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Assessment of the Effect of Soil Conservation Practices on Sustainable Crop Production in Ngororero, Rwanda

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Authors' contributions

This work was carried out in collaboration between both authors. Author AB contributed to conceptualization, data collection, formal analysis, and writing of the original draft. Author ES contributed to supervision, methodological review, and critical review and editing of the manuscript. Both authors read and approved the final manuscript.

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Abstract

Aims: This study assessed the effectiveness of soil conservation practices (SCPs) in controlling soil erosion and examined their contribution to sustainable crop production, using the Food Basket Sites (FoBaSi) programme of Ngororero District, Rwanda, as a case study.
Study Design: A cross-sectional, descriptive-explanatory research design combining quantitative and qualitative methods was adopted.
Place and Duration of Study: The study was conducted between 2025 and 2026 across 50 Food Basket Sites in the 13 sectors of Ngororero District, an East African highland agricultural landscape in Western Province, Rwanda.
Methodology: Cross-sectional mixed-methods was employed for the study of 367 farming households (Yamane's formula, stratified sampling) plus 39 key informants across Ngororero District. Data came from household surveys, field observations, interviews, and secondary records. Quantitative data were analyzed using descriptive statistics, correlation, and multiple regression in SPSS; qualitative data were analyzed thematically.
Results: Radical terracing (85%) and progressive terracing (78%) were the most widely adopted SCPs, whereas cover cropping (45%) and water harvesting (40%) showed relatively low adoption. Indicators of soil erosion remained prevalent, including bare

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soil patches (70%), rills (65%), and gullies (40%), suggesting inadequate maintenance and limited integration of biological conservation measures. Soil conservation practices were significantly and positively associated with crop yield, yield stability, land productivity, and household food security ($p < 0.01$). Multiple regression analysis showed that terracing, agroforestry, mulching, and cover cropping explained 68% of the variation in sustainable crop production ($R = 0.825$, $R^2 = 0.680$, Adjusted $R^2 = 0.676$; $F(4,362) = 45.2$, $p < 0.001$), with terracing ($\beta = 0.45$) and agroforestry ($\beta = 0.35$) being the strongest predictors. Furthermore, 80% of farmers reported increased and more stable crop yields, 65% reported higher farm income, and 74.1% perceived improved resilience to climate variability.

Conclusion: Integrated implementation of structural and biological soil conservation practices significantly enhances sustainable crop production despite persistent erosion challenges. Strengthening maintenance, expanding biological conservation measures, and improving extension support and financial access are essential to increase agricultural productivity and climate resilience in Rwanda's highland Food Basket Sites.

Keywords: Soil conservation practices; sustainable crop production; soil erosion; food basket sites; climate resilience.

1. Introduction

Soil degradation is one of the most serious threats to food security, environmental health, and sustainable development worldwide, with more than one-third of the world's soils estimated to be degraded and their productive potential correspondingly diminished (FAO, 2015). Sustainable land management practices including soil conservation, agroforestry, and crop diversification are widely regarded as essential for reversing this trend, building climate resilience, and delivering the Sustainable Development Goals (IPBES, 2018).

Across Sub-Saharan Africa, agriculture remains the backbone of national economies even as soils deteriorate under rainfall variability, population pressure, and smallholder overexploitation of limited land. In response, many African countries have intensified the promotion of terracing, agroforestry, and contour farming as core strategies for restoring soil fertility, stabilising erosion, and enhancing productivity (Kassam et al., 2019; IPCC, 2022). This is particularly urgent in the highland agricultural systems of East Africa, where steep terrain and intense rainfall combine to make soils highly susceptible to erosion and to compromise crop yields (Mati, 2006; IPCC, 2022).

Rwanda exemplifies this vulnerability. Its rugged terrain and high proportion of rain-fed farming expose an estimated 10–50 tonnes of soil per hectare per year to erosion in critical areas (MINAGRI, 2023), even though agriculture underpins the livelihoods of roughly 70% of the national labour force (NISR, 2022). The Government of Rwanda has invested heavily in structural and agronomic conservation measures radical and progressive terracing, contour farming, mulching, and agroforestry through national programmes such as Land Husbandry, Water Harvesting and Hillside Irrigation (MINAGRI, 2019; World Bank, 2019).

Ngororero District, in Rwanda's Western Province, is among the areas at highest erosion risk: about 62% of its land area (41,450 of 66,700 ha) is exposed to soil erosion, with individual sectors such as Sovu and Ndaro at 86% and 85% risk, respectively (RWB, 2020). Despite extensive conservation coverage some 38,573 ha under erosion control and 16,386 ha under agroforestry the district continues to record severe (3.6%), moderate (6%), and low (12.4%) erosion risk (REMA, 2022), alongside a climate vulnerability index of 0.503, indicating medium exposure, sensitivity, and inadequate adaptive capacity (REMA, 2022). With 82,102 households cultivating some 43,700 ha under rain-fed systems, average yields remain low 1.35 t/ha for maize, 0.88 t/ha for beans, and 5.61 t/ha for Irish potatoes (NISR, 2025).

This pattern reveals an apparent contradiction: substantial and sustained investment in soil conservation infrastructure coexists with persistently high erosion and low productivity. Most existing evaluations have focused on reporting the physical extent of conservation coverage rather than its environmental and economic effectiveness, leaving a clear knowledge gap on how and how well soil conservation practices (SCPs) translate into sustainable crop production at the farm level, particularly within Rwanda's Food Basket Sites (FoBaSi), a national programme established under the 5th Strategic Plan for Agricultural Transformation to consolidate land into high-productivity, well-managed units (MINAGRI, 2021).

This study addresses that gap by assessing the effectiveness of SCPs in the FoBaSi of Ngororero District. Specifically, the study sought to: (i) assess the effectiveness of SCPs in controlling soil erosion in the Food Basket Sites of Ngororero District; (ii) evaluate the sustainability of crop production in these sites; and (iii) analyse the relationship between SCP adoption and crop productivity outcomes. The study is guided by an integrated conceptual framework drawing on sustainable land management, ecosystem services, and agricultural innovation systems theory, in which SCPs (terracing, agroforestry, mulching, and cover cropping) act as the primary explanatory variables, soil and environmental conditions serve as mediating factors, and crop yield, yield stability, soil fertility, and household food security constitute the outcome variables all shaped by socio-economic and institutional context (Hall et al., 2006).

2. Methodology

2.1 Description of the Study Area

The study was conducted in Ngororero District, Western Province of Rwanda, situated on the Congo–Nile Divide watershed between 1°45′–2°15′ South and 29°20′–29°45′ East, and covering 742 km² across 13 sectors (Bwira, Gatumba, Hindiro, Kabaya, Kageyo, Kavumu, Matyazo, Muhanda, Muhororo, Ndaro, Ngororero, Nyange, and Sovu). The district has a population of over 367,955 (53.5% female) at a density of 551 persons/km², with 92,623 households, 95.1% of them rural (NISR, 2022). Elevation ranges from 1,500 to 2,500 m above sea level, and the district experiences a temperate tropical highland climate, with 1,200–1,500 mm of rainfall annually across two wet seasons (March–May and September–December) and mean temperatures of 15–22 °C. Of the district's 82,102 agricultural households, 4,486 cultivate roughly 1,445 ha across 50 advanced Food Basket Sites, supported by seven dedicated FoBaSi extension agents (MINAGRI, 2023).

2.2 Research Design

The study used a cross-sectional, descriptive-explanatory design within a mixed-methods framework, combining a structured quantitative household survey with qualitative key-informant interviews (KIIs), focus group discussions (FGDs), and field observation.

2.3 Sampling Design

The target population comprised farming households practicing SCPs across the 50 FoBaSi of Ngororero District (4,486 households), together with key informants holding technical or institutional roles in soil conservation and agricultural development including district environmental and forest officers, RAB staff, district and sector agronomists, FoBaSi extension agents, and cooperative leaders. Sample size was determined using Yamane's (1967) formula, $n = N / [1 + N(e)^2]$, with a 5% margin of error: $n = 4{,}486 / [1 + 4{,}486(0.05)^2] \approx 367$ households. Households were allocated proportionally across the 13 sectors and selected through stratified random sampling; 39 key informants were selected purposively, giving a total of 406 respondents.

2.4 Data Collection

Primary data were collected through structured household questionnaires covering SCP adoption and condition, perceived soil erosion, crop production and yield, household food security, climate perceptions, and access to extension services; field observation checklists to verify the physical condition of structural and biological SCPs; semi-structured KII guides for technical and institutional stakeholders; and FGDs with farmer groups. Secondary data were drawn from MINAGRI, RAB, REMA, NISR, and Meteo Rwanda records, as well as from published literature.

2.5 Validity, Reliability, and Ethical Considerations

Instrument validity was ensured through expert and supervisor review prior to fielding, and reliability was strengthened through pretesting on a non-sample population, enumerator training, and GPS verification of spatial data. Institutional permissions were obtained prior to data collection, and informed consent and confidentiality were maintained throughout.

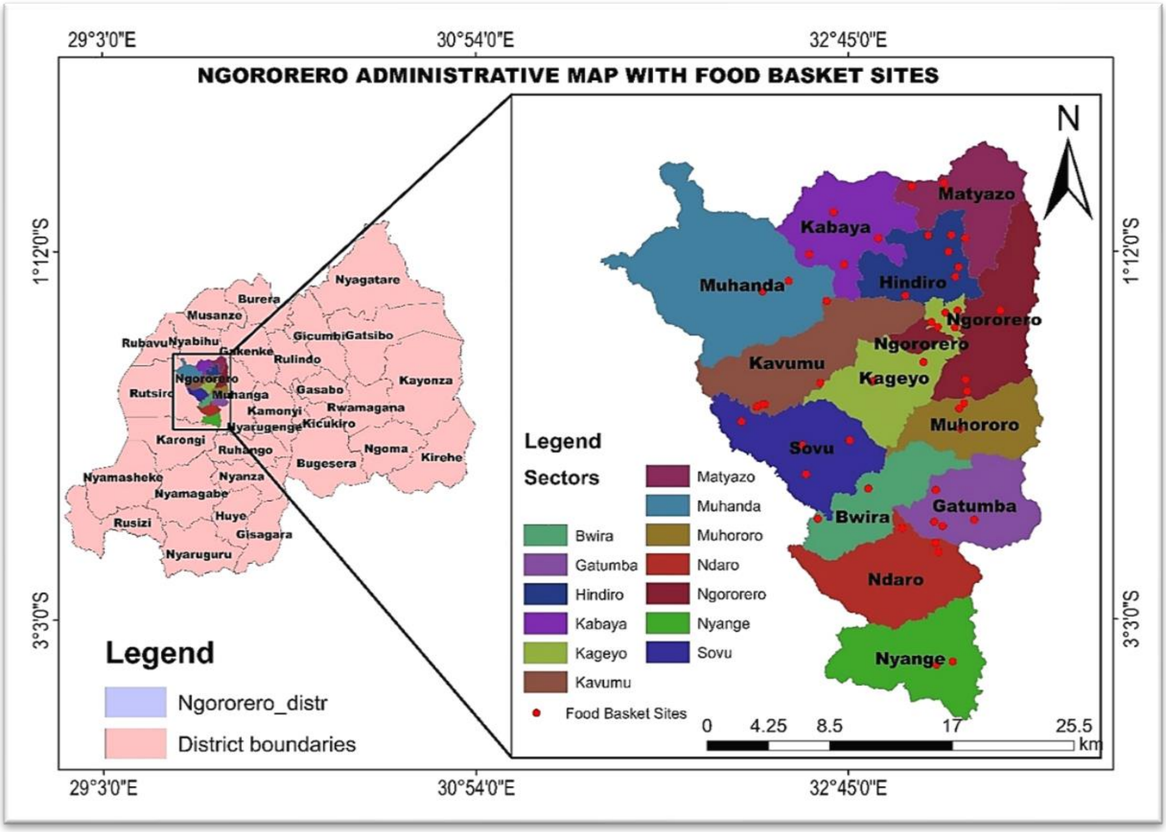

Fig. 1. Illustrational map of the study area

2.6 Data Analysis

Quantitative data were analysed in SPSS using descriptive statistics (frequencies, percentages, means, and standard deviations). SCP adoption measured on a 1–5 Likert scale was classified using equal-interval class bounds: 1.00–1.80 (very low), 1.81–2.60 (low), 2.61–3.40 (moderate), 3.41–4.20 (high), and 4.21–5.00 (very high); a standard deviation below 0.5 was interpreted as indicating consistent responses (FAO, 2017). Yield stability was assessed using the coefficient of variation, CV = $(\sigma/\mu) \times 100\%$, where σ is the standard deviation and μ the mean yield. Pearson correlation (two-tailed) tested associations between the four SCP variables terracing (X_1), agroforestry (X_2), mulching (X_3), and cover cropping (X_4) — and sustainable crop production outcomes (crop yield, yield stability, land productivity, and food security). Multiple linear regression was used to model sustainable crop production (Y) as a function of the SCP variables:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \varepsilon$$

where β_0 is the constant, β_1–β_4 are regression coefficients, and ε is the error term. Model fit was assessed using R^2, adjusted R^2, and an ANOVA F-test. Qualitative data from KIIs and FGDs were analysed thematically and used to contextualise and triangulate the quantitative findings.

3. Results and Discussion

3.1 Results

3.1.1 Socio-demographic and Farm Characteristics of Respondents

Out of the 367 household respondents, 60% were male and 40% female. More than half (56%) fell within the economically active 25–44-year age bracket, and 63% were married. Educational attainment was modest: 44% had completed only primary education and 4% had a university degree. Landholding was highly fragmented 69.2% of respondents owned less than 1 ha and 45% farmed on steep slopes, with a further 40% on moderate slopes, underscoring the district's high inherent erosion risk. Maize (82%), beans (76%), and Irish potatoes (55%) were the dominant crops, and 45% of households practiced intercropping (Table 1).

Table 1. Socio-demographic and farm characteristics of respondents

Variable	Category	Frequency	Percentage (%)
Sex	Male	220	60.0
	Female	147	40.0
Age group (years)	Below 25	40	10.9
	25–34	95	25.9
	35–44	110	30.0
	45–54	75	20.4
	55 and above	47	12.8
Marital status	Married	230	62.7
	Single	60	16.3
	Widowed	50	13.6
	Divorced	27	7.4
Education level	No formal education	55	15.0
	Primary	160	43.6
	Secondary	110	30.0
	TVET	25	6.8
	University	17	4.6
Household size	1–3 persons	80	21.8
	4–6 persons	190	51.8
	7+ persons	97	26.4
Total land owned	Less than 1 ha	254	69.2
	1–2 ha	83	22.7
	Greater than 2 ha	30	8.1
Farm slope	Flat	55	15.0
	Moderate	147	40.1
	Steep	165	45.0
Main crops grown*	Maize	300	82.0
	Beans	280	76.0
	Irish potatoes	200	55.0
	Other crops	60	16.0
Farming system	Monocropping	37	10.1
	Intercropping	165	45.0
	Crop rotation	55	15.0
	Mixed farming	110	30.0

*Source: Field survey data, 2026. *Multiple responses permitted; percentages do not sum to 100*

3.1.2 Adoption and Maintenance Status of Soil Conservation Practices

Radical terraces (85%) and progressive terraces (78%) were the most widely adopted SCPs, and both were reported in comparatively good physical condition (70% and 65% "good", respectively) consistent with their longer average duration of use. Biological practices lagged behind: cover cropping (45%) and water harvesting (40%) recorded the lowest adoption and the poorest maintenance condition (Fig. 2). Overall, 75% of respondents reported actively maintaining their SCPs. Farmers cited erosion control (80%), improved soil fertility (75%), and increased yield (70%) as the main motivations for adoption, with government programmes (65%) the leading source of support. Labour shortages (62%), financial constraints (58%), and limited technical knowledge (50%) were the most frequently cited barriers to sustained adoption.

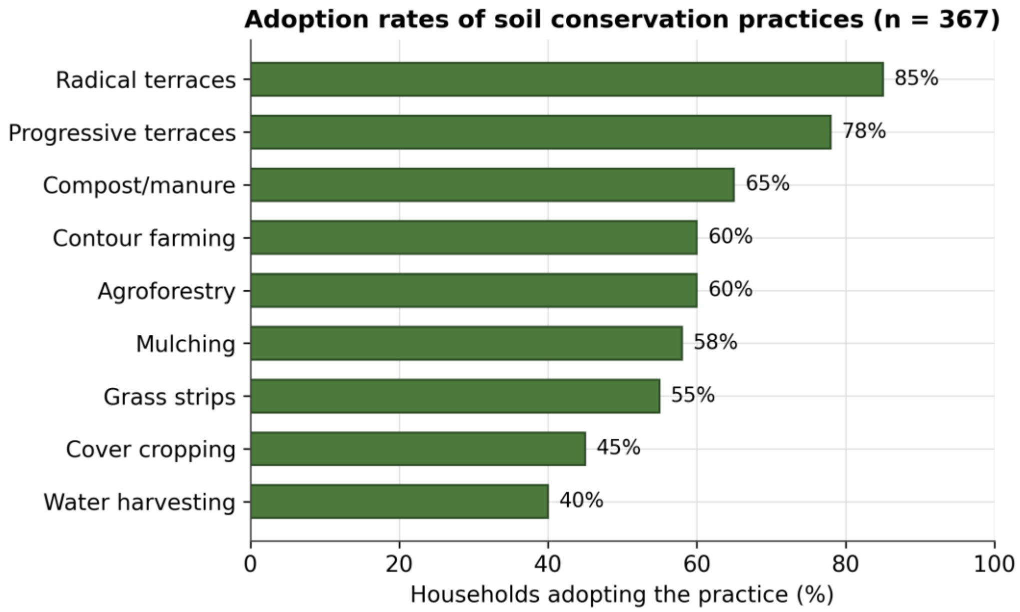

Fig. 2. Adoption rates of soil conservation practices

3.1.3 Soil Erosion Indicators Despite SCP Adoption

Notwithstanding widespread SCP adoption, visible erosion indicators remained common. Bare soil patches (70%) and rill erosion (65%) were the most frequently observed signs, followed by sediment deposits (55%) and exposed roots or stones (50%); gullies were less frequent (40%) but tended to be more severe where present (Table 2; Fig. 3). Correspondingly, when asked about change in erosion over time, 40% of respondents reported substantial reduction and 30% some reduction, but 20% reported no change and 10% reported an increase indicating that conservation gains have not been uniform across the district.

Table 2. Types and severity of soil erosion indicators observed on farmland (n = 367)

Indicator	Observed (%)	Severity: Low (%)	Moderate (%)	High (%)
Bare soil patches	70	25	45	30
Rills (small channels)	65	30	45	25
Sediment deposits	55	35	45	20
Exposed roots/stones	50	30	40	30
Gullies (large channels)	40	25	40	35

Source: Field survey data, 2026

3.1.4 Climate Variability and Perceived Effectiveness of SCPs for Climate Adaptation

Rainfall records for six meteorological stations (2010–2025) show marked spatial and inter-annual variability, with mean annual rainfall ranging from 883.9 mm at Muhanga to 1,401.2 mm at Kabaya, and individual years ranging from as low as 203 mm (Muhanga, 2014) to as high as 2,329 mm (Sovu, 2018). The vast majority of respondents (95%) perceived changing rainfall patterns, most commonly more erratic rainfall (50%) and more intense rainfall events (30%). Mean temperatures likewise varied by station (16.45 °C at Sovu to 20.01 °C at Nyange) with an upward trend at several stations. Against this backdrop, 40% of farmers rated SCPs as "very helpful" and 35% as "moderately helpful" in reducing climate-related risk, and combining respondents reporting significant and slight improvement, 74.1% reported improved resilience to climate variability following SCP adoption although a residual 15–20% of households reported little or no improvement, reflecting differences in adoption intensity and socio-economic capacity.

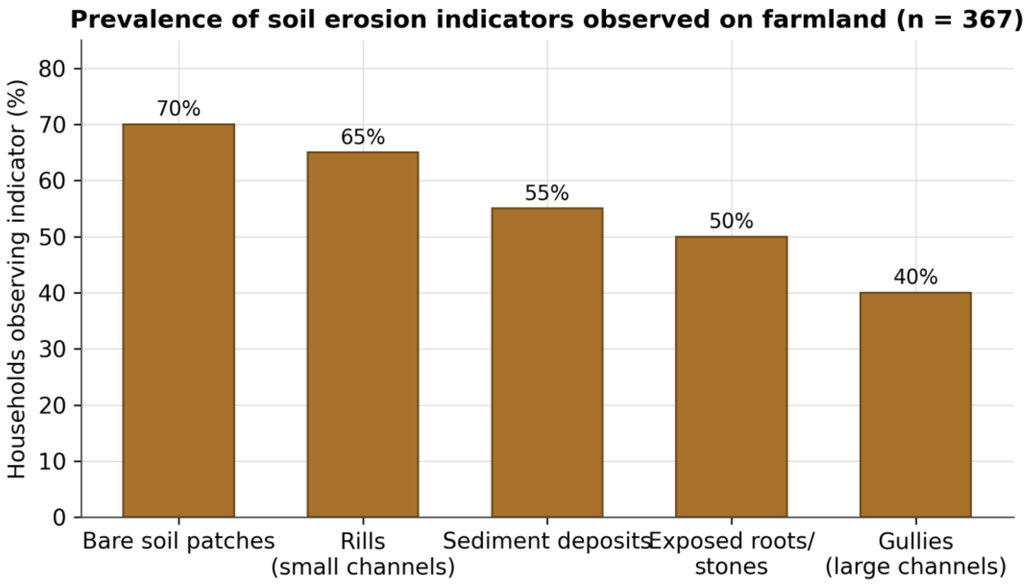

Fig. 3. Prevalence of soil erosion indicators observed on farmland

3.1.5 Effects of SCPs on Crop Yield, Stability, Income, and Food Security

About 80% of farmers reported an increase in crop yield after adopting SCPs (45% significant, 35% slight), and a similar proportion reported improved yield stability (50% more stable, 30% slightly more stable). Sixty-five percent reported increased farm income. At the household level, 55% reported adequate food availability throughout the preceding 12 months, while 45% experienced shortages of varying duration; 65% reported never or rarely experiencing food insecurity in the preceding month, though 35% reported experiencing it sometimes or often (Fig. 4).

Crop-level yield estimates confirm this pattern of improvement but reveal differing degrees of stability across staple crops. Irish potatoes recorded both the highest mean yield (8.75 t/ha) and the lowest coefficient of variation (15.0%, "more stable"), while beans recorded the lowest mean yield (2.15 t/ha) and the highest variability (CV = 25.1%, "less stable"); maize fell between the two (3.04 t/ha; CV = 20.1%, "moderately stable") (Table 3; Fig. 5).

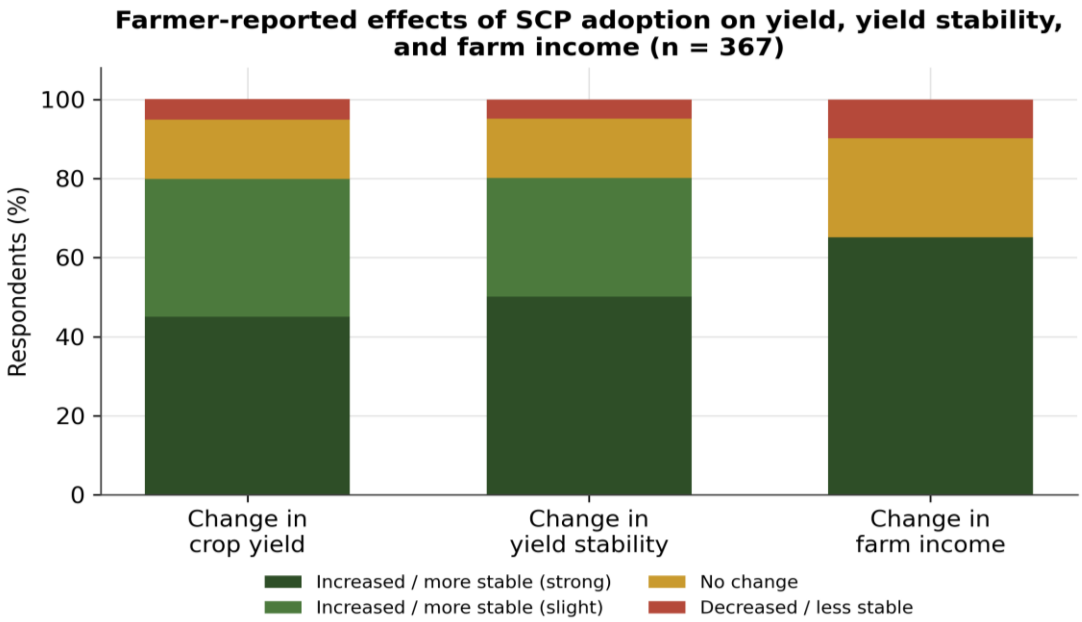

Fig. 4. Farmer-reported effects of SCP adoption on yield, yield stability, and farm

Table 3. Mean yield and coefficient of variation (CV) of major crops (n = 367)

Crop	Mean area (ha)	Mean yield (t/ha)	SD (kg/ha)	CV (%)	Stability
Maize	0.8	3.04	610	20.1	Moderately stable
Beans	0.6	2.15	540	25.1	Less stable
Irish potatoes	0.5	8.75	1,313	15.0	More stable

Source: Field survey data, 2026

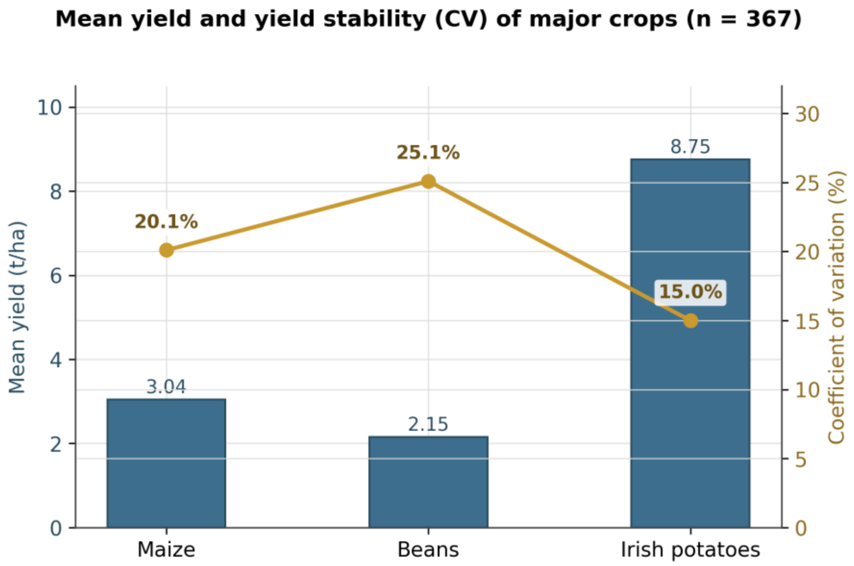

Fig. 5. Mean yield and coefficient of variation (CV) of major crops

3.1.6 Relationship between SCPs and Sustainable Crop Production Outcomes

Pearson correlation analysis showed that all four SCPs were significantly and positively associated with crop productivity, yield stability, food security, and household income (all $p < 0.01$; Table 4; Fig. 6). Terracing showed the strongest association with crop productivity ($r = 0.74$) and yield stability ($r = 0.70$), while agroforestry showed the strongest association with food security ($r = 0.70$). Mulching and cover cropping showed moderate but still significant associations across all four outcomes.

Table 4. Pearson correlation coefficients between SCPs and sustainable crop production outcomes

SCP	Crop productivity	Yield stability	Food security	Livelihood (income)
Terracing (X_1)	0.74**	0.70**	0.68**	0.66**
Agroforestry (X_2)	0.65**	0.62**	0.70**	0.64**
Mulching (X_3)	0.58**	0.60**	0.63**	0.59**
Cover cropping (X_4)	0.50**	0.55**	0.60**	0.54**

*** Correlation is significant at p < 0.01 (two-tailed). Source: Field survey data, 2026*

Multiple regression confirmed a strong overall model fit: the four SCP variables jointly explained 68% of the variance in sustainable crop production ($R = 0.825$, $R^2 = 0.680$, adjusted $R^2 = 0.676$, standard error = 0.40), and the model was highly statistically significant ($F(4,362) = 45.2$, $p < 0.001$; Table 5).

Table 5. Multiple regression model summary and ANOVA for the effects of SCPs on sustainable crop production

Statistic	Value
R	0.825
R^2	0.680
Adjusted R^2	0.676
Standard error of estimate	0.40
Regression sum of squares (df = 4)	120.5
Residual sum of squares (df = 362)	56.8
Total sum of squares (df = 366)	177.3
F-value	45.2
Significance (p)	< 0.001

Predictors: (constant), terracing (X_1), agroforestry (X_2), mulching (X_3), cover cropping (X_4). Dependent variable: sustainable crop production (yield, yield stability, land productivity, food security). Source: Field survey data, 2026

All four predictors contributed significantly and positively to the model (Table 6; Fig. 6). Terracing was the strongest predictor (B = 0.40, β = 0.45, t = 5.0, p < 0.001), followed by agroforestry (B = 0.30, β = 0.35, t = 4.3, p < 0.001), mulching (B = 0.20, β = 0.25, t = 3.3, p = 0.001), and cover cropping (B = 0.15, β = 0.20, t = 3.0, p = 0.003). The resulting regression equation is:

$$Y = 1.25 + 0.40X_1 + 0.30X_2 + 0.20X_3 + 0.15X_4 + \varepsilon$$

Table 6. Regression coefficients for the effects of SCPs on sustainable crop production

Variable	B	Std. error	Beta (β)	t	Sig.
(Constant)	1.25	0.30	—	4.2	< 0.001
Terracing (X_1)	0.40	0.08	0.45	5.0	< 0.001
Agroforestry (X_2)	0.30	0.07	0.35	4.3	< 0.001
Mulching (X_3)	0.20	0.06	0.25	3.3	0.001
Cover cropping (X_4)	0.15	0.05	0.20	3.0	0.003

Dependent variable: sustainable crop production. Source: Field survey data, 2026

3.1.7 Qualitative Insights from Key Informants and Focus Group Discussions

Findings from KIIs and FGDs corroborated and enriched the quantitative results. Participants consistently identified terracing and agroforestry as the SCPs most valued for controlling runoff and building resilience to erratic rainfall, and attributed persistent erosion in some areas to inconsistent maintenance and incomplete integration of biological measures rather than to the inadequacy of the practices themselves. Institutional actors RAB staff, district agronomists, and FoBaSi extension agents reported that although 75% of farmers had some access to extension services, only 30% received monthly visits, limiting the continuity of technical support needed to sustain complex, labour-intensive practices. Farmers and cooperative leaders alike noted that the distribution of benefits from SCPs was uneven, shaped by differences in farm size, labour availability, and financial capacity rather than by SCP adoption alone.

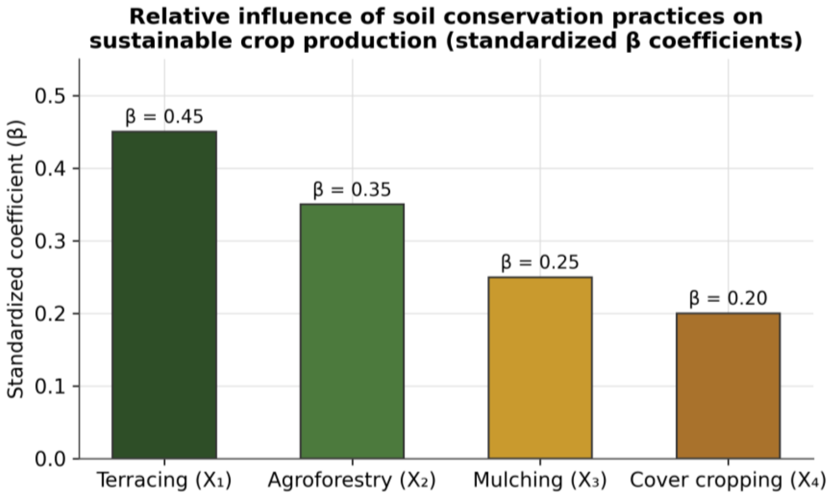

Fig. 6. Relative influence (standardized β coefficients) of SCPs on sustainable crop production

3.2 Discussion

This study set out to assess the effectiveness of SCPs in controlling soil erosion, evaluate the sustainability of crop production, and analyse the relationship between SCP adoption and productivity in the Food Basket Sites of Ngororero District.

With respect to the first objective, the high adoption of structural measures radical terracing (85%) and progressive terracing (78%) alongside the persistence of visible erosion indicators such as bare soil patches (70%) and rills (65%) points to what might be termed a conservation paradox: extensive physical infrastructure coexists with continuing land degradation. This is consistent with Lal's (2001) observation that the effectiveness of terracing depends critically on construction quality and ongoing maintenance rather than on coverage alone, and it echoes the district-level finding that only a minority of farmers had adopted biological measures such as cover cropping (45%) and water harvesting (40%), which Nyssen et al. (2007) and Mekonnen et al. (2018) identify as essential complements to structural works for stabilising soil, retaining moisture, and improving infiltration in erosion-prone highlands.

On the second objective, the evidence indicates that SCPs are contributing meaningfully though unevenly to sustainable crop production. Roughly 80% of farmers reported higher and more stable yields and 65% reported higher income, broadly consistent with the 20–40% productivity gains reported for integrated terracing–agroforestry systems in the neighbouring Congo-Nile Highlands (Mugabo, 2013) and with Rwanda's own radical-terracing evidence base (MINAGRI, 2020). At the same time, a substantial minority of households roughly one in five for yield and income, and over a third for recent food insecurity reported limited or no improvement, reinforcing Pretty's (2008) argument that sustainable production outcomes depend on more than aggregate yield gains and must be evaluated against stability and equity of access as well. Differences in crop-level yield stability (Irish potatoes markedly more stable than beans) further suggest that the benefits of SCPs are mediated by crop-specific agronomic responses to improved moisture retention and soil structure.

The third objective, addressed through correlation and regression analysis, provides the strongest evidence in the study. The consistently significant, positive correlations between all four SCPs and crop productivity, yield stability, food security, and income (Table 6) confirm that structural and biological practices operate in a complementary rather than substitutive manner, in line with Lal's (2015) argument for integrated soil management. The regression model's explanatory power ($R^2 = 0.68$) is comparable to or exceeds that reported in similar Rwandan and regional studies, and the dominance of terracing ($\beta = 0.45$) and agroforestry ($\beta = 0.35$) as predictors mirrors RAB's (2021) finding that radical terracing alone can reduce gross erosion by more than half on steep slopes. The unexplained 32% of variance is consistent with the conceptual framework's emphasis on mediating and moderating factors rainfall variability, input access, farm size, and institutional support that this study's climate and qualitative findings help to illuminate. Notably, 95% of farmers perceived changing rainfall patterns and inter-station rainfall extremes exceeded a ten-fold range across the study period, underscoring the IPCC's (2022) observation that variability, rather than average rainfall alone, drives much of the residual agricultural vulnerability in climate-sensitive highland regions.

Taken together, these findings suggest that the binding constraint on sustainable crop production in Ngororero District's Food Basket Sites is no longer primarily one of SCP coverage but of SCP quality, balance, and maintenance. The comparatively low uptake and poor maintenance of biological practices, combined with inconsistent extension contact (only 30% of farmers received monthly visits despite 75% having some access), point to the institutional dimension emphasized by Hall et al. (2006): the effectiveness of agricultural innovations depends on sustained interaction among farmers, extension systems, and supporting institutions, not on the introduction of the technology alone. Addressing labour, finance, and knowledge constraints the three most commonly cited barriers to SCP maintenance in this study will likely be as important to future gains as further expansion of terraced area.

4. Conclusion and Recommendations

4.1 Conclusion

This study provides robust evidence that soil conservation practices are significantly associated with sustainable crop production in the Food Basket Sites of Ngororero District, explaining 68% of the variance in production outcomes and correlating positively with yield, yield stability, food security, and household income. Terracing and agroforestry emerged as the most influential practices, while biological measures such as mulching and cover cropping, though less widely adopted, contributed complementary and statistically significant effects. At the same time, the persistence of visible erosion indicators despite extensive conservation coverage demonstrates that investment in SCPs alone is not sufficient: effectiveness depends on the balance between structural and biological measures, the quality of construction and maintenance, and the consistency of institutional support. The uneven distribution of benefits across households further indicates that socio-economic constraints labour, finance, land, and knowledge continue to limit the extent to which conservation investment translates into resilient, food-secure livelihoods for all farmers in the district.

4.2 Recommendations

Based on these findings, the study recommends the following:

1. Transition to integrated soil fertility management: Promote the combined use of structural (terracing) and biological (agroforestry, mulching, cover cropping) practices rather than reliance on terracing alone, to jointly address erosion control, soil fertility, and moisture retention.

2. Strengthen extension effectiveness: Increase the frequency and consistency of extension contact beyond the current 30% receiving monthly visits through field-based training and farmer demonstration sites.

3. Address socio-economic constraints to adoption: Introduce targeted financial mechanisms, input support, and labour-saving technologies to help resource-poor households sustain SCP maintenance.

4. Integrate SCPs into climate-smart agricultural planning: Combine SCPs with complementary measures such as water harvesting and climate-resilient cropping systems, given the high inter-annual rainfall variability documented in the district.

5. Prioritise equity in scaling SCPs: Design support mechanisms that reach smallholder and resource-constrained farmers who currently benefit least from conservation investment.

5. Limitations and Future Research

This study relied on a cross-sectional design and self-reported perceptions of yield and erosion change rather than a pre-intervention baseline or direct plot-level measurement, and its findings are specific to Ngororero District and should not be generalised to other contexts without due caution. Future research should pursue longitudinal or plot-level assessments of SCP performance, examine spatial variability in effectiveness across agro-climatic zones, and explore the long-term role of integrated SCPs in carbon sequestration and climate change mitigation.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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