $p = 0.704$ (Not statistically significant)

Concerning productivity trends over the past five seasons (2020–2026), **Table 4.7** shows that 78.9% of all farmers reported “much higher (>30% increase)” in yields, 12.3% reported “slightly higher (10–30%)”, and 8.8% reported “no change”. However, when disaggregated by restoration status, 97.8% of adopters reported much higher yields compared to only 5.7% of non-adopters. This stark contrast suggests that the perceived productivity improvement is overwhelmingly concentrated among adopters of restoration practices. Input-use efficiency, measured as the output/input ratio (kg yield per kg of fertilizer), averaged 79.1 (standard deviation 48.5, range 27–516). The high variability and extreme values (up to 516) may reflect measurement issues or exceptional cases, but the median of 74 suggests that most farmers achieve moderate to high efficiency.

Table 3.8 : Yield Change Over Five Seasons by Restoration Status (%)

Yield change	All farmers (%)	Non-adopters (%)	Adopters (%)
Much higher (>30%)	78.9	5.7	97.8
Slightly higher (10–30%)	12.3	51.4	2.2
No change ($\pm 10\%$)	8.8	42.9	0.0

Source: Source: Primary Data, 2026 Season A.

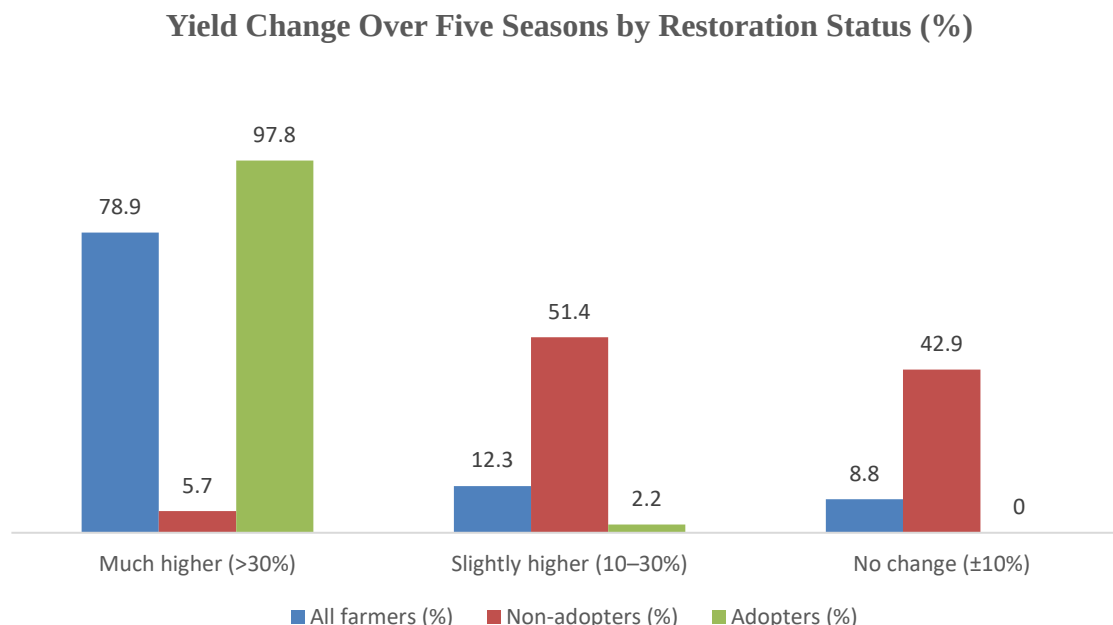


Figure 3.4 Yield Change Over Five Seasons by Restoration Status (%)

4.2.5. Agronomist Testimony on Terracing Effect

The Jenda Sector Agronomist, drawing on his personal farming experience, reported that before terracing (pre-2020) his plot yielded below 700 kg/ha per season. After constructing terraces and adhering to the full agronomic protocol (certified seed, manure, crop protection, regular maintenance), yields exceeded 20,000 kg/ha, a twenty-eight-fold increase. He emphasized that terracing alone is insufficient; the full protocol must be followed for maximum gains.

3.2.6 Bivariate Statistical Analysis

Table 3.8. Summarizes. Independent t-tests revealed that each intervention is associated with a statistically significant yield increase ($p < 0.001$ for all). Farmers with radical terraces achieved 20,241 kg/ha versus 16,309 kg/ha for those without (difference +3,932 kg/ha). Progressive terraces added 2,939 kg/ha (19,717 vs. 16,778), and agroforestry added 3,335 kg/ha (19,464 vs. 16,129). The effect size for “any restoration” was exceptionally large (Cohen’s $d = -9.92$), indicating a very strong association. Among farmers with terraces, one-way ANOVA showed that terrace type (radical only, progressive only, or mixed) explained 35.5% of yield variation ($F(2,96) = 26.36$, $p < 0.001$). Post-hoc tests indicated that radical terraces and mixed types yielded significantly higher than progressive only, but the absolute differences were modest.

Table 3.9: Bivariate Comparison of Yield (kg/ha) by Individual Intervention

Intervention	With intervention (Mean $\pm$ SD)	Without intervention (Mean $\pm$ SD)	Difference	t-value	p-value
Radical terraces	20,241 $\pm$ 427	16,309 $\pm$ 4,340	+3,932	-6.99	0.000
Progressive terraces	19,717 $\pm$ 667	16,778 $\pm$ 4,478	+2,939	-4.75	0.000
Agroforestry	19,464 $\pm$ 731	16,129 $\pm$ 4,910	+3,335	-6.01	0.000

All results significant at $p < 0.001$.

On table 3.9 regarding, Pearson correlation analysis confirmed moderate to strong positive associations between each intervention and yield: radical terraces ($r=0.474$, $p<0.001$), agroforestry ($r=0.420$, $p<0.001$), and progressive terraces ($r=0.343$, $p<0.001$). Age showed a small but significant negative correlation ($r=-0.266$, $p=0.0004$), suggesting that older farmers tend to have slightly lower yields. Surprisingly, fertilizer application (kg/ha) showed no linear correlation with yield ($r=0.000$, $p=1.000$), a finding explored further in the regression analysis.

Table 3.10 : Pearson Correlation Coefficients with Yield (kg/ha)

Variable	Correlation (r)	p-value
Radical terraces	0.474	0.000
Progressive terraces	0.343	0.000
Agroforestry	0.420	0.000
Age	-0.266	0.000
Farm area	0.094	0.220
Fertiliser use	0.000	1.000

3.2.7. Multiple Linear Regression (Main Model)

The Table 3.10 in order to isolate the independent effect of each restoration intervention while controlling for potential confounders, a multiple linear regression model was estimated with yield (kg/ha) as the dependent variable. Independent variables included the three binary intervention indicators, fertiliser (kg/ha), an institutional support index (combining extension visits, cooperative benefit, and seed/fertiliser access), farm area (ha), and education level (1–6 ordinal scale). Robust standard errors were used to correct for heteroskedasticity. The model was highly significant ($F(7,163) = 28.41$, $p<0.001$) and explained 63.0% of the variance in yield (adjusted $R^2=0.630$).

All three restoration interventions remained highly significant ($p<0.001$) after controlling for the other variables. Specifically, adopting radical terraces increased yield by 4,733 kg/ha (95% CI: 3,930–5,536), progressive terraces by 3,873 kg/ha (95% CI: 3,046–4,701),

and agroforestry by 4,049 kg/ha (95% CI: 3,284–4,813). None of the control variables – fertilizer, institutional support, farm area, or education were statistically significant ($p > 0.05$ in all cases). This indicates that the restoration interventions have strong, independent effects that are not explained by these household characteristics.

Table 3.11 : Multiple Linear Regression Results (Dependent Variable: Yield kg/ha)

Variable	Coefficient	Robust SE	t	p-value	95% CI
Radical terraces	4,733.3	406.6	11.64	0.000	3,930 – 5,536
Progressive terraces	3,873.1	419.0	9.24	0.000	3,046 – 4,701
Agroforestry	4,048.8	387.2	10.46	0.000	3,284 – 4,813
Fertiliser	0.26	2.42	0.11	0.914	-4.52 – 5.04
Institutional support	-137.0	335.6	-0.41	0.684	-800 – 526
Farm area	529.1	488.0	1.08	0.280	-435 – 1,493
Education	-26.0	155.0	-0.17	0.867	-332 – 280
Constant	12,886.9	1,211.9	10.63	0.000	10,494 – 15,280

4.2.8 Log-Linear Regression (Robustness Check)

On the **Table 3.11** Because residuals from the linear model were not normally distributed (Shapiro-Wilk $p < 0.001$), a log-linear model with $\ln(\text{yield})$ as the dependent variable was estimated to provide percentage changes. The log-linear model confirmed that restoration interventions increase yields by 31–37% after controlling for confounders. Radical terraces showed the largest relative effect (+37.1%, $p < 0.001$), followed by agroforestry (+33.6%, $p < 0.001$) and progressive terraces (+31.0%, $p < 0.001$). Again, none of the control variables were significant. The consistency between the linear and log-linear models strengthens confidence in the findings.

Table 3.12: Log-Linear Regression Results (Dependent Variable: $\ln(\text{Yield})$)

Variable	Coefficient	Robust SE	t	p-value	% Change
Radical terraces	0.3151	0.0293	10.77	0.000	+37.1%
Progressive terraces	0.2698	0.0304	8.88	0.000	+31.0%
Agroforestry	0.2898	0.0283	10.25	0.000	+33.6%
Fertiliser	0.00001	0.00017	0.05	0.957	~0%
Institutional support	-0.0057	0.0246	-0.23	0.818	-0.6%
Farm area	0.0434	0.0359	1.21	0.229	+4.4%
Education	-0.0029	0.0114	-0.25	0.799	-0.3%

3.9. Composite Landscape Restoration Index

On table 3.12 A composite LRI index (mean of the three binary interventions) was also tested. Each one-unit increase in the index, adopting one additional intervention was associated with a yield increase of 12,617 kg/ha ($p < 0.001$, adjusted $R^2 = 0.628$), confirming the additive benefit of combining multiple interventions.

Table 3.13 : Regression with Composite Landscape Restoration Index (LRI)

Variable	Coefficient	Std. Err.	t	p-value	95% CI
LRI Index	12,617.2	749.9	16.82	0.000	11,136 – 14,098
Fertiliser	0.68	2.75	0.25	0.805	-4.75 – 6.12
Institutional support	-157.7	342.7	-0.46	0.646	-834 – 519
Farm area	657.4	468.0	1.40	0.162	-267 – 1,581
Education	-54.5	151.3	-0.36	0.719	-353 – 244
Constant	12,827.4	1,338.3	9.58	0.000	10,185 – 15,470

All regression assumptions were checked. Variance inflation factors ranged from 1.02 to 1.07 (mean=1.04), well below the threshold of 5, indicating no multicollinearity. The Breusch-Pagan test indicated mild heteroskedasticity ($\chi^2=4.20$, $p=0.041$), which was addressed by using robust standard errors. Cook's distance identified five observations with values greater than 4/177 (0.023); these were reviewed but retained as they represent legitimate high-performing farms. The non-normality of residuals was managed through the log-linear transformation.

5. References

- Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal*, 9(2), 27–40. <https://doi.org/10.3316/QRJ0902027>
- Branca, G., Lipper, L., McCarthy, N., & Jolejole, M. C. (2021). Food security, climate change, and sustainable land management: A review. *Agronomy for Sustainable Development*, 33(4), 635–650. <https://doi.org/10.1007/s13593-013-0133-1>
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp063oa>
- Clay, N., & Zimmerer, K. S. (2020). Who is resilient in Africa's green revolution? Sustainable intensification and climate smart agriculture in Rwanda. *Land Use Policy*, 97, 104558. <https://doi.org/10.1016/j.landusepol.2020.104558>
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approach* (5th ed.). Sage Publications.
- Field, A. (2018). *Discovering statistics using IBM SPSS statistics* (5th ed.). Sage Publications.
- Food and Agriculture Organization. (2022). *Soil fertility definition and indicators*. FAO.
- Fuglie, K. (2018). Is agricultural productivity slowing? *Global Food Security*, 17, 73–83. <https://doi.org/10.1016/j.gfs.2018.05.001>
- Gachene, C. K., Mureithi, J. G., & Gicheru, P. T. (2020). Effects of soil and water conservation measures on soil fertility and crop yields in the Lake Victoria basin. *East African Agricultural and Forestry Journal*, 83(2), 113–128.
- Gann, G. D., McDonald, T., Walder, B., Aronson, J., Nelson, C. R., Jonson, J., ... Hall, T. (2019). *International principles and standards for the practice of ecological restoration* (2nd ed.). *Restoration Ecology*, 27(S1), S1–S46. <https://doi.org/10.53819/81018102t2615>

<https://doi.org/10.1111/rec.13035>

- Government of Rwanda. (2017). *National Strategy for Transformation (NST1) 2017–2024*. Republic of Rwanda.
- International Union for Conservation of Nature. (2020). *Forest landscape restoration: Principles and approaches*. IUCN.
- Kagabo, D. M., Stroosnijder, L., Visser, S. M., & Moore, D. (2020). Soil erosion, soil fertility and crop yield on bench terraces in the highlands of Rwanda. *Soil and Tillage Research*, 198, 104534. <https://doi.org/10.1016/j.still.2019.104534>
- Kelly, V., Murekezi, A., & Mpyisi, E. (2020). *Fertilizer use in Rwanda: A review of recent trends and policy options*. Food Security Collaborative Working Papers.
- Krueger, R. A., & Casey, M. A. (2015). *Focus groups: A practical guide for applied research* (5th ed.). Sage Publications.
- Kuyah, S., Öborn, I., Jonsson, M., Dahlin, A. S., Barrios, E., Muthuri, C., Öberg, G. (2019). Trees in agricultural landscapes enhance provision of ecosystem services in sub-Saharan Africa. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 12(1–2), 255–273.
- Lal, R. (2020). Soil conservation and restoration. In *Encyclopedia of soil science* (3rd ed., pp. 1–8). CRC Press.
- Le, H. D., Smith, C., & Herbohn, J. (2020). What drives the success of reforestation projects in tropical developing countries? A meta-analysis. *Forests*, 11(4), 401. <https://doi.org/10.3390/f11040401>
- Minh, T. T., Neef, A., & Hoffmann, V. (2021). Agricultural innovation: Does social capital matter? *Journal of International Development*, 33(4), 654–671.
- Ministry of Agriculture and Animal Resources. (2021). *Annual report 2020–2021*. Republic of Rwanda.
- Nair, P. K. R. (2019). *An introduction to agroforestry*. Kluwer Academic Publishers.
- National Institute of Statistics of Rwanda. (2021). *Seasonal agricultural survey report 2020*. NISR.
- National Institute of Statistics of Rwanda. (2022). *Rwanda population and housing census 2022: Main indicators report*. NISR.
- Niyonzima, T., Bizimana, J. P., & Uwimana, A. (2022). Agroforestry adoption and household food security in Rwanda's Western Province. *Rwanda Journal of Agricultural Sciences*, 4(1), 12–28.
- Nkonya, E., Mirzabaev, A., & von Braun, J. (Eds.). (2021). *Economics of land degradation and improvement: A global assessment for sustainable development*. Springer Open. <https://doi.org/10.1007/978-3-319-19168-3>
- Nyabihu District. (2021). *Nyabihu District development strategy 2021–2025*. Republic of Rwanda.