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Assessing Effectiveness of Soil and Water Conservation Practices for Enhancing Productivity: A Case Study of Rwabicuma Hillsides Irrigation Scheme

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Abstract: **Soil erosion and declining agricultural productivity remain major challenges in Rwanda's hillside farming systems, highlighting the need for effective soil and water conservation (SWC) practices. This study evaluated the effectiveness of SWC practices in improving agricultural productivity in the Rwabicuma Hillside Irrigation Scheme, Southern Rwanda. Specifically, the study identified the SWC practices implemented, assessed their effects on crop productivity, and examined the relationship between SWC practices, crop yield improvement, and soil erosion reduction. A mixed-methods research design was employed, combining structured questionnaires administered to 300 randomly selected farmers, interviews with 15 key informants, and field observations. Quantitative data were analyzed using descriptive statistics, chi-square tests, analysis of variance (ANOVA), and correlation analysis, while qualitative data were analyzed thematically.**

The findings showed that terracing was the dominant SWC practice (34.29%), followed by terracing combined with mulching (29.21%), whereas cover crops were the least adopted (1.90%). Crop productivity increased significantly following the adoption of SWC practices, with mean yields rising from 5.84 ± 0.70 t ha^{-1} before implementation to 10.33 ± 1.24 t ha^{-1} after implementation, representing an overall increase of 56.52% ($p < 0.0001$). Integrated SWC practices demonstrated stronger positive relationships with crop yield improvement than terracing alone, with terrace plus mulching showing the strongest correlation ($r = 0.82$, $p = 0.01$).

The study concludes that integrating structural and biological SWC practices within hillside irrigation systems substantially enhances agricultural productivity while strengthening soil conservation. It recommends expanding farmer training, promoting integrated conservation practices, and strengthening institutional support to improve the sustainability of hillside agriculture in Rwanda.

Keywords: **Agricultural productivity; hillside irrigation; Soil and water conservation; sustainable land management, terracing.**

1. INTRODUCTION

Agricultural production systems worldwide are increasingly threatened by land degradation, declining soil fertility, water scarcity, and climate variability, which undermine food security and rural livelihoods (Dimkpa et al., 2023; Diop et al., 2022; Omotoso et al., 2023). Soil erosion remains one of the most severe forms of land degradation, affecting large areas of agricultural land through nutrient depletion, reduced soil productivity, and ecosystem deterioration (Jiru & Wegari, 2022; J. Wang et al., 2023). These challenges are particularly pronounced in mountainous and hilly environments, where steep slopes and heavy rainfall accelerate runoff and soil erosion. Consequently, soil and water conservation (SWC) practices have become essential strategies for improving soil health, enhancing water retention, and sustaining agricultural productivity under changing climatic conditions (Cárceles Rodríguez et al., 2022; Rajbanshi et al., 2023).

In Sub-Saharan Africa, smallholder farming systems are highly vulnerable to land degradation due to dependence on rain-fed agriculture, population pressure, and cultivation of fragile landscapes (Diop et al., 2022; Eekhout & de Vente, 2022). Soil erosion and declining fertility have contributed to reduced agricultural productivity and increased vulnerability among farming communities. Integrated SWC practices, including terracing, contour bunds, agroforestry, mulching, and water harvesting, have been promoted to reduce soil loss, improve moisture availability, and enhance climate resilience (Cárceles Rodríguez et al., 2022; Ebabu et al., 2022). However, the effectiveness of these practices depends on local environmental conditions, management approaches, institutional support, and farmer adoption.

Rwanda faces similar challenges due to its mountainous terrain, high population density, and strong dependence on agriculture. More than 80% of the population is engaged directly or indirectly in agriculture, while a large proportion of cultivated land is located on steep hillsides that are highly vulnerable to erosion, declining soil fertility, and reduced agricultural productivity (Diop et al., 2022; Majoro et al., 2023). Soil erosion remains one of the major land degradation challenges in Rwanda, particularly in highland agricultural areas where intense rainfall, steep slopes, and continuous cultivation accelerate soil and nutrient losses (Du et al., 2022; Majoro et al., 2023). To address these challenges, the Government of Rwanda has implemented integrated land management initiatives, including the Land Husbandry, Water Harvesting (LWH) and Hillside Irrigation program, which combines terracing, water harvesting, irrigation development, and improved agricultural practices to enhance hillside agricultural productivity and climate resilience (Ngango & Seungjee, 2021; Rutebuka et al., 2021).

Irrigation expansion is an important component of Rwanda's strategy to intensify agricultural production and reduce dependence on increasingly variable rainfall patterns. Irrigation improves water availability, supports crop intensification, enables production during dry periods, and contributes to increased agricultural productivity when combined with appropriate management practices (Zizinga et al., 2022). However, irrigation alone cannot guarantee sustainable productivity in fragile hillside environments because poorly managed irrigation systems may increase runoff, erosion risks, and nutrient transport losses (Kamamia et al., 2022; Wang et al., 2022). Without appropriate SWC measures, irrigated systems may experience declining soil quality, reduced infiltration capacity, sediment accumulation, and inefficient water use (Diop et al., 2022; Du et al., 2022). Therefore, integrating SWC practices with irrigation development is essential for achieving sustainable agricultural intensification and long-term resilience of hillside farming systems.

Previous studies have demonstrated that SWC practices contribute significantly to agricultural improvement (Byiringiro et al., 2023; Rutebuka et al., 2021; Uwacu et al., 2021). Terraces and contour bunds reduce runoff and soil erosion while improving soil moisture conditions and crop performance (Uwacu et al., 2021). Agronomic practices such as mulching and conservation tillage enhance soil organic matter and water-use efficiency, while biological measures such as agroforestry improve nutrient cycling and soil stability (Kassam et al., 2020). In Rwanda, research has confirmed the importance of SWC practices in reducing land degradation and improving agricultural productivity (Byiringiro et al., 2023; Ruticumugambi et al., 2024). However, most existing studies have focused either on rain-fed hillside agriculture or irrigation development separately, with limited attention to the combined effects of SWC practices within irrigated hillside systems.

The Rwabicuma Hillside Irrigation Scheme in Nyanza District provides an important opportunity to evaluate the effectiveness of integrated irrigation and soil and SWC management. Established under the LWH and Hillside Irrigation Program, the scheme covers ~ 471 ha of hillside farmland characterized by sloping terrain, where erosion control and efficient water management are essential for sustainable agricultural production (Land Husbandry Water Harvesting [LWH], 2016; World Bank, 2018). Despite substantial investments in hillside irrigation infrastructure and land husbandry technologies in Rwanda, limited empirical evidence exists on how the combined application of SWC practices and irrigation management influences crop productivity under irrigated hillside conditions.

Therefore, a knowledge gap remains regarding the effectiveness of SWC practices within integrated hillside irrigation systems. Previous research has not sufficiently quantified how conservation practices interact with irrigation to influence crop productivity, nor has it adequately assessed productivity changes before and after irrigation scheme establishment (Nyirenda & Balaka, 2021; Patra et al., 2021; Su et al., 2021). Addressing this gap is necessary to improve conservation strategies, guide agricultural extension services, and enhance the sustainability of irrigation investments.

This study therefore aimed to evaluate the effectiveness of soil and water conservation practices under irrigation conditions in enhancing agricultural productivity in the Rwabicuma Hillside Irrigation Scheme. Specifically, the study aimed to: (1) assess the current SWC practices implemented within the Rwabicuma Hillside Irrigation Scheme; (2) evaluate agricultural productivity before and after the establishment of the irrigation scheme; and (3) determine the effect of SWC practices on agricultural productivity in the study area.

2. MATERIALS AND METHODS

2.1 Study area description

The study was conducted in the Rwabicuma Hillside Irrigation Scheme, located in Rwabicuma Sector (2°22′40″ S, 29°41′50″ E), Nyanza District, Southern Province, Rwanda (Figure 1). The sector covers 65 km² and is characterized by undulating terrain with elevations ranging from 1550 to 1680 m above sea level, while the irrigation scheme is situated at ~ 1630 m (LWH, 2016). The scheme covers 471 ha across Four sectors of Nyanza district (Rwabicuma, Nyagisozi, Cyabakamyi, and Busasamana sector) and comprises an earth dam with a storage capacity of 150000 m³, 12 km of primary and secondary irrigation canals, and about 1300 ha of terraced hillsides. Slopes range between 5% and 25%, making the area highly susceptible to runoff and soil erosion.

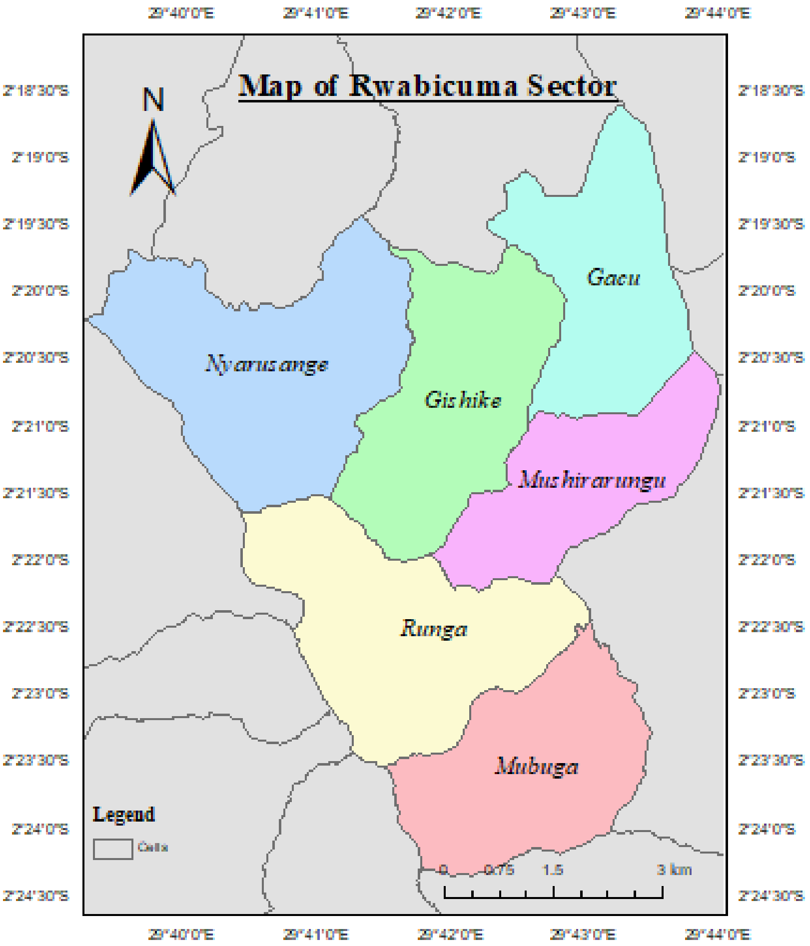

Figure 1. Map of Rwabicuma sector.

The dominant soils are Humic Acrisols and Dystric Cambisols, with depths varying from 30 to 80 cm depending on slope position and erosion intensity. The area experiences a humid tropical highland climate, receiving an average annual rainfall of 1200 mm and a mean annual temperature of 20°C. Rainfall is bimodal, with a long rainy season from February to May and a short rainy season from September to December (National Institute of Statistics of Rwanda [NISR], 2024). Agriculture is the principal livelihood, engaging more than 90% of the population, with average farm sizes ranging between 0.5 and 1 ha. Major crops include avocado, cabbage, hot pepper, eggplant, maize, beans, Irish potato, and vegetables. The combination of irrigation infrastructure, conservation measures, erosion-prone soils, and intensive smallholder farming makes the scheme an appropriate site for evaluating the effectiveness of SWC practices under irrigated hillside conditions.

2.2 Data acquisition, source and processing

A mixed-methods research approach was adopted, integrating quantitative and qualitative data. Primary data were collected through structured household questionnaires, field observations, and key informant interviews. The questionnaire captured information on household characteristics, SWC practices implemented by farmers, crop productivity before and after establishment of the irrigation scheme, and farmers' perceptions of the effectiveness of conservation practices. Field observations were conducted using a standardized checklist to verify the presence and condition of SWC practices in the study area. Key informant interviews involving irrigation scheme managers, agronomists, cooperative representatives, and district agricultural officers provided complementary information on irrigation management, conservation practices, and institutional support. Secondary data, including agricultural production records, irrigation reports, policy documents, and project reports, were obtained from MINAGRI, RAB, the Rwanda Water Board (RWB), the LWH project, and local government offices.

The target population comprised 1200 smallholder farmers participating in the Rwabicuma Hillside Irrigation Scheme. A stratified random sampling technique was employed, with the six administrative cells serving as strata to ensure proportional representation. The required sample size was determined using Yamane's (1967) formula:

$$n = \frac{N}{1 + N(e^2)}$$

where n is the sample size, N is the population size (1200), and e is the allowable sampling error (0.05). The calculation yielded a sample of 300 farmers, while an additional 15 purposively selected key informants were included, resulting in a total of 315 respondents.

The questionnaire was initially prepared in English, translated into Kinyarwanda, and pre-tested outside the study area to improve clarity and consistency. Content validity was established through expert review by university supervisors and agricultural specialists, while reliability was assessed during the pilot survey using Cronbach's alpha, which exceeded the recommended threshold of 0.70, indicating acceptable internal consistency.

2.3 Data analysis

Quantitative data were coded, cleaned, and analyzed using RStudio (version 4.4.2) at a 95% confidence level ($\alpha = 0.05$). Descriptive statistics were used to summarize respondents' characteristics and identify the soil and water conservation practices implemented within the irrigation scheme, thereby addressing the first study objective. Cross-tabulations and Chi-square (χ^2) tests were applied to examine associations between categorical variables.

To evaluate agricultural productivity before and after the establishment of the irrigation scheme, crop yield data for avocado, cabbage, hot pepper, and eggplant were compared using Analysis of Variance (ANOVA). Correlation analysis was subsequently performed to examine relationships between the adoption of soil and water conservation practices and agricultural productivity, thereby addressing the third objective.

Qualitative data obtained from key informant interviews and field observations were analyzed using thematic analysis. Responses were coded into categories, and used to complement the quantitative findings. Results were presented using tables and figures to facilitate interpretation.

Ethical approval for the study was obtained from the relevant university authorities before fieldwork commenced. Participation was voluntary, informed consent was obtained from all respondents, and confidentiality and anonymity were maintained throughout the research process.

3. RESULTS

3.1 Demographic characteristics of respondents

This section presents the demographic characteristics of respondents within the Rwabicuma Hillside Irrigation Scheme.

A total of 315 respondents participated in the study. Most respondents belonged to the economically active age groups of 30-50 years, with the 40-50 years category representing the largest proportion (27.94%), followed by the 30-40 years group (21.27%) (Table 1). Farmers with 11-20 years of farming experience constituted the largest experience category (25.71%), while primary education was the dominant education level across all age groups and experience categories. Less than 5% of respondents had tertiary education. Overall, 53.65% of respondents cultivated their own land, whereas 46.35% farmed rented land. Most respondents cultivated plots smaller than 1 ha, indicating the predominance of smallholder farming.

3.2 Soil and water conservation practices implemented in the Rwabicuma Hillside Irrigation Scheme

This section presents the SWC practices currently implemented within the Rwabicuma Hillside Irrigation Scheme

Field observations confirmed that all cultivated plots within the irrigation scheme were terraced, with additional SWC measures implemented to varying degrees. The distribution of conservation practices differed significantly among respondents (χ^2, $p < 0.0001$). Terracing alone was the most common practice (Figure 2), adopted by 34.39% of respondents, followed by terracing combined with mulching (29.29%), terracing with agroforestry (12.70%), terracing with contour bunds (11.81%), terracing with infiltration trenches (10.79%), and terracing with cover crops (1.90%).

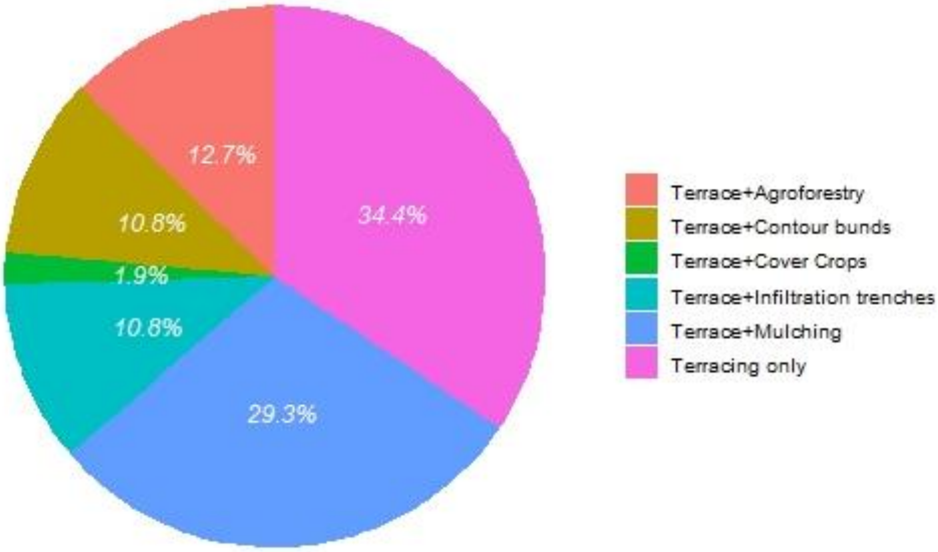

Figure 2. SWC practices implemented in the Rwabicuma Hillside Irrigation Scheme.

Selection of SWC practices was significantly associated with crop type ($p = 0.002$), land ownership ($p = 0.010$), and education level ($p = 0.006$). No significant association was observed with respondent gender ($p = 0.41$), while age showed no meaningful influence on practice selection.

Table 1: Distribution of respondents by age, gender, education level, and farming experience.

Age (yrs)	Experience (Yrs) Education	Female					Male					Over all percentage
		Less 5	5-10	11-20	Over 20	%	Less 5	5-10	11-20	Over 20	%	
Less 20	Primary	4				1.27	8				2.54	3.81
	Secondary	2				0.63	2				0.63	1.27
20-30	Primary		2	5		2.22		5	1		1.90	4.13
	Secondary		6	8		4.44		4	4		2.54	6.98
	Tertiary	1	3			1.27	1	1			0.63	1.90
30-40	Primary		19	8		8.57		10	9		6.03	14.60
	Secondary		2	8		3.17		7	4		3.49	6.67
	Tertiary		3			0.95		1			0.32	1.27
40-50	No formal education			10		3.17					0.00	3.17
	Primary		1	17		5.71		17	25		13.33	19.05
	Secondary		12	1		4.13		1	2		0.95	5.08
	Tertiary		8			2.54					0.00	2.54
50-60	No formal education			4	6	3.17		1	4	1	1.90	5.08
	Primary			10	6	5.08		6	6	2	4.44	9.52
	Secondary			1	1	0.63		2	1	1	1.27	1.90
Over 60	No formal education			9	7	5.08			7		2.22	7.30
	Primary				5	1.59				13	4.13	5.71
Total		2.22	17.78	25.71	7.94		3.49	17.46	20.00	5.40		100

3.3 Agricultural productivity before and after establishment of the irrigation scheme

This section compares crop productivity before and after adoption of SWC practices under irrigation. Crop yield significantly increased following the adoption of SWC practices (ANOVA, $p < 0.0001$). Across all evaluated crops and conservation practices, mean yield increased from 5.84 ± 0.70 t ha⁻¹ before implementation to 10.33 ± 1.24 t ha⁻¹ after implementation, representing an overall increase of 56.52% (Figure 3).

The magnitude of yield improvement varied among SWC practices. The highest increase was recorded under terrace combined with agroforestry, where average crop yield increased by 64.28% compared with the pre-adoption period. This was followed by terrace combined with cover crops (59.16%), terrace combined with mulching (56.44%), terrace combined with infiltration trenches (55.39%), terracing combined with contour bunds (50.83%), and terracing alone (51.45%).

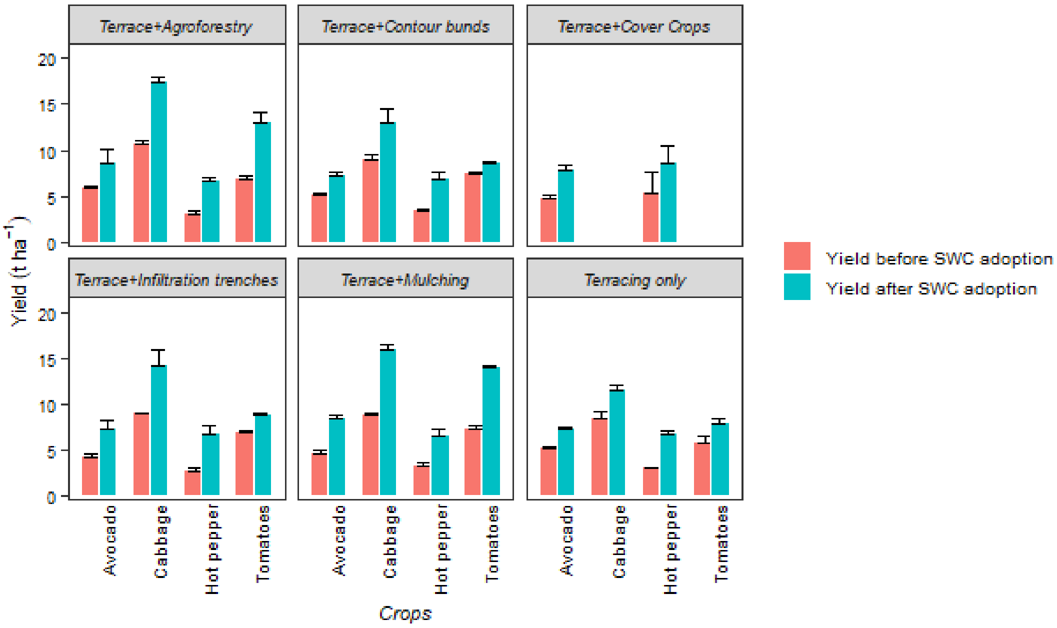

Figure 3. Crop yield performance before and after adoption of soil and water conservation practices in the Rwabicuma Hillside Irrigation Scheme.

Yield responses differed among crops and conservation practices (Figure 3). Integrated practices involving biological and structural conservation measures showed the highest improvements, particularly terrace combined with mulching and terrace combined with agroforestry. Under terrace plus mulching, cabbage and tomato yields increased from 9 ± 0.16 and 7 ± 0.33 t ha⁻¹ before implementation to 16 ± 0.51 and 14 ± 0.31 t ha⁻¹ after adoption, respectively. Similarly, terrace combined with agroforestry resulted in substantial yield increases, with cabbage and tomato reaching 17 ± 0.67 and 13 ± 1.05 t ha⁻¹ after implementation.

Water conservation-oriented practices also enhanced crop performance. Terrace combined with infiltration trenches increased cabbage yield to 14 ± 0.10 t ha⁻¹, while avocado and hot pepper also showed improved yields compared with the pre-adoption period. Terrace combined with contour bunds resulted in moderate yield increases across all crops, with the greatest response observed in cabbage. Terracing alone improved yields but consistently showed lower increases compared with practices combining terraces with additional biological or water-retention measures.

3.4 Relationship between soil and water conservation practices and agricultural productivity

This section presents the association between SWC practices and changes in crop productivity.

The analysis of SWC practices and crop yield change in the Rwabicuma Hillside Irrigation Scheme revealed clear differences in productivity outcomes depending on the type of practice adopted. The strength of the relationship between SWC practices and crop yield varied according to the conservation practice adopted (Table 5). Farmers implementing terracing only reported a mean yield change of 3.52 ± 0.45, with a weak positive correlation that was not statistically significant ($r = 0.42$, $p = 0.12$).

Table 2. Relationship between soil and water conservation practices and changes in crop productivity.

SWC Practice	Mean Yield Change	Correlation coefficient (r)	p-value
Terracing only	3.52 ± 0.45	0.42	0.12
Terrace + Agroforestry	3.40 ± 0.90	0.71	0.03
Terrace + Contour bunds	2.97 ± 0.45	0.65	0.04
Terrace + Cover Crops	3.75 ± 0.66	0.73	0.02
Terrace + Infiltration trenches	2.95 ± 0.90	0.77	0.01
Terrace + Mulching	5.55 ± 0.39	0.82	0.01

All integrated conservation practices exhibited statistically significant positive relationships with crop yield change. Terrace combined with agroforestry showed a strong positive correlation ($r = 0.71$, $p = 0.03$) and a mean yield change of 3.40 ± 0.90, while terrace combined with contour bunds recorded $r = 0.65$ ($p = 0.04$) with a mean yield change of 2.97 ± 0.45. Similarly, terrace combined with cover crops showed a strong positive correlation ($r = 0.73$, $p = 0.02$) and a mean yield change of 3.75 ± 0.66. Terrace combined with infiltration trenches produced a correlation coefficient of 0.77 ($p = 0.01$) with a mean yield change of 2.95 ± 0.90. The strongest relationship was observed for terrace combined with mulching, which recorded the highest mean yield change (5.55 ± 0.39) and the strongest positive correlation with crop productivity ($r = 0.82$, $p = 0.01$).

4. DISCUSSION

This study examined the implementation of SWC practices and their contribution to agricultural productivity in the Rwabicuma Hillside Irrigation Scheme. The findings demonstrate that while terracing provides the foundation for soil conservation in the scheme, integrating structural and biological SWC practices produces greater benefits for crop productivity. These results support the premise of sustainable land management, which argues that combining complementary conservation measures improves soil quality, water availability, and agricultural productivity more effectively than relying on a single intervention.

4.1 Soil and Water Conservation Practices Implemented in the Rwabicuma Hillside Irrigation Scheme

The findings show that terracing is the dominant SWC practice in the Rwabicuma Hillside Irrigation Scheme, while complementary practices such as mulching, agroforestry, contour bunds, infiltration trenches, and cover crops are adopted at varying levels. This pattern suggests that terracing forms the basis of conservation efforts in the irrigation scheme because it effectively reduces runoff and stabilizes cultivated slopes. However, the lower adoption of biological practices indicates that farmers may still face technical, financial, or knowledge-related barriers that limit the integration of more comprehensive conservation strategies.

These findings are consistent with studies conducted in Rwanda, which identify terracing as the principal intervention for controlling erosion on steep agricultural landscapes (Hategekimana et al., 2025; Rutebuka et al., 2021). Likewise, previous research has shown that biological practices such as mulching and agroforestry are often less widely adopted despite their long-term benefits for improving soil organic matter, nutrient cycling, and moisture conservation (Aaron et al., 2024; Demo & Asefa Bogale, 2024; Tranchina et al., 2024). The results therefore support the Sustainable Land Management framework, which emphasizes that combining structural and biological conservation measures provides more sustainable protection of soil and water resources than isolated interventions.

4.2 Effect of Soil and Water Conservation Practices on Crop Productivity

The study found that crop productivity increased substantially following the adoption of SWC practices, with integrated conservation practices producing greater yield improvements than terracing alone. This finding indicates that effective soil conservation does not simply prevent land degradation but also creates favorable conditions for crop growth by improving soil moisture, reducing nutrient losses, and enhancing root development. Consequently, productivity gains are greatest where farmers combine physical and biological conservation measures rather than relying solely on structural interventions.

These findings agree with previous studies reporting that integrated SWC systems significantly improve crop yields under hillside farming conditions (Luo & Dou, 2024; Salpina & Pagliacci, 2022). Similar improvements have been documented in Rwanda's Land Husbandry, Water Harvesting and Hillside Irrigation program, where combining irrigation with conservation practices increased agricultural productivity and strengthened household food security (MINAGRI, 2025). Thes observed differences among crop types further suggest that crop response depends on crop physiology and management requirements, with vegetables responding more strongly because they benefit greatly from improved soil moisture and nutrient availability. These findings reinforce the Sustainable Agricultural Intensification theory, which argues that productivity can be increased while maintaining natural resources through integrated land management rather than agricultural expansion.

4.3 Contribution of Soil and Water Conservation Practices to Crop Yield Improvement

The findings indicate that SWC practices contribute to sustainable agricultural productivity by creating conditions that support better crop performance in hillside farming systems. The results suggest that conservation effectiveness depends not only on the presence of physical structures but also on the integration of complementary practices that improve soil quality, moisture availability, and nutrient cycling.

The limited effect of terracing alone highlights that erosion control measures may not automatically translate into substantial productivity gains unless combined with practices that address soil fertility and water availability. This agrees with other studies which reported that terraces provide important land protection benefits but achieve greater agricultural benefits when integrated with biological and water management practices (Abiye, 2022; Adil et al., 2022; Jiru & Wegari, 2022).

The stronger performance of integrated approaches, particularly those involving organic matter management and water conservation, demonstrates the importance of combining different mechanisms of soil improvement. Mulching enhances moisture retention and nutrient cycling, while infiltration structures improve water availability for crops. Similar studies have shown that integrated SWC systems improve resource-use efficiency and strengthen the resilience of smallholder farming systems (Anantha et al., 2021; Mhlanga et al., 2021; Ojo et al., 2021).

The findings support the Sustainable Land Management theory, which emphasizes that long-term agricultural productivity is achieved through coordinated management of soil, water, and biological resources. Thus, promoting integrated SWC practices is essential for sustainable intensification of hillside agriculture in Rwanda.

5. CONCLUSION

This study evaluated the effectiveness of SWC practices in improving agricultural productivity in the Rwabicuma Hillside Irrigation Scheme, Rwanda. First, it identified terracing as the dominant conservation practice, with varying levels of integration with mulching, agroforestry, contour bunds, infiltration trenches, and cover crops. Second, it found that the adoption of SWC practices significantly increased crop productivity, with mean yields rising from 5.84 ± 1.09 t ha^{-1} before implementation to 10.33 ± 1.53 t ha^{-1} after implementation, representing an overall increase of 56.52%. Third, the study demonstrated that integrated SWC practices were more strongly associated with crop yield improvement than terracing alone, highlighting the advantages of combining structural and biological conservation measures.

These findings contribute to the growing body of evidence that integrated SWC practices provide greater agricultural and environmental benefits than single conservation measures in hillside farming systems. Practically, the study provides evidence to support the design and implementation of conservation strategies that simultaneously enhance soil protection and agricultural productivity in irrigated landscapes.

The study was limited to one irrigation scheme and relied partly on farmers' recall for historical yield information, which may have introduced recall bias and limited the wider generalization of the findings. Based on the results, the Rwanda Agriculture and Animal Resources Development Board (RAB) should strengthen extension services promoting integrated SWC practices, particularly mulching and agroforestry. The Ministry of Agriculture and Animal Resources (MINAGRI) should increase technical and financial support for the maintenance of conservation structures within hillside irrigation schemes. Local governments and irrigation scheme managers should provide regular farmer training on the proper implementation and maintenance of integrated SWC practices to maximize their effectiveness.

Future research should evaluate the long-term impacts of integrated SWC practices on soil quality, productivity, and climate resilience across multiple hillside irrigation schemes in Rwanda using longitudinal field measurements.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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