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PERFORMANCE AND ADOPTABILITY OF MULCHING TECHNOLOGY TO CONTROL SOIL EROSION: CASE STUDY OF THE SEBEYA CATCHMENT IN RWANDA

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ABSTRACT

Soil erosion is a pressing environmental concern that poses significant threats to agricultural productivity, watershed health, and ecosystem stability. This research investigates the performance and adoptability of mulching technology as a Soil Erosion Control Measure (SECM) within the Sebeya catchment. This study employed various methods including a review of existing literature, on-site visits, structured interviews, and focus group discussions to evaluate the factors contributing to soil erosion, its impacts, and the variety of SECM within the Sebeya catchment. Among the 96 farmers surveyed in this research, it was evident that the natural reasons for soil erosion in the Sebeya drainage area were often attributed to the intense rainfall (23%) and steep slopes (22%). Also, the influence of lack of SECM and the continuous ploughing is significant with 22% and 22% respectively. The availability of mulching materials can vary significantly based on the geographic location, agricultural practices, and economic factors. In the Sebeya catchment, mulching materials often sourced from crop residues and vegetative residues. To address the risks associated with soil erosion, various site-specific measures were recommended. Using the Universal Soil Erosion Equation (USLE) model, the suggested Soil Erosion Control measures (SECM) were simulated with a significant decrease in soil loss, dropping from 73.05 t/ha/y to 19.62 t/ha/y. By incorporating mulching technology into the recommended SECM to mitigate soil erosion, the soil erosion rates reduced to permissible soil loss from 19.62 t/ha/y to 11.26 t/ha/y. To effectively reduce the high rates of soil erosion to acceptable levels within the Sebeya drainage area, this study advocates for the implementation of the recommended site-specific soil erosion control measures combined with mulching, drainage channels, and the stabilizing grasses on the same farmland. **I**mplementing SECM stands as the optimal choice for enhancing soil productivity while reducing sedimentation in downstream rivers and lakes.

KEYWORDS: Soil erosion control, mulching, Sebeya, Rwanda

1. INTRODUCTION

Accelerated soil erosion poses severe threats to the agricultural productivity and the downstream water quality in rivers, water reservoirs, and lakes (Molla & Sisheber, 2017; Nambajimana et al., 2020; Li et al., 2021).

Situated in the Western Province of Rwanda, the Sebeya drainage is delineated by steep slopes, abrupt topography, and heavy rainfall, which induce severe soil erosion (MoE, 2018).

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Efforts to combat soil erosion in Rwanda have been a priority for the government and various stakeholders (RWB, 2022). Initiatives such as forestation, land integration, soil conservation ditches and terraces programs have been implemented to mitigate erosion risks and restore degraded lands (MINILAF, 2017; NISR, 2019).

For an effective reduction of soil erosion to tolerable soil loss rates, mulching technology has emerged as a promising approach to mitigate soil erosion and conserve soil health. The mulching technique involves the application of protective materials, such as organic residues, plastic sheets, or living vegetation, on the soil surface to help in reducing the impact of erosive forces by minimizing water runoff, preventing soil detachment, and improving the retention of soil moisture (Iqbal et al., 2020; El-Beltagi et al., 2022). Consequently, mulching has shown significant potential in reducing erosion rates, stabilizing soil structure, and enhancing water infiltration. Its efficacy varies based on factors such as the type of mulch used, soil characteristics, climatic conditions, and land management practices (Solgi et al., 2022).

The performance and adoptability of mulching technology in mitigating soil erosion has been a subject of extensive research worldwide (Prosdocimi et al., 2016). Smallholder farmers, especially in developing countries, often face resource constraints and require accessible and affordable technologies such as mulching practices among diverse farming communities for soil conservation (Waaswa et al., 2021). Studies suggest that the knowledge, dissemination, access to resources, cost-effectiveness, and compatibility with existing farming systems significantly influence farmers' willingness to adopt mulching techniques (Liu et al., 2018).

The main goal of this study was to promote a comprehensive assessment of mulching technology regarding its performance and adoption to control soil erosion in the Sebeya drainage area.

2. METHODOLOGY AND DATA

2.1 Study area representation

Found in the west region of Rwanda, as depicted in Figure 1, the Sebeya drainage area spans across four administrative units known as Rutsiro Nyabihu, Rubavu, and Ngororero Districts. The Sebeya catchment exhibits a covering area of 363.1km^2 and an estimated population density of 644 inhabitants per square kilometer, in contrast to the countrywide figures of 26,338 square kilometers and 415 inhabitants per square kilometer. There are numerous causative factors to accelerate water erosion in the Sebeya drainage area, comprising its high altitude (1,462 m - 2,979 m) and abundant precipitation (1,200 mm - 1,700 mm) (IWRM, 2018).

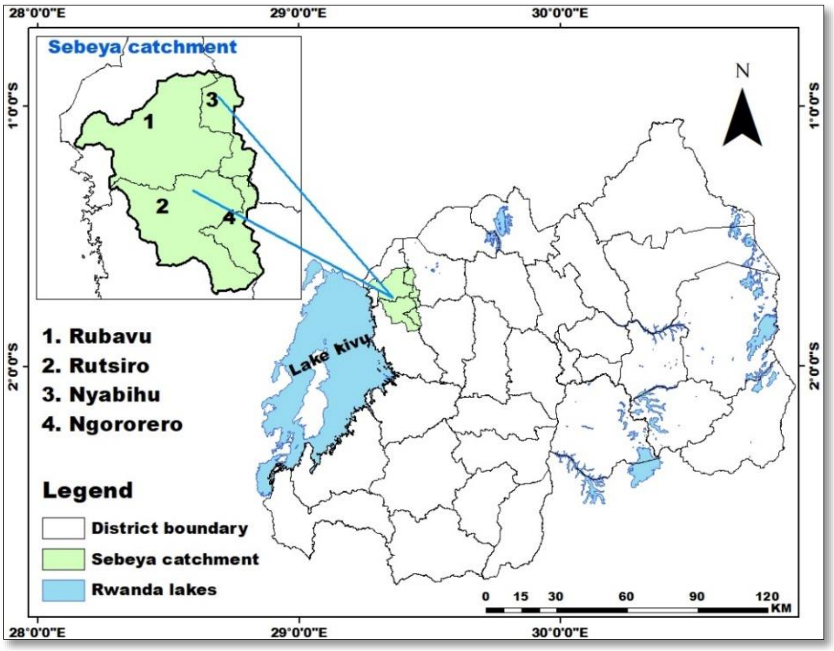

Figure 1. Rwanda map showing the Sebeya drainage area

2.2 Sampling procedures and sample size definition

In this particular research, a sample of 96 participants was meticulously chosen using systematic random selection process (Eq.1) for a reliability level of 95%, a variability of 0.5 degrees, and a 10% permissible error (Neilson, 2011). Structured interviews were conducted with farmers residing in six specifically acknowledged sectors (namely: Rugerero; Gisenyi; Kanama; Nyundo; Nyakiriba, and Nyabirasi). The objective was to obtain at the firsthand the farmers's knowledge and differents views on soil erosion, its impacts, and their behaviors concerning the execution of soil impairment prevention in the Sebeya drainage area.

$$n = \frac{Z^2\hat{p}\hat{q}}{e^2} = \frac{(1.96)^2(0.50)(0.50)}{(0.10)^2} = 96 \text{ farmers} \qquad \text{Eq.1}$$

2.3 Data gathering

The study gathered information on soil impairments rates, factors, and control methods in the Sebeya drainage area from literature and government reports, offering a comprehensive overview. Extensive site visits included Global Position System (GPS) prominent of topography and socio-economic features, soil and land use observations, hydrographic network analysis, crop assessment, river monitoring, and evaluation of existing SECM. Focus group discussions and interviews with local farmers assessed their understanding of soil erosion and control methods.

Rainfall data, Digital Elevation Model (DEM) data and shapefiles were obtained from Center of GIS of the University of Rwanda (UR-CGIS) and Rwanda Water Resources Board (RWB) for creating erosion and topographic maps, as well as soil texture of the Sebeya drainage area. This study utilized the USLE type-model to estimate erosion rates, with specific parameters (Equation2).

$$A = R \times K \times LS \times C \times P \qquad \text{Eq.2}$$

Where: A is the estimated soil loss (t/ha/y); R is the rainfall erosivity factor; K is the soil erodibility factor; LS is the slope length and steepness factor; C is the cover and management factor and P is the support practice factor.

Step1: Using Equation (3) similarly to Hassan (2011), the rainfall erosivity in the Sebeya drainage area, with an annual mean rainfall of 1318 mm (IWRM, 2018), is approximately 582.34 MJ x mm/h/y.

$$R = 81.50 + 0.38\overline{P} \qquad \text{Eq.3}$$

Step2: Ranging between 0 to 1, the minimum and maximum K-factors for erosion susceptibility of soil texture from published papers are 0.03 and 0.3 (Oruk et al., 2012) with an average of 0.14.

Step3: The steepness (LS) factor, calculated using Equation (4) with GIS applications (Ganasri & Ramesh, 2016), is approximately 11.35 (unit less), as suggested by various researchers using field erosion plots and specific parameters such as As the upstream area, β the slope angle and coefficients "m" and "n".

$$LS = \left(\frac{A_s}{22.13}\right)^m \times \left(\frac{\sin\beta}{0.0896}\right)^n \qquad \text{Eq.4}$$

Step 4: The P and C factor typically varies from 0 to 1, where 0 indicates no erosion control, and 1 signifies complete erosion control. On the other hand, 0 for C-factor signifies that there is no vegetative cover while 1 signifies that there is vegetative cover. Table 1 provides a compilation of typical P and C factor values for different SECM aimed at mitigating extreme soil loss amounts within the Sebeya drainage area and adopted from different researchers (Kuok et al., 2013; Panagos et al., 2015; Basnyat et al., 2020); Endalamaw et al., 2021)

Table 1: Different SECM with their typical values of C and P from literature

Suggested SECM	C	P
Afforestation	0.020	0.001
Agroforestry	0.080	0.500
Bamboo to close gullies	0.010	0.500
Bench terraces	0.150	0.128
Contour bank terraces	0.150	0.150
Contour banks	0.500	0.600
Grassed channels	0.200	0.100
Hedgerows	0.200	0.000
No-till	0.250	0.100
Perennial crops	0.230	0.800
Reforestation	0.020	0.001
River side bamboo	0.010	0.500
Silvopastoralism	0.090	0.000
Rainwater reservoirs	0.000	0.800
Drainage waterways	0.580	0.800
Forestry	0.000	0.000

2.4 Data interpretation

The study comprehensively reviewed soil erosion signs, factors, and ramifications, using a variety of data sources and tools, including shapefiles from RWB and the USLE-type model. This allowed for an assessment of the recommended SECM effectiveness in the Sebeya drainage area, using USLE parameters. Data analysis utilized ArcGIS and Excel for mapping and tabulation.

3. Results

3.1 Farmers' socioeconomic characteristics

Table 2 presents qualitative results obtained from analyzing various socioeconomic characteristics of farmers in the Sebeya catchment area, with a sample size of 96, using SPSS. It encompasses several attributes (variables) such as gender, age, marital status, education level, and distance from residence, farm size, types of fertilizer used, and satisfaction with net income from agriculture. The frequency distribution reveals insights into the demographic composition and agricultural practices of the surveyed farmers. For instance, the majority of respondents were male (57.3%) compared to female farmers (42.7%). The age distribution indicates a varied representation across different age brackets, with significant numbers falling within the 38-47 age group (35.4%). Moreover, a substantial proportion of the surveyed farmers were married (80.2%) and had attained primary education (62.5%). Regarding agricultural practices, a high percentage of farmers owned farm plots of less than or equal to 1.0 hectares (91.7%) and utilized organic or compost manure as their primary fertilizer (44.8%). Notably, a significant majority expressed dissatisfaction with their net income from agriculture (90.6%). This study offers a comprehensive overview of the socioeconomic characteristics and agricultural patterns within the Sebeya catchment, providing valuable insights for targeted interventions and policy formulation aimed at addressing the identified needs and challenges of the local farming community.

Table 2: The qualitative outcomes derived from the analysis of various socioeconomic traits of farmers within the Sebeya catchment area (n = 96) using SPSS software

Variables	Occurrence	Variables	Occurrence
1. Gender		**5. Distance from residence**	
Male	55(57.3%)	Less than 10 min walk	22(22.9%)
Female	41(42.7%)	Between 10-30 min walk	51(53.1%)
2. Age		Greater than 30 min walk	23(24%)
18-27	10(10.4%)	**6. Total farm land size**	
28-37	21(21.9%)	<=1.0ha	89(91.7%)
38-47	34(35.4%)	>1.0ha	8(8.3%)
48-57	21(21.9%)	**6. Types of fertilizer**	
>57	10(10.4%)	Organic or compost manure	43(44.8%)
3. Marital status		Industrial fertilizers	3(3.1%)
Married	71(80.2%)	Both fertilizers (O and I)	45(46.9%)
Single	6(6.3%)	No fertilizers use	5(5.2%)
Divorced	41(4.2%)	**7. Satisfaction of net income from agriculture**	
Widowed	9(9.4%)	No	87(90.6%)
4. Education		Yes	9(9.4%)
Illiterate	16(16.7%)		
Primary education	60(62.5%)		
Secondary education	18(18.8%)		
University education	2(2.1%)		

The quantitative data and statistical analysis outcomes were gathered by the researchers and represented in Table 3.

Table 3: The numerical findings concerning diverse socioeconomic attributes of farmers within the Sebeya catchment area (n = 96), analyzed utilizing SPSS software

Variables	Minimum	Maximum	Mean	Std. Deviation
Income from sorghum per household (kg/season)	.00	20.00	.21	2.04
Income from maize per household (kg/season)	.00	800.00	133.94	148.01
Income from beans per household (kg/season)	.00	400.00	111.81	75.92
Income from banana per household (kg/season)	.00	3500.00	244.54	495.17
Income from rice per household (kg/season)	.00	70.00	.73	7.14
Income from peas per household (kg/season)	.00	300.00	6.29	31.04
Number of cows per household	.00	15.00	1.04	2.19
Number of pigs per household	.00	150.00	4.16	18.53
Number of goats per household	.00	6.00	1.25	1.84
Number of cheeps per household	.00	5.00	1.32	1.83
Number of poultry per household	.00	500.00	12.16	53.84
Number of rabbits per household	.00	90.00	2.54	9.61

Based on the findings from the interview data presented in Table 6, this study demonstrated that the overall income per household (in kilograms) from sorghum, maize, beans, banana, rice, and peas fell within the ranges of 0 to 20, 0 to 800, 0 to 400, 0 to 3500, 0 to 70, and 0 to 300, respectively. The average values were approximately 0.21, 133.94, 111.81, 244.54, 0.73, and 6.29 kilograms squared per household. This research quantitatively highlighted the variation in the number of domestic animals per household, ranging from 0 to 15 cows, 0 to 150 pigs, 0 to 6 goats, 0 to 5 sheep, 0 to 500 poultry, and 0 to 90 rabbits. On average, households in the Sebeya catchment area possessed approximately 1.04 cows, 4.16 pigs, 1.25 goats, 1.32 sheep, 12.16 poultry, and 2.54 rabbits.

3.2 Farmers' perceptions on soil erosion in the Sebeya cachement

3.2.1 Analysis of review questionnaire

1. What are the tangible indicators of soil erosion in the drainage area?

Various indicators of soil erosion were assessed (Table 4). Among these indicators, rain drop and soil detachment by rain and runoff (22.2%) and river sedimentation (14.5%) stand out as prominent factors contributing significantly to soil erosion. Additionally, the occurrence of landslides (14.0%), a decrease in land productivity (12.7%) and channels formation in the fields (10.2%) suggests severe consequences, while gully formation (7.4%), reduced soil depth (8.9%) and compaction of the bare soil (9.8%) signify ongoing erosion processes. These indicators collectively underscore the complex interplay of natural forces like rainfall and runoff, emphasizing the urgency for effective erosion control strategies to safeguard agricultural productivity, land stability, and environmental sustainability. Correspondingly, Biratu and Asmamaw (2016) stated that 93.1% of participants acknowledged extreme soil impairment in their farmlands

Table 4: Visual indicators of soil erosion in the Sebeya catchment

Indicators of soil erosion	**Percentage (%)**
Rain drops and soil detachment by rain and runoff	22.2
Channels formation in the fields	10.2
Reduced soil depth	8.9
Compaction of the bare soil	9.8
Decreasing in productivity of land	12.7
Gully formation	7.4
Landslides	14.0
River sedimentation	14.5
Total	**100.0**

2. What are the primary causes of soil erosion in the Sebeya drainage area?

The responses provided offer insights into the diverse causes and contributors to soil erosion, emphasizing the multifaceted nature of this environmental challenge (Table 5). Factors such as the slope of the terrain (23.8%) and rainfall coupled with runoff (25.7%) emerge as primary natural causes, highlighting their substantial impact on soil stability. Similar factors were identified in studies conducted by Belay and Mengistu (2019); Leta and Megersa (2021), while Shit et al. (2015) confirmed that heavy rainfall and steep slopes were the primary and secondary causes of soil erosion, respectively. Moreover, the scarcity of land for farming and settlements stands out as a significant factor contributing to the ongoing deforestation in the Sebeya drainage area (IWRM, 2017).

Anthropological activities, however, notably cultivation techniques like tillage, terracing, and drainage channels (19.3%), and others human activities for non-agricultural purposes such as deforestation, construction of roads, mining, quarries and building construction and borrow pits for power transmission underscore the significant role in soil erosion at (10.4%) in total.

Moreover, the inclusion of seismic activities (4.0%) and high wind (16.8%) further broadens the spectrum of erosion triggers. This comprehensive array of factors elucidates the need for holistic approaches encompassing land management practices, infrastructure development, and environmental policies to effectively mitigate soil erosion, preserving both natural landscapes and human-built environments.

Table 5: Farmers' perceptions on causes of soil erosion in the Sebeya catchment

Main causes of soil erosion in the Sebeya catchment	Percent (%)
Slope of the terrain	23.8
Rainfall and runoff	25.7
Human activities (agricultural tillage, terracing, anti-erosive ditches and other drainage channels)	19.3
Human activities for non-agricultural purpose (deforestation, roads construction and buildings, quarries and building construction and borrow pits for power transmission)	10.4
High wind	16.8
Earthquakes	4.0
Total	**100.0**

3. What are various factors influencing soil erosion in the Sebeya catchment?

Figure 2 indicates that, among the numerous factors influencing soil erosion, rainfall emerges as the most significant factor at 23%, indicating its substantial contribution to soil erosion processes. Steep slopes closely follow at 22%, emphasizing their influential role in accelerating erosion. Notably, continuous cultivation without periods of fallow land (21%) and the absence of erosion control measures (22%) are also substantial contributors, underscoring the impact of human activities and land management practices on soil degradation. Deforestation, though at 7%, signifies another significant anthropogenic factor affecting erosion. The distribution of these factors displays the interplay between natural elements like rainfall and slope with human-driven activities, emphasizing the need for comprehensive strategies that integrate both environmental and land administration practices to mitigate soil erosion effectively and sustain soil health for future generations.

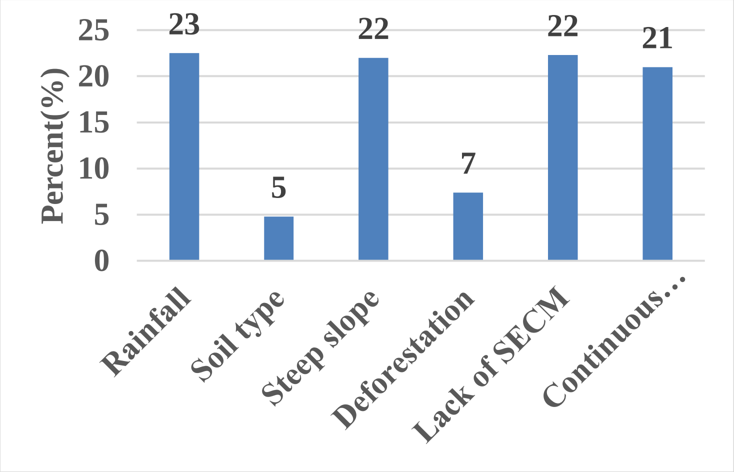

Figure 2. Various factors influencing soil erosion in the Sebeya catchment

4. What kind of Best Management Practices (BMPs) of erosion control do you have in your farmland?

This study identifies prevalent soil erosion control measures in the Sebeya catchment farmland (Table 6), including progressive terraces (7.0%), bench terraces (9.0%), contour bunds (8.4%), contour tillage (8.9%), and mulching (8.2%). These strategies emphasize topographical adaptations and agronomic practices, especially on steep slopes. Afforestation (7.5%), compost (7.8%), industrial fertilizers (7.6%), Anti-erosive ditches (7.0%), protective grasses (7.4%), and agroforestry (7.3%) are also significant, showcasing diverse erosion management approaches.

While, sand bags, grass-lined channels, stones' blocks in channels, hillside water ponds and roof runoff and cisterns have limited use in the farmland at (13.9%) in total. This array reflects the acknowledgment of diverse strategies in combating soil erosion, with an emphasis on modifying the land topography and integrating biological and agronomic methods.

Table 6: Availability of BMPs for erosion control in the Sebeya catchment farmlands

Best Management Practices (BMPs) of erosion control	Percentage (%)
To adopt progressive terraces (if steep slope: 16-40%)	7.0
To adopt bench terraces (if steep slope: 40-60%)	9.0
Afforestation (if very steep slope: >60%)	7.5
To adopt contour bunds (To adopt farm bunds)	8.4
To adopt contour tillage practice	8.9
To use compost fertilizers	7.8
To use industrial fertilizers as indicated by the agricultural technician	7.6
To mulch your farmland	8.2
Anti-erosive ditches and other drainage channels against runoff erosion in farmland	7.0
To stabilize the farmland bunds with protective grasses	7.4
Agroforestry	7.3
Others (sand bags, Grass-lined channel, Stones blocks in channels, Hillside water ponds and Roof runoff and cisterns)	13.9
Total	**100.0**

5. Do you plan to implement sufficient SECM in your farmland?

This study highlights the rate of implementation SECM in the Sebeya catchment (Table 7), such as progressive terraces (8.4%), bench terraces (9.0%), contour tillage (8.9%), contour bunds (8.4%), and mulching (8.2%). These measures emphasize altering land topography and agricultural practices for effective erosion control, especially on slopes. Proposals for afforestation (7.5%), the use of compost (7.8%) and industrial fertilizers (7.6%) show a focus on biological and agronomic approaches.

In addition, farmers wish to anti-erosive ditches and stabilize the farmland bunds with protective grasses at 9.4% and 10.5% respectively. While, agroforestry, grass-lined channels, stone blocks, sandbags, hillside water ponds, roof runoff and cisterns may have limited implementation at (13.2%) in total.

This diverse array of proposals reflects a comprehensive approach to address soil erosion concerns, with bench terraces, contour practices, and soil amendments being primary considerations. Afforestation and various fertilization methods demonstrate a balanced approach integrating ecological and agronomic interventions. However, lower proposals measures may signal a lack of awareness or implementation challenges, emphasizing the need for further education, research, or site-specific assessments to encourage broader adoption of erosion control practices for sustainable land management.

Table 7: Farmers' plan to implement sufficient SECM in their farmlands in the Sebeya catchment

Erosion Control Measures	Implementation rate (%)
Progressive terraces (steep slope: 16-40%)	9.5
Bench terraces (steep slope: 40-60%)	9.0
Contour tillage practice	8.9
Contour Bunds (To adopt farm bunds)	8.4
Mulching	8.2
Afforestation	7.5
Compost	7.8
Industrial Fertilizers	7.6
Anti-erosive ditches and other drainage channels	9.4
Stabilize the farmland bunds with protective grasses	10.5
Others (agroforestry, grass-Lined channels, stone blocks, sandbags, hillside water ponds, Roof runoff and cisterns)	13.2
Total	**100**

6. For which purpose farmlands are mulched?

This study comprehensively assessed various purposes of mulching in the farmland. Figure 3 revealed that its primary role is to control soil erosion (22%) and to protect against excessive sun heat (22%). Mulch acts as a protective cover, preventing erosion and reducing moisture loss. The study also highlights mulching's agronomic benefits, including improving soil moisture conservation (16%) and increasing organic matter (21%), enhancing soil fertility and moisture retention for better plant growth. Furthermore, the role of mulch in preventing wild weed growth (19%) underscores its multifunctional nature in fostering healthy soil conditions, making it essential for sustainable land management practices.

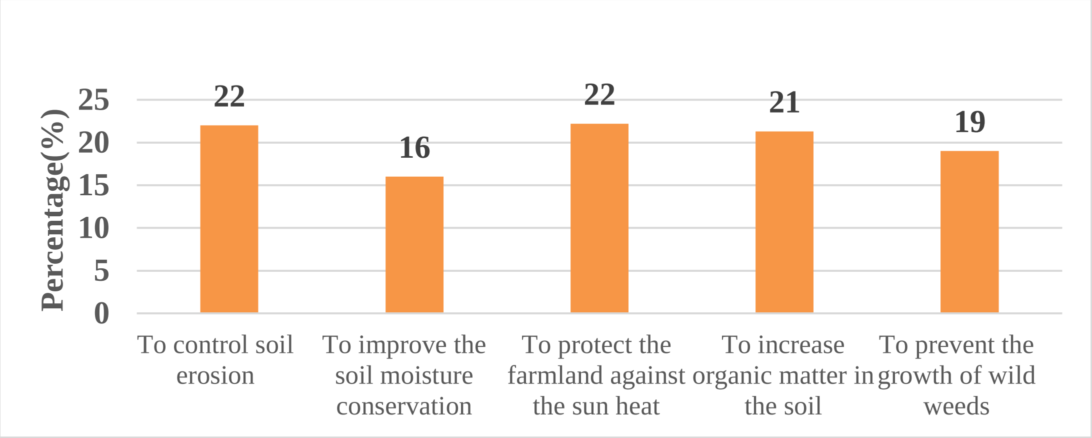

Figure 3: Various purposes of mulching

7. Indicate various uses of crop residues from your farmland

The respondents declared that crop residues serve various purposes, predominantly as mulching material (30%) and for composting (28%) (Figure 4). These purposes underscore the agricultural significance of crop residues in soil conservation and nutrient management. Mulching serves as a protective cover, aiding in moisture retention, erosion control, and weed suppression, while composting transforms residues into valuable organic matter for soil enrichment and fertility. Furthermore, the utilization of crop residues as a fuel source for cooking (24%) emphasizes their role in meeting energy needs in certain contexts, displaying their importance beyond agricultural applications. The use of residues for fencing (18%) signifies their versatility in providing materials for physical barriers, demonstrating the resourcefulness of crop residues in fulfilling various functional needs within local communities and agricultural practices.

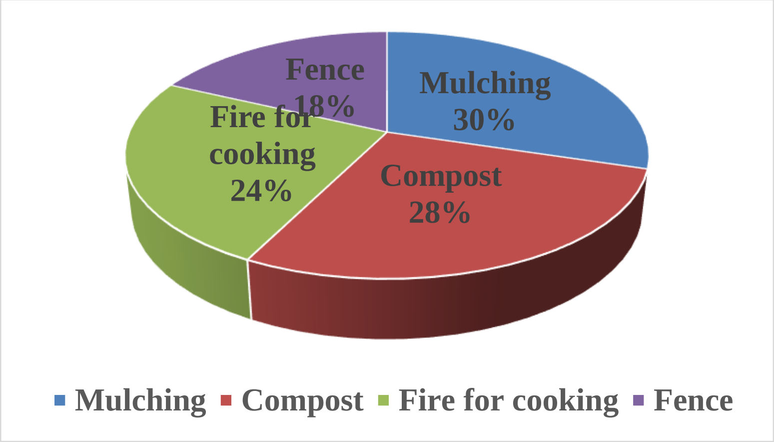

Figure 4. Various uses of crop residues

8. What are the main uses of vegetative residues from your farmland?

Based on farmers' responses in the Sebeya catchment, vegetative residues employed for multiple purposes (Figure 5), with a substantial percentage dedicated to fencing (28%) and utilizing residues as fuel for cooking (25.5%) These statistics emphasize the practical roles of vegetative residues in both meeting household energy needs and providing materials for physical barriers in the form of fences.

Moreover, the considerable utilization of residues for composting (26%) and mulching (21%) highlights their significant contribution to soil fertility enhancement and agricultural practices, demonstrating their versatility in supporting both soil health and household activities. This diversification in the use of vegetative residues underscores their multifunctional nature and displays their importance in sustainable resource management, serving both agricultural and domestic purposes within the community.

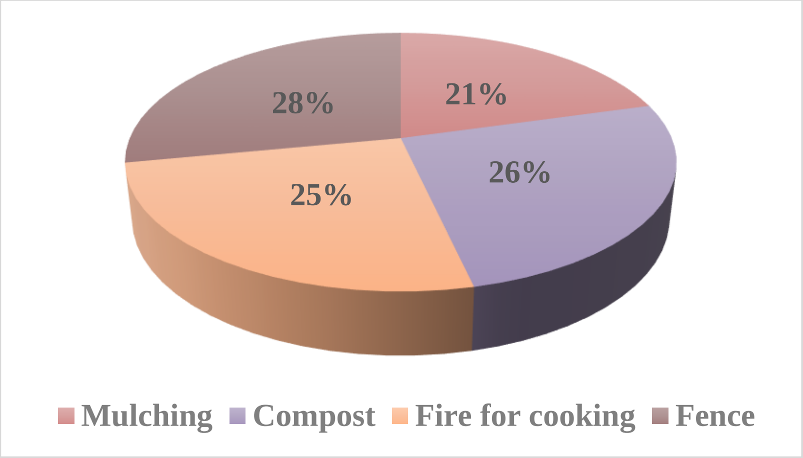

Figure 5. Various uses of vegetative residues

3.3 Actual soil loss rates in the Sebeya catchment

By utilizing various shapefiles acquired through the Rwanda Water Resources Board, Figure 6 illustrates multiple established Soil Erosion Control Measures (SECM) and the dispersion of soil impairment rates across the Sebeya catchment. Ultimately, Table 8 highlights an annual soil loss of approximately 73 t/ha/y from the Sebeya catchment.

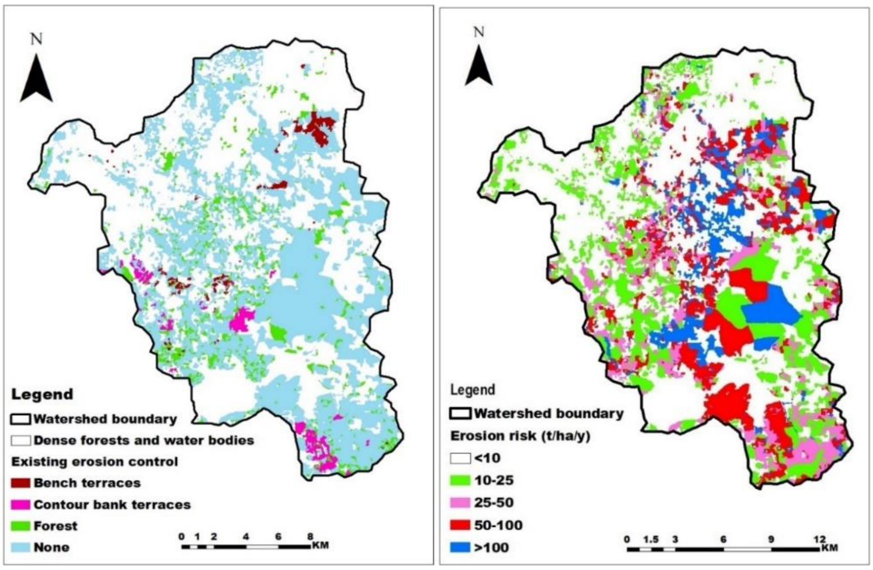

Figure 6. Current strategies implemented to control soil erosion and the extent of soil loss observed within the Sebeya catchment area.

Table 8: Current SECM and their induced erosion rates in the Sebeya catchment

(a) Current SECM			(b) Computation of the actual soil loss				
Existing SECM	**Area covered (ha)**	**%**	**Erosion risk (t/ha/y)**	**Peak value Ai (t/ha/y)**	**Coverage ai (ha)**	**% of area covered**	**Weighted value (Ai x ai)**
None	15,319	42	<10	10	18,009	50	180,087
Forest plantation	1959	5	10-25	25	6936	18	173,408
Contour bunds terraces	606	2	25–50	50	3484	10	174,195
Bench terraces	442	1	50–100	100	4917	14	491,707
Water bodies and dense forest	18,009	50	>100	600	2989	8	1,791,702
Total	36,335	100	Total		36,335	100	2,654,323
			The current soil loss from the Sebeya catchment is 2,654,323/36,335 = 73.05 t/ha/y				

3.4 Site-specific suggested SECM and associated erosion rates in the Sebeya catchment

In the absence of adequate Best Management Practices (BMPs), there will be a continual rise in soil erosion over time (NISR, 2019). Consequently, the need for enhancing SEC will persist, and reaching the T-value (the upper limit rate of soil loss) within the catchment. For instance, an interview with farmers in Nigeria highlighted their unanimous requirement for improvements across all SECM in the Kogi region (Onu & Mohammed, 2014). Using various shapefiles attained from the RWB, Figure 7 illustrates the recommended SECM, aiming to mitigate extreme erosion rates in the Sebeya catchment. By means of the USLE model, defined by its five variables in Equation (1), the subsequent sections detail the procedures adopted to predict soil erosion rates.

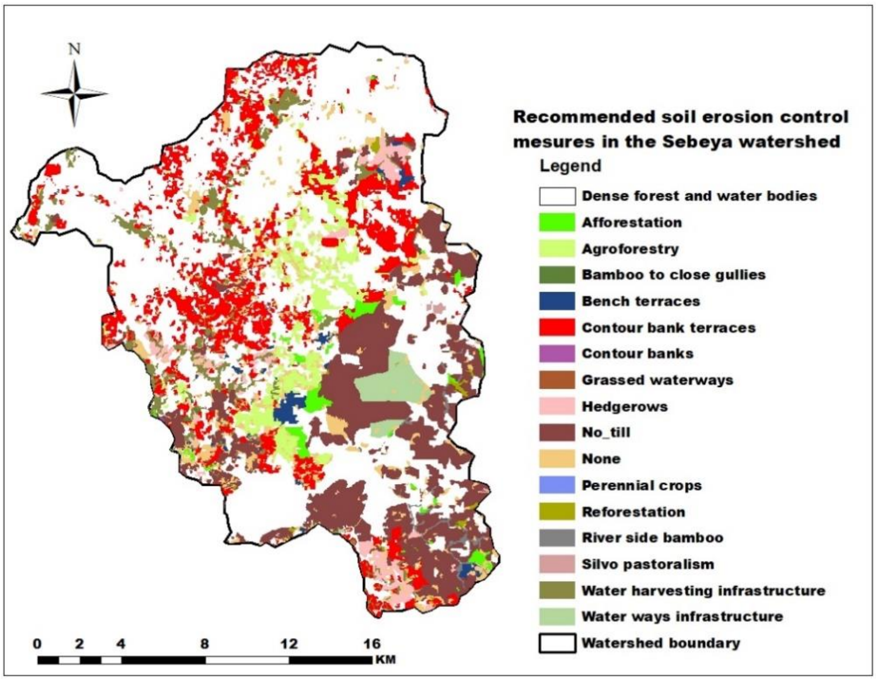

Figure 7. Suggested SECM in the Sebeya catchment

Figure 7 displays a range of site-specific Soil Erosion Control Measures (SECM) proposed to mitigate the high erosion rates of 73 t/ha/y in Table 8. Meanwhile, Table 9 delineates the specific coverage areas for each SECM implemented. Table 9 demonstrates the estimates of erosion rates linked to the advised SECM in the Sebeya drainage area. In comparison, the recommended SECM notably reduced soil loss from 73 t/ha/y (Table 8) to 20 t/ha/y (Table 9), elevating the efficiency of SECM to 73.14%. Effectively, addressing the issue of extreme erosion rates within the Sebeya drainage area, this study underscores the application of site-specific SECM combined with mulching on the same agricultural land.

Table 9: Erosion rates induced by the site-specific suggested SECM in the Sebeya catchment

Recommended erosion control measures	**R**	**K**	**L.S**	**C**	**P**	**A (t/ha/yr)**	**Area covered ai (Ha)**	**Weighted soil loss (Ai*ai)**
Afforestation	582.34	0.14	11.35	0.02	0.001	0.019	479.2	8.868
Agroforestry	582.34	0.14	11.35	0.08	0.500	37.013	1750	64773.68
Bamboo to close gullies	582.34	0.14	11.35	0.01	0.500	4.627	28.4	131.398
Bench terraces	582.34	0.14	11.35	0.15	0.128	17.767	320.8	5699.491
Contour bank terraces	582.34	0.14	11.35	0.15	0.150	20.820	4942.8	102909.6
Contour bunds	582.34	0.14	11.35	0.50	0.600	277.601	6.5	1804.41
Grassed waterways	582.34	0.14	11.35	0.20	0.100	18.507	7.2	133.249
Hedgerows	582.34	0.14	11.35	0.20	.00	0	871.4	0
No-till	582.34	0.14	11.35	0.25	0.100	23.133	5832.3	134921.3
Existing SECM*	582.34	0.14	11.35	0.22	0.341	69.419	2041.9	141746.4
Perennial crops	582.34	0.14	11.35	0.23	0.800	170.262	0.2	34.05245
Reforestation	582.34	0.14	11.35	0.02	0.001	0.019	102.4	1.895093
River side bamboo	582.34	0.14	11.35	0.01	0.500	4.627	176.7	817.5364
Silivo pastoralism	582.34	0.14	11.35	0.09	.00	0	35.7	0
Rainwater harvesting pond	582.34	0.14	11.35	.00	0.80	0	1265.3	0
Drainage channels	582.34	0.14	11.35	0.58	0.80	429.357	605.2	259846.8
Build-up, dense forest, and water bodies	582.34	0.14	11.35	0	0	0	17869.4	0
Total							**36335.4**	**712828.7**
Average soil loss =712828.7/ 36335.4 = 19.62 t/ha/y								

This study evaluated the effectiveness of mulching in controlling soil erosion rates from 19.62 t/ha/y induced by recommended SEC measures to 11.26 t/ha/y, indicating overall efficacy of mulching to 42.61% starting from existing soil loss rate in the Sebeya catchment Table 10. Recent study reported that, mulching significantly reduced erosion rates, stabilized soil structure, and enhanced water infiltration (Solgi et al., 2022).

Table 10: Performance of mulching in the Sebeya catchment

Recommended erosion control measures	R	K	L.S	C	P	A (t/ha/yr)	Area covered ai (Ha)	Weighted soil loss (Ai*ai)
Afforestation	582.34	0.14	11.35	0.02	0.001	0.0185	479.2	8.868442
Agroforestry+ mulching	582.34	0.14	11.35	0.006	0.13	0.761	1750	1330.451
Bamboo to close gullies	582.34	0.14	11.35	0.01	0.5	4.627	28.4	131.398
Bench terraces+ mulching*	582.34	0.14	11.35	0.012	0.033	0.365	320.8	117.0676
Contour bank terraces+ mulching	582.34	0.14	11.35	0.012	0.039	0.428	4942.8	2113.764
Contour bunds + mulching	582.34	0.14	11.35	0.039	0.156	5.702	6.5	37.06257
Grassed waterways	582.34	0.14	11.35	0.2	0.1	18.507	7.2	133.2487
Hedgerows	582.34	0.14	11.35	0.2	0	0	871.4	0
No-till+ mulching	582.34	0.14	11.35	0.020	0.026	0.475	5832.3	2771.283
Existing SECM*	582.34	0.14	11.35	0.22	0.341	69.419	2041.9	141746.4
Perennial crops	582.34	0.14	11.35	0.23	0.8	170.262	0.2	34.05245
Reforestation	582.34	0.14	11.35	0.02	0.001	0.0185	102.4	1.895093
River side bamboo	582.34	0.14	11.35	0.01	0.5	4.627	176.7	817.5364
Silivo pastoralism	582.34	0.14	11.35	0.09	0	0	35.7	0
Rainwater harvesting pond	582.34	0.14	11.35	0	0.8	0	1265.3	0
Drainage channels	582.34	0.14	11.35	0.58	0.8	429.357	605.2	259846.8
Build-up, dense forest, and water bodies	582.34	0.14	11.35	0	0	0	17869.4	0
Total							**36335.4**	**409089.9**

Average soil loss =409089.9/ 36335.4 = 11.26 t/ha/y

*Note: combined C (Bench terraces+ Mulching) and combined P (Bench terraces+ Mulching) were obtained by multiplication of C-bench terraces and C-Mulching=

- C (Bench terraces+ Mulching) = C(bench terraces)* C(Mulching)= 0.15*0.079=0.012(Table 10)
- P (Bench terraces+ Mulching) = P(bench terraces)* P(Mulching)= 0.128*0.26=0.033 (Table 10)

4. Discussions

4.1 Benefits of mulching

Mulching plays a pivotal role in mitigating soil erosion by acting as a protective cover (Matisic et al., 2023). It effectively reduces erosion rates by preventing soil detachment due to droplet strike and minimizing overland flow (Matisic et al., 2023; Shi et al., 2013). Mulches contribute significantly to enhancing soil health by retaining moistness and regulating soil heat. They act as insulators, reducing evaporation and maintaining optimal soil moisture levels (Iqbal et al., 2020).

In addition, it suppresses weed growth by limiting light availability and competing for nutrients, thus reducing weed pressure and enhancing nutrient availability for cultivated crops (Iqbal et al., 2020; Hüppi et al., 2015); Nwosisi et al., 2019) and it helps maintain a more stable soil heat, preserving plant roots from excessive heat or cold stress (Iqbal et al., 2020). Furthermore, mulching minimizes water usage by reducing evaporation and runoff, thereby improving water retention in the soil (El-Beltagi et al., 2022)

4.2 Field performance of different mulches on soil erosion

Studies have extensively compared the influence of diverse mulches on erosion control, highlighting their varying degrees of effectiveness in diverse environmental contexts (Solgi et al., 2022; Prosdocimi et al., 2016). Organic mulches, such as crop residues, straw, and grass, have demonstrated significant soil erosion reduction by acting as protective covers (Kavian et al., 2020; Prosdocimi et al., 2016). These materials create a barrier against rainfall impact, minimize surface runoff, and enhance soil moisture retention (Iqbal et al., 2020). Field experiments across different terrains have shown that organic mulches effectively reduce soil detachment and erosion rates, promoting soil stability and improving overall soil health (Parhizkar et al., 2021; Wu et al., 2022).

Firstly, inorganic mulches, including materials like plastic sheeting, gravel, and geotextiles, have shown promising results in reducing soil erosion by forming physical barriers that impede water runoff and limit soil movement (Tibash et al., 2023).

Field studies indicate that plastic mulches, when properly applied, effectively reduce erosion rates by shielding the soil from raindrop impact and maintaining a stable surface (Iqbal et al., 2020).

Secondary, living mulches, encompassing cover crops and perennial vegetation, have demonstrated remarkable erosion control capabilities due to their continuous soil cover and root systems' binding action. Field trials have shown that cover crops, like legumes or grasses, planted as living mulches effectively reduce soil erosion by stabilizing soil aggregates, enhancing infiltration, and reducing surface runoff (Neri et al., 2021).

Comparative field studies evaluating the performance of different mulching techniques have underscored the need for context-specific approaches in erosion-prone areas (Kader et al., 2017; Montenegro et al., 2013). Integrating various mulching methods or combining mulches with other erosion control practices may offer synergistic benefits in combating soil erosion, emphasizing the importance of adopting integrated soil conservation strategies (Prosdocimi et al., 2016).

4.3 Adoptability of mulching technology in the Sebeya catchment

The adoptability of mulching technology is influenced by various factors encompassing socio-economic, technological, cultural, and environmental aspect (NGAIWI et al., 2022). Factors such as the cost-effectiveness of mulching materials, availability of resources, and financial incentives significantly influence adoption rates. Affordability and accessibility of mulching materials and equipment play a pivotal role in the willingness of farmers to implement these practices (Khose et al., 2023). Government subsidies, financial support, or incentives can encourage farmers to adopt mulching, particularly in regions with limited financial resources (Murindangabo et al., 2021). Moreover, the perception of cost-effectiveness, long-term benefits, and return on investment influences farmers' decisions regarding the integration of mulching into their agricultural practices (NGAIWI et al., 2022).

Farmers' familiarity with the technology, its ease of use, and its integration with traditional farming practices impact the likelihood of adoption (Olum et al., 2020).

Awareness programs, education, and knowledge dissemination efforts are essential in influencing farmers' attitudes and behaviors towards mulching practices (Bwalya et al., 2023). Community participation, engagement, and demonstration plots displaying the benefits of mulching can foster acceptance and adoption among farmers.

In addition, the adaptability of mulching practices is contingent on the environmental context, including factors like soil type, climate, topography, and land use practices (Iqbal et al., 2020).

Addressing these multifaceted aspects through targeted interventions, awareness programs, technological advancements, supportive policies, and community engagement is pivotal in enhancing the adoption and integration of mulching practices into agricultural systems.

4.4 Ill-effects (Disadvantages of Mulching Technology)

Mulching is a widely practiced agricultural technique with numerous benefits, yet there are some notable associated disadvantages.

One significant drawback is the potential for increased pest and disease pressure. Mulch provides a favorable environment for pests and pathogens to thrive, offering shelter and moisture for their growth and reproduction (Iqbal et al., 2020). Additionally, certain types of mulch, especially organic materials like straw or compost, may harbor weed seeds, inadvertently contributing to weed proliferation instead of suppressing weed growth as intended (Du et al., 2022).

Moreover, excessive or improper application of mulch can lead to detrimental consequences such as soil compaction and reduced aeration (Mbukwa et al., 2023). When mulch layers are excessively thick or compacted, they can impede the mobility of air and water into the soil, hindering proper root respiration and nutrient uptake by plants (Mbukwa et al., 2023). Therefore, proper monitoring and adjustment of mulch depth and type are crucial to prevent these adverse consequences for soil texture and plant growth (Pavlů et al., 2021).

Furthermore, in specific climatic conditions, especially in regions with high humidity or excessive rainfall, mulching can contribute to the retention of excess moisture, leading to overly wet soil conditions (El-Beltagi et al., 2022).

It can also create an environment favorable for the proliferation of certain pests, influencing plant health negatively (Panth et al., 202); Chen et al., 2023).
Mulching is a widely practiced agricultural technique with numerous benefits, yet there are some notable associated disadvantages.

4.4 SWOT analysis on performance and adoption of mulching technology

A SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of mulching technology regarding its performance and adoption in soil conservation provides a comprehensive understanding of its internal and external factors (Table 11). This analysis aids in assessing the advantages, challenges, potential areas for improvement, and external influences affecting the adoption and effectiveness of mulching techniques.

Table 11: SWOT analysis on the performance and adoption of mulching technology

Strength	Weakness
Erosion Control effectiveness: Mulching demonstrates significant efficacy in reducing soil erosion rates by preventing soil detachment, minimizing surface runoff, and enhancing soil stability.	**Degradation and Renewal:** Some mulching materials degrade over time, necessitating regular renewal or replacement, which could be a constraint for resource-limited farmers.
Soil Health Improvement: Mulching contributes to enhanced soil moisture retention, preservation of soil composition, and increased organic matter content, fostering improved soil fertility and microbial activity.	**Seasonal Variation in Effectiveness:** The effectiveness of mulching practices might fluctuate depending on seasonal changes, especially in extreme weather conditions.
Cost-Effective: Utilizing locally available materials for mulching, such as crop residues, can be cost-effective and sustainable for farmers, reducing the need for external inputs.	**Skill and Knowledge Gap:** Adequate knowledge and technical skills are essential for the proper application and management of mulching, which might pose a challenge for some farmers.
Environmental Sustainability: Mulching aligns with sustainable agricultural practices by conserving water, sequestering carbon, and reducing the environmental impact associated with soil erosion.	**Technological Constraints inorganic mulches**: Inadequate access to appropriate equipment or lack of technological advancements in mulching methods may hinder widespread adoption.
Opportunities	**Threats**
Degradation and Replenishment: Organic mulches require replenishment and maintenance, as they decompose over time, potentially leading to a need for frequent reapplication.	**Resource Constraints**: Limited availability of mulching materials, high initial investment costs, and lack of financial support may hinder adoption, especially among resource-constrained farmers.
Education and Outreach: Awareness programs, farmer training, and extension services can improve knowledge dissemination and encourage greater adoption among farmers	**Resistance to Change**: Traditional farming practices (use of crop residues and vegetative grasses for cooking, composting and fencing instead of using them as mulches in their farmlands) and reluctance to adopt new techniques could impede the adoption of mulching practices.
Policy Support: Supportive policies, incentives, and government initiatives promoting sustainable land management practices, including mulching, can foster increased adoption	**Environmental Challenges**: Extreme weather events, soil degradation, and changing climate patterns may influence the effectiveness of mulching and pose threats to its long-term viability.
Integration with Agroforestry: Integrating mulching with agroforestry systems offers opportunities to enhance soil conservation, biodiversity, and overall ecosystem health.	**Inadequate Support Services:** Lack of access to extension services, technical guidance, or financial support might hinder the adoption of mulching technology among farmers.

4.5 Future work

Currently, considerable investigation has been approved the effectiveness and adoption of mulching technology in soil erosion mitigation, encompassing diverse mulching materials, methods, and their impacts on soil health and crop yield (Prosdocimi et al., 2016). Existing studies have evaluated the efficacy of various mulching techniques, including organic and inorganic materials, in controlling erosion rates, conserving soil moisture, and improving soil fertility in different agro-ecological contexts (Thakur and Kumar, 2021).

However, future work will focus on enhancing the scalability and applicability of mulching practices by addressing socio-economic barriers, promoting farmer awareness, and tailoring mulching strategies to suit local environmental conditions. Additionally, future research aims to delve deeper into the long-duration effects of mulching on soil health, biodiversity, and ecosystem resilience, while integrating stakeholders' perspectives and experiences to facilitate wider adoption and sustainable implementation of mulching technology.

5. CONCLUSION AND RECOMMENDATIONS

This study aimed to assess the effectiveness of mulching technologies in controlling soil erosion in the Sebeya catchment. The initial soil loss under the existing SECM was estimated very high at 73.05 t/ha/y due to steep slopes and excessive rainfall. With an ultimate interest and consideration using USLE model, the simulated site-specific SECM

reduced the annual soil loss to 19.62 t/ha/y. For effective soil erosion control to permissible soil loss rates in the Sebeya catchment, the integration of mulching with the recommended SECM significantly reduced the soil loss from 19.62 to11.26 t/ha/y, demonstrating a 42.61% of efficiency. The current study suggests the implementation of a comprehensive educational program and awareness campaigns focused on local farmers and communities. To this end, this study suggests workshops and farmers' training sessions to improve the understanding and adoption of mulching practices in achieving a sustainable soil erosion control in the Sebeya catchment.

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