Sustainable Land Management (SLM): Guidelines and Policy Brief Based on Five-Years Research Results of the SATREPS (Science and Technology Research Partnership for Sustainable Development)-Ethiopia Project:

"Development of Next-generation Sustainable Land Management (SLM) Framework to Combat Desertification"

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Executive Summary

In Ethiopia, inappropriate land use and management practices such as intensive tillage, under/over utilization of agricultural inputs, indiscriminate cutting of natural vegetation and plantations, and overgrazing of grasslands/rangelands have been reported as the main causes for land/soil degradation and malfunctioning of ecosystems. Thus, the need to develop and implement sustainable land use and management practices is increasingly recognized as an important tool for securing the long-term ecosystem services and livelihoods while maintaining and restoring the proper functioning of essential resources (soil, water, biodiversity, and others).

Scaling out sustainable land management (SLM) requires an interplay of four general principles: targeted policies and institutions, a sustainable land and participatory framework, stakeholder involvement and partnerships at all levels, and an integration of natural resource utilization at the ecosystem scale. The SLM indicators included in this brief are directly or indirectly related to the targets of seven of the UN’s Sustainable Development Goals (SDGs): (1) land formalization and security (SDG 1/Target 4), (2) secured land rights and accessibility (SDG 2/Target 3), (3) empowerment of women through property ownership, financial service, and technology (SDG 5/Target 5), (4) resource efficiency and sustainable land uses (SDG 11/Target 3), (5) land adaptation against climate change impacts (SDG 13/Targets 1 and 3), (6) afforestation, land conservation, and land degradation neutrality (SDG 15/Targets 1, 2, and 3), and (7) land administration and property rights (SDG 16/Target 3). Participatory monitoring and evaluation of SLM strategies and tools is, therefore, critically essential to ensuring broader adoption of the most effective SLM technologies and approaches.

This guideline and policy brief is intended to offer a description of research-based approaches and evidence that can support policy makers and experts in designing and implementing SLM technologies, as well as tools for practical evaluation of integrated watershed management practices. To this end, multidisciplinary research has been carried out for five years (2017–2021) in different agro-ecological zones of the Upper Blue Nile basin of Ethiopia, involving key stakeholders from relevant institutions from Japan and Ethiopia. The guideline and policy brief also offers key policy recommendations to achieve improved adoption of SLM through effective use and management of financial and human resources.

1. Overviews

1.1. Land mismanagement and degradation

Land is the area that supports various natural resources and the vast majority of human activities. It provides essential conditions for improved environmental management, including source/sink functions for carbon, recycling of nutrients, amelioration and filtering of pollutants, and transmission and purification of water as part of the hydrologic cycle (http://www.ciesin.org/lw-kmn/slm/slm.html). In the Anthropocene, however, human-driven pressures and improper land use practices are imposing adverse impacts and have caused a decline in the ecosystem services of landscapes worldwide, particularly in developing countries, like Ethiopia, where a larger proportion of the population is essentially dependent on land resources (Barbier and Falco, 2021). Rapid population increase, severe soil loss, low vegetative cover, and unsuitable crop and livestock production systems have been reported as the major cases of land degradation in Ethiopia (Taddesse, 2001).

1.2. Definition and necessity of SLM

Sustainable land management (SLM) is defined as a knowledge-based procedure promoting the adoption of land use systems through appropriate management practices that enable the maximization of economic and social benefits from the land while maintaining or enhancing the ecological support functions of its resources (FAO, 2009). Also, as defined by de Vente et al. (2017), SLM refers to the integrated management of soil, water, and biodiversity to adequately maintain and improve ecosystem functions and services for present and future generations. There are three stages of interventions for SLM (Liniger et al., 2019): prevention (avoiding), reduction (reducing), and restoration (reversing) of land degradation. **Figure 1** shows an example where the natural vegetation has been restored following the implementation of soil and water conservation (SWC) practices in a watershed that represents the dry sub-humid environments of Ethiopia.

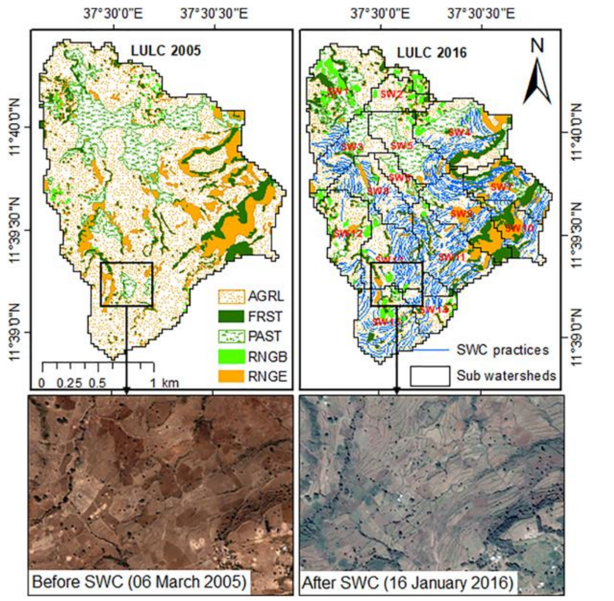

Figure 1. Contrasts in land use and land cover before March 2005) and after (January 2016) implementation of SWC in Kecha watershed (Berihun et al. 2020). Vegetation cover was poor and soil was highly vulnerable to erosion by water before SWC. Ecosystem functions were healthier after treatment with SWC measures such as terracing and exclosures. AGRL: cultivated land; FRST: forest land; PAST: grazing land; RNGB: khat cultivation; RNGE: bushland.

The necessity of SLM has been recognized for centuries. It has been described as a tool for harmonizing the complimentary goals of providing environmental, economic, and social opportunities for the benefit of present and future generations, while maintaining and enhancing the quality and function of land resources (soil and water) (Smyth and Dumanski, 1993). SLM combines technologies, approaches, policies, and activities aimed at integrating socioeconomic principles with environmental concerns, considering the five pillars of sustainability: productivity, stability/resilience, protection, viability, and acceptability/equity. These five pillars are thus the basic principles of SLM, and participatory research is required to develop, evaluate, and implement improved technologies and approaches in relation to sustainable development goals (Abouelhamd et al., 2020).

1.3. Purpose of this guideline and policy brief

This guideline and policy brief is aimed at providing the theoretical and practical bases as well as evidence for supporting SLM, with a focus on three specific objectives: reducing/preventing soil erosion, improving land productivity, and increasing income of rural households based on findings from comprehensive analyses of effective watershed management practices. For the past five years, monitoring and evaluation of potential SLM technologies and approaches has been conducted at the plot and watershed scales targeting three different land use types (cropland, grazing land, and degraded hillsides) in the Upper Blue Nile basin of Ethiopia. Best SLM technologies and approaches were then selected through a participatory review of the results for dissemination at larger scales following the process indicated in **Figure 2** below. Reports (38) of case studies presenting the evidence/findings discussed in this document are given in the bibliography list.

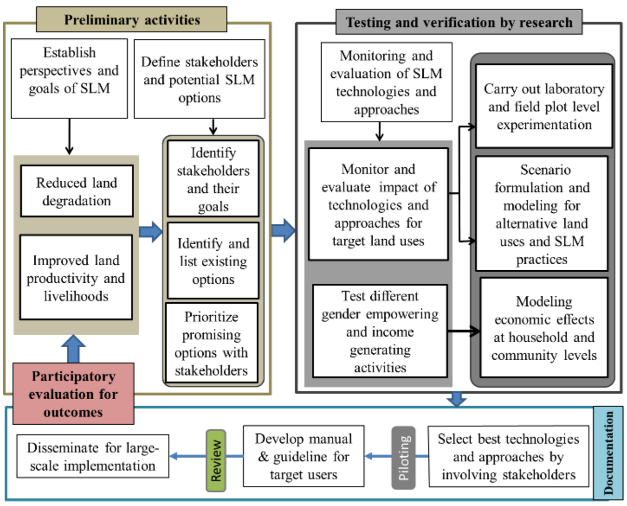

Figure 2. A framework adopted for developing, evaluating, and disseminating SLM technologies and approaches.

2. Principles and evidence of SLM

2.1. Reduced soil erosion and degradation

Significant reduction in soil erosion and possible on-site and off-site impacts can be achieved by using improved soil and water conservation measures such as establishing bunds reinforced with grass in combination with the application of organic and inorganic soil amendments (e.g., polyacrylamide [PAM], lime, biochar, etc.) for croplands, and establishing exclosures and trenches for grazing and degraded hillsides. Case studies have proven the substantial effectiveness of such land management technologies in reducing soil loss due to soil erosion by water at the plot scale in different agro-ecological zones of the Upper Blue Nile basin, Ethiopia **(Table 1** and **Fig. 3)**. It is worth mentioning that the use of PAM may need to be certified by the concerned ministry with regard to the environmental impact before its dissemination.

Table 1. Efficiency of different SLM technologies in reducing soil loss (Ebabu, et al., 2019; Kebede et al., 2021).

Land use type	SLM type	Soil loss reduction (%)		
		Lowland	Midland	Highland
CL	SB	75	61	72
	SB + G	87	66	79
	PAM	ND	45	ND
	L	ND	27	ND
	PAM + L	ND	49	ND
GL	E	38	57	71
	E + T	86	78	77
DH	E	55	72	39
	E + T	86	94	84

CL, Cropland; GL, grazing land; DH, degraded hillside; SB, soil bunds; G, grass; PAM, polyacrylamide, L, lime; E, exclosure; T, trench. ND: no data.

Table 2. Increase in SOC due to use of combined SLM technologies (Ebabu et al., 2020).

Land use type	SLM type	Soil SOC stock (Mg/ha)*		
		Lowland	Midland	Highland
CL	Control	34.5	15.6	58.9
	SB + G	70.5	54.5	66.0
	Increase (%)	104	249	12
GL	Control	59.4	29.7	50.2
	E + T	66.3	65.3	62.4
	Increase (%)	12	120	24
DH	Control	67.8	32.1	47.4
	E + T	71.5	68.2	57.7
	Increase (%)	5	112	22

*Based on analysis before (control) and 3 years after establishing SLM technologies (SB + G and E + T). See Table 1 for definition of terms. SOC: soil organic carbon.

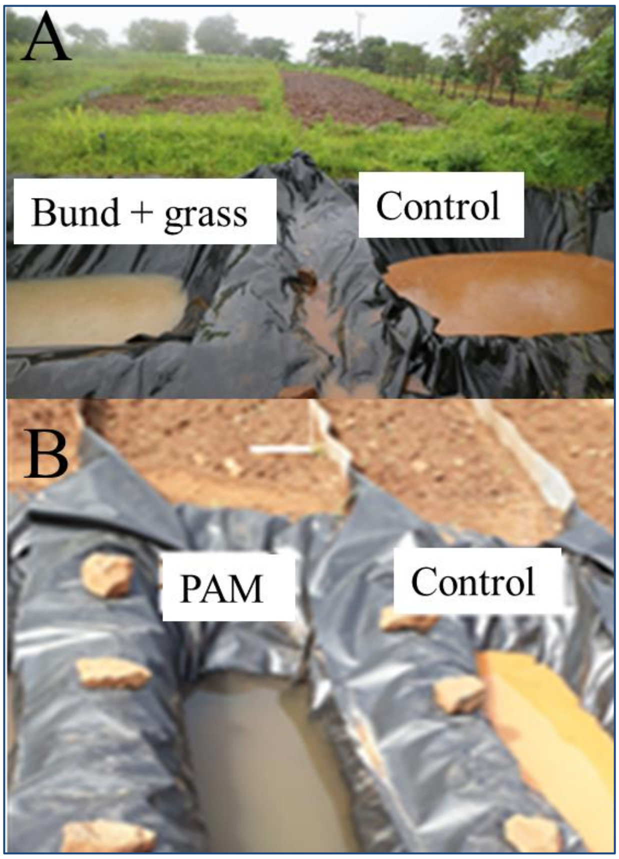

Figure 3. Effectiveness of improved SLM technologies in reducing soil loss from croplands: (A) soil bunds reinforced with vetiver grass in the lowland agro-ecological zone (photo by Professor Atsushi Tsunekaw), and (B) polyacrylamide (PAM) in the midland agro-ecological zone (photo by Dr. Birhanu Kebede).

SWAT (Soil & Water Assessment Tool) model results revealed that soil erosion at the watershed scale can be reduced by 66% to 95% if croplands are treated with the best performing SLM practices, such as reduced tillage, soil bunds reinforced with grass, and soil amendments (e.g., PAM + lime), and if non-croplands are treated with exclosures combined with trenches. Also, these model-based results have policy implications, that is, that land-capability-based implementation of land use and management practices is pivotal to achieve reduced soil erosion and land degradation in complex watersheds.

Biophysical SLM technologies have also been proven to maintain or improve key soil quality indicator parameters, such as soil organic carbon (SOC), regardless of land use type and climatic regions (**Table 2**). This supports the fact that nature-based land use and management practices are effective in enhancing SOC stock and can improve soil health and fertility through improving water and nutrient retention and availability to plants, thereby helping to improve resilience and the production potential of soils in different land use systems (e.g., grazing lands, croplands, and terraced hillsides). Research findings further indicated that the desired positive responses to implementation of SLM technologies are dependent on land use type and other local conditions (e.g., rainfall amount and land use characteristics). For example, the impact of implementing integrated SLM practices on increasing SOC was greater in the midland agro-ecological site in which rainfall and grazing intensity, and the associated soil erosion and degradation, have long been more prevalent. Hence, the careful identification and prioritization of locations based on vulnerability or resilience to soil degradation is important for targeted and effective intervention when conducting SLM.

2.2. Increased land productivity

Higher yields are often perceived as opportunities for policy makers and land managers to encourage farmers to adopt SLM practices and approaches. However, lack of knowledge, inefficient land use and management practices, and inappropriate implementation of promising SLM technologies are still challenges to improving and sustaining productivity of various land use types. Results from plot experiments and farmers' demonstration activities proved that land productivity can be increased by 67% to more than 100% when the best SLM technologies are properly implemented and monitored (**Table 3**). It is also clear that the productivity of dairy cows can be improved when they are fed improved forage (**Table 4**). Thus, policy instruments and actions should enhance efforts of watershed development through empowering rural communities to adopt best performing SLM practices.

Table 3. Effects of different SLM types on land productivity (Ebabu et al., 2019, Bayable et., 2021; Mihrite et al, 2021a; Mulualem et al., 2021a, Walie et al., 2021b).

LU	SLM Type	Effect on biomass (grain/grass) yield (t/ha) in three agro-ecological zones[a]		
		Lowland	Midland	Highland
CL, under Teff (target crop)	Control	ND	5.8	ND
	PAM + L	ND	7.4	ND
	Increase (%)	-	28	-
	Control	ND	0.9	ND
	RT + RP	ND	1.5	ND
	Increase (%)	-	67	
	Control	ND	ND	1.8
	Lodging controlled	ND	ND	3.2
	Increase (%)	-		78
GL	Control[b]	0.6	0.6	0.6
	E + T	5.8	9.0	5.2
	Increase (%)	867	1400	767
	Control (natural)		4.4	ND
	Desho + FYM + Desmodium	ND	8.4	ND
	Increase (%)	ND	91	ND
DH	Control[b]	0.6	0.6	0.6
	E + T	5.6	3.6	1.2
	Increase (%)	833	500	100

[a]Based on results of plot-level experiments and farmer field demonstrations; [b]source: Yayneshet et al. (2009). PAM, polyacrylamide; L, lime; RT, reduced tillage; RP, row planting; E, exclosure; T, trench; FYM, farmyard manure; ND, no data.

Table 4. Increase in milk yield of dairy cows fed with treated teff straw, Napier grass hay, and *Brachiaria* hybrid grass hay compared to that of cows fed with natural pasture hay (Mekuriaw et al., 2020).

Feed type	Milk yield (kg/day)	Increase (%)
Natural pasture hay (control)	1.77	0
Treated teff straw	2.34	32
Napier grass hay	2.71	53
Brachiaria hybrid grass hay	3.34	89

2.3. Improved farmers' livelihood

Promoting inclusive watershed development approaches could make a large contribution to the sustainability of program efforts. Improving the economic bases of less advantaged sections of the community (e.g., landless people, women, and young people) represents an essential precondition to improving on current gains and ensuring future positive outcomes from ongoing watershed development programs. This requires introducing economic incentives for disadvantaged groups to engage them in different income-generating activities (IGAs), such as vegetable and fruit production, livestock fattening, dairy farming, and poultry farming. To this end, two IGAs were implemented and monitored: dairy farming, involving 24 selected women/youth, at the midland agro-ecological site (Aba Gerima), and poultry farming, involving 12 selected women/youth, at the highland agro-ecological site (Guder). The estimated changes in annual income are apparent in **Figure 4**.

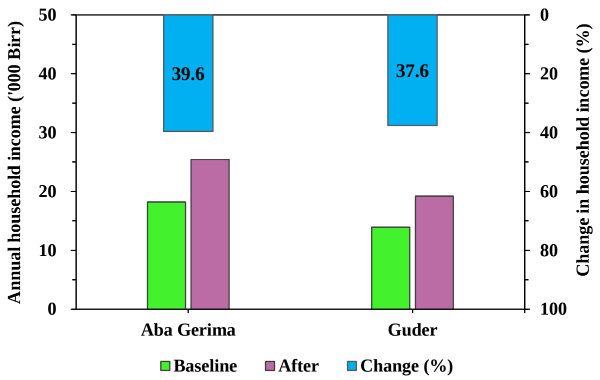

Figure 4. Change in household income after implementing income-generating activities: dairy farming at Aba Gerima (midland) and poultry farming at Guder (highland) (Nigussie et al., 2021c).

2.4. Incentivizing value-adding activities for land rehabilitation

The agroforestry system presents opportunities for small-scale farmers through providing sustainable income and creating incentives for the adoption of tree-based solutions as win-win alternatives for land restoration. For example, *Acacia decurrens* plantation systems offer various economic and non-economic benefits. These include improved crop yields through nitrogen fixation, increased organic matter and reduced soil erosion, significant cash income generation (**Table 5**), and employment opportunities.

Charcoal is the key traditional bioenergy product derived from acacia stems. Additionally, woody biomass residues (twigs, branches) could represent a significant resource with a high energy potential to serve as a feedstock for producing improved bioenergy products. This activity could bring new and upgraded bioenergy products (e.g., briquettes, pellets) to the bioenergy market while simultaneously opening new avenues of income generation and employment opportunities.

Table 5. Undiscounted cash flows and NPVs for three different investment alternatives for cultivated land (Nigussie et al., 2020).

Production system	NPV	Net cash flow	Mean net cash flow
Acacia + teff	97,884	188,154	37,631
Teff only	59,543	67,917	13,583
Acacia only	86,207	174,896	34,979

All values are ETB per ha. NPV = net present value.

3. Strategies of evaluating and disseminating SLM technologies and approaches

3.1. Stakeholder engagement and capacity building

Stakeholder engagement, from the viewpoint of SLM, is a means of involving individuals or groups in decisions and activities for developing and adopting best land use and management practices. Identifying relevant stakeholders and involving them at various stages (monitoring, evaluation, verification, and documentation) is critically important to support decision-making towards large-scale and enhanced implementation of SLM technologies and approaches. The cocreation of integrated and transferable practices is a participatory multistakeholder process to select, test, and adopt practices with farmers. Once the technology is tested at research sites and farmers' fields through the collaboration of farmers and research groups, relevant stakeholders should have a forum to share their opinions because there are many, often competing, options for SLM. Each option must be assessed and sometimes negotiated prior to implementation or referred for further testing and verification.

Stakeholders relevant to evaluating and proving SLM technologies and approaches must be determined in accordance with their importance for collaboration in achieving common goals. In the process of evaluating and implementing SLM, stakeholders that need to be involved are (1) land users, (2) agricultural advisors (experts), (3) researchers, (4) government authorities, and (5) decision makers at all levels (Schwilch et al., 2012). For example, decision makers at regional agricultural offices and research institutes play a central role in determining and approving SLM principles and actions; experts at the district level (developmental agents and extension workers) are key actors to facilitate the implementation of SLM technologies and approaches by farmers (the immediate land users).

Stakeholder workshops are imperative for proper evaluation and dissemination of SLM technologies, approaches, and tools at broader scales. To support the SLM principles and evidence contained in this brief guideline, a series of workshops have been organized involving stakeholders at different levels and institutions. The outcomes from the workshops include:

- Participatory planning and evaluation of policy tools for SLM.
- Promotion of efforts and plans for SLM within the context of nationwide principles and goals.
- Integration of activities into local to national level strategies.
- Improved collaborations for SLM at local, regional, and national levels.
- Improved approval and dissemination of best SLM practices.

Training-of-trainers (TOT) is a key strategy to build a capacity for scaling-up SLM through the main actors (extension workers and farmers). It involves detailed training of relevant experts on practical specifications of proposed SLM technologies or approaches followed by piloting at farmers' field conditions as per the user's manuals (guidebooks) developed for the purpose. TOT and farmers' demonstration can help to maximize utilization of experts and immediate land users for effective and consistent implementation of promising SLM technologies and approaches at various local contexts.

Innovative approaches for enhancing farmers' awareness and self-help capacity should be considered as a bottom-up approach to increase their willingness to adapt SLM practices. The fact is that many smallholders are still not aware of, or don't care for or don't prioritize, land protection activities, even though numerous SLM technologies/approaches have been developed for more than 40 years. Using the bottom-up approach could be an efficient way to bring about spontaneous desired behavioral changes in smallholders that can be adopted at larger scales. It should also be noted that such an approach must be developed by considering the social and economic conditions across areas.

3.2. Develop innovation platforms

In the context of SLM, developing an **innovation platform** (IP) is all about establishing an operational system that helps bring together stakeholders (key actors from various sectors, including farmers, researchers, extension workers, service providers, and policy makers) to deal with shared challenges. The system involves a network of institutions or individuals engaged in contributing new technologies, approaches, and knowledge derived from SLM studies; the system is enabled by collaboration and exchange of knowledge among diverse actors (Tukahirwa et al., 2013). For the purpose of this guideline, IP is considered to operate at four levels (**Figure 5**): farmers' research group (FRG), local (district), regional, and national. **Figure 6** illustrates the methodological framework that describes activities to facilitate decision-making for appraisal and scaling out of SLM activities through IPs. The framework can be applied by projects or programs at different levels of intervention for SLM and helps to effectively engage stakeholders at various stages (from identification to approval of best SLM practices).

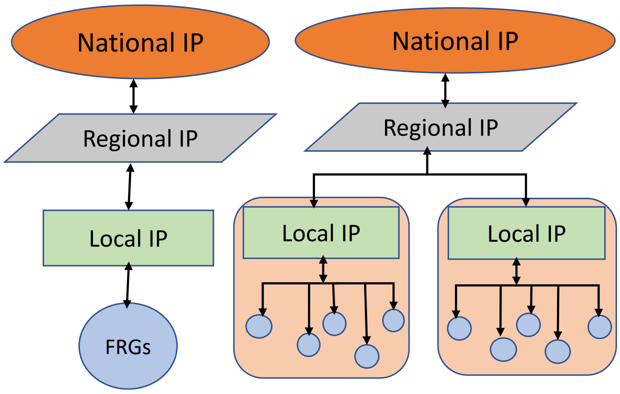

Figure 5. Schematic diagram illustrating operational innovation platforms (IPs) and flow of information across different levels in the processes of implementing, evaluating, and disseminating SLM technologies and approaches.

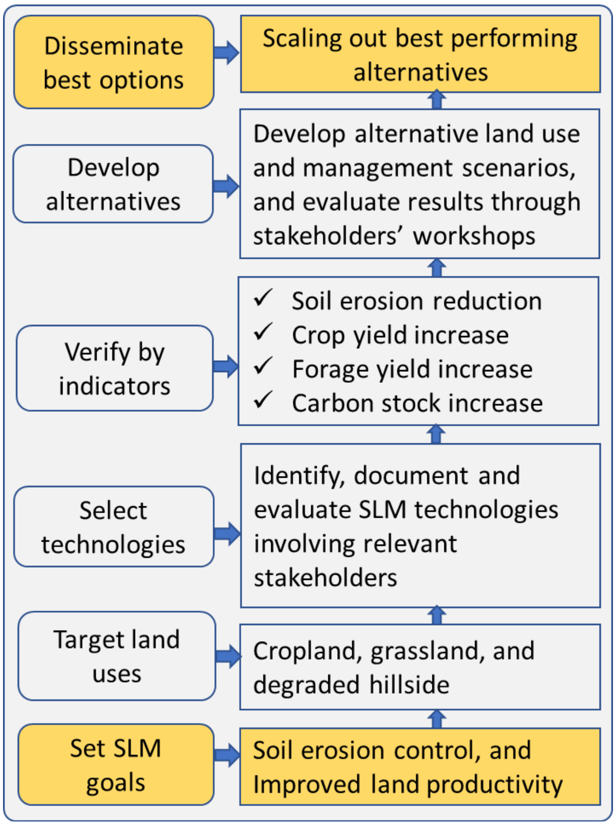

Figure 6. An integrated methodological framework for land use-based evaluation and scaling out of SLM practices to watershed management.

3.3. Develop alternative land use and management scenarios

Developing alternative land use and management scenarios is an effective approach for evaluating possible options by exploring the implications of implementing different land use and management practices at watershed to regional levels. This process involves integrating land use and management options based on land capability classification (i.e., the grouping and mapping of land units into various classes based on inherent limitations for sustainable use; it is mainly associated with soil attributes, topography, drainage, and climate) and efficiency of selected technologies verified through field plot experiments. Such an approach provides possible future land use and management options coupled with their estimated impacts on the natural environment and their economic return. The approach facilitates stakeholders' decision-making when selecting and scaling out suitable land use and management practices implementation.

The practicality of alternative land use and management scenario development for improved evaluation and adaption of integrated watershed management was demonstrated in a case study sponsored by the SATREPS-Ethiopia project by spatially modeling the impact of five proposed land use and management scenarios on changes in selected indicators (soil erosion, soil carbon stock, and land productivity) at the watershed scale in the Upper Blue Nile basin of Ethiopia (**Table 6**). Results suggest that forage development in suitable areas and implementation of SLM practices in the watershed were the best options to control soil erosion and increase SOC stock and land productivity (SCIV in **Table 6**, with an overall change of 104%).

Table 6. Estimates and changes in watershed-scale annual soil loss, SOC stock, and land productivity for alternative land use (LU) and management scenarios (SCI–V), based on results of a case study for a watershed in the midland agro-ecological zone (Fenta, 2021c).

Indicator	Scenario	Types		Change (%)	
		LU	LU + SLM	LU	LU + SLM
Soil loss (t/ha)	Baseline	101.4	–		
	SCI	101.4	34.1	0	-66.4
	SCII	68.4	19.5	-32.5	-80.8
	SCIII	27.2	11.2	-73.2	-88.9
	SCIV	17.6	4.8	-82.6	-95.2
	SCV	18.7	10.4	-81.5	-89.6
SOC stock (Mg/ha)	Baseline	33.3	–	–	–
	SCI	33.3	54.1	0	62
	SCII	43.5	62.8	30	88
	SCIII	49.7	60.5	49	82
	SCIV	41.1	62.4	41	87
	SCV	58.4	73.3	75	120
Productivity (Birr/ha)	Baseline	28,079	–	–	–
	SCI	27,636	44,851	-2	60
	SCII	22,111	39,270	-21	40
	SCIII	44,803	54,780	60	95
	SCIV	26,617	57,278	-5	104
	SCV	21,421	38,114	-23	36

Baseline, existing conventional/farmers' practices; **SCI,** current land use + SLM practices; **SCII,** no crop cultivation on steep slopes (>30%) + SLM practices; **SCIII**, plantation on suitable areas + SML practices; **SCIV,** forage development on suitable areas + SLM practices; **SV,** reforestation of communal lands and hilly croplands + SLM practices.

4. Policy recommendations for improved adoption of SLM

- **Need for a transdisciplinary framework:** It is essential to develop a national or regional level framework aimed at bridging the science–policy–development divide by integrating coevolving local and scientific knowledge and including multiple stakeholder perspectives in the development and dissemination of SLM practices.
- **Improve farmers' awareness and support:** Development of improved strategies that facilitate awareness of smallholder farmers and access to inputs/services (demonstrations, assistance from appropriate experts, finance, and credit) is needed for effective adoption of SLM technologies and approaches at the grassroots level.
- **Need to develop alternative SLM options:** Offering alternative land use and management options (pro-ecological, pro-economic, or a combination of the two) is essential for suitable implementation of SLM technologies and approaches, considering differences in biophysical and social settings at watershed to basin and regional scales.
- **Getting accessible findings into the hands of policy makers in understandable language:** Engagement between researchers and policy makers from the early phases of policy design can certainly help overcome communication barriers. There is a strong need to take specific measures to help with issues of translation. Research results need to be communicated in plain, simple, and straightforward local as well as international languages.
- **Need for participatory and integrated implementation of SLM technologies and approaches:** In addition to implementing SLM through community campaigns for a specific period or for the purpose of obtaining scientific evidence, an evidence-based policy is required that addresses the needs for the efficient and suitable functioning of activities (e.g., monitoring and evaluation, service provision, etc.) to achieve sustainability.
- **Improved market linkage and access:** In addition to providing credit and extension services, improving the linkage and access to reliable markets for inputs and products can play an important role in enhancing the adoption and sustainability of promising land use and management practices by individuals and groups.
- **Proper intervention and exit strategies for SLM projects:** SLM project interventions in a certain geographical area should be based on a multistakeholder evaluation of common goals and possible areas of collaboration with existing projects. Prior to intervention, current environmental and socioeconomic conditions must be assessed and documented to help successfully plan and implement suitable activities. The termination of SLM projects should always be based on best exit strategies that can ensure the project results will remain to benefit targeted beneficiaries after the project is completed. Thus, the exit strategy of a given project must be considered during the planning, implementation, monitoring, and evaluation processes.
- **Associate SLM implementation with social and religious institutions:** The principles and implementation of promising SLM practices should be thoroughly supported or associated with social, cultural, and religious institutions/activities through which the local community is governed by a set of bylaws and dedicated to shared responsibilities.
- **Conduct ex-post evaluation:** Ex-post evaluations are generally conducted for three years after project completion, with an emphasis on the effectiveness and sustainability of the project. This evaluation aims at deriving lessons learned and recommendations to improve the project as well as to help plan and implement more effective and efficient projects.
- **Harmonization of SLM monitoring and assessment tools in a database:** A central database on implemented SLM practices by various stakeholders, including those developed by researchers, is necessary for upscaling suitable SLM technologies and approaches, particularly when considering variations in socioeconomic and environmental settings within and across regions.

Acknowledgments

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Bibliography

Abebe, G., Tsunekawa, A., Haregeweyn, N., Takeshi, T., Wondie, M., Adgo, E., Masunaga, T., Tsubo, M., Ebabu, K., Berihun, M.L., Tassew, A., 2020. Effects of land use and topographic position on soil organic carbon and total nitrogen stocks in different agro-ecosystems of the Upper Blue Nile Basin. *Sustainability*, *12*(6), 2425.

Abebe, G., Tsunekawa, A., Haregeweyn, N., Taniguchi, T., Wondie, M., Adgo, E., Masunaga, T., Tsubo, M., Ebabu, K., Mamedov, A. and Meshesha, D.T., 2020. Effect of Soil Microbiome from Church Forest in the Northwest Ethiopian Highlands on the Growth of Olea europaea and Albizia gummifera Seedlings under Glasshouse Conditions. *Sustainability*, *12*(12), 4976.

Abouelhamd, I., 2020. Analytical study of the relation between the Sustainable land management indicators (SLM) and the Sustainable Development Goals (SDGs).

Alemu, G.T., Tsunekawa, A., Haregeweyn, N., Nigussie, Z., Tsubo, M., Elias, A., Ayalew, Z., Berihun, D., Adgo, E., Meshesha, D.T., Molla, D., 2021. Smallholder farmers' willingness to pay for sustainable land management practices in the Upper Blue Nile basin, Ethiopia. *Environ. Dev. Sustain. 23*(4), 5640–5665.

Assefa W., 2020. Value chain analysis of *Acacia decurrens* -based charcoal: The Case of Fagita-Lekoma District, North-Western Ethiopia. MSc thesis, Bahir Dar University, Ethiopia.

Barbier, E. B., Di Falco, S., 2021. Rural populations, land degradation, and living standards in developing countries. *Rev. Environ. Econ. Policy*, *15*(1), 115–133.

Bayable, M., Tsunekawa, A., Haregeweyn, N., Ishii, T., Alemayehu, G., Tsubo, M., Adgo, E., Tassew, A., Tsuji, W., Asaregew, F., Masunaga, T., 2020. Biomechanical properties and agro-morphological traits for improved lodging resistance in Ethiopian teff (*Eragrostis tef* (Zucc.) Trottor) accessions. *Agronomy*, *10*(7), 1012.

Bayable, M., Tsunekawa, A., Haregeweyn, N., Alemayehu, G., Tsuji, W., Tsubo, M., Adgo, E., Tassew, A., Ishii, T., Asaregew, F., Masunaga, T., 2021. Yield Potential and Variability of Teff (Eragrostis tef (Zucc.) Trotter) Germplasms under Intensive and Conventional Management Conditions. *Agronomy*, *11*(2), 220.

Berihun, M.L., Tsunekawa, A., Haregeweyn, N., Meshesha, D.T., Adgo, E., Tsubo, M., Masunaga, T., Fenta, A.A., Sultan, D., Yibeltal, M., 2019a. Exploring land use/land cover changes, drivers and their implications in contrasting agro-ecological environments of Ethiopia. Land Use Policy 87, 104052.

Berihun, M.L., Tsunekawa, A., Haregeweyn, N., Meshesha, D.T., Adgo, E., Tsubo, M., Masunaga, T., Fenta, A.A., Sultan, D., Yibeltal, M., Ebabu, K., 2019b. Hydrological responses to land use/land cover change and climate variability in contrasting agroecological environments of the upper Blue Nile basin, Ethiopia. Sci. Total Environ. 689, 347‑365.

Berihun, M.L., Tsunekawa, A., Haregeweyn, N., Dile, Y.T., Tsubo, M., Fenta, A.A., Meshesha, D.T., Ebabu, K., Sultan, D., Srinivasan, R., 2020. Evaluating runoff and sediment responses to soil and water conservation practices by employing alternative modeling approaches. *Sci.Total Environ. 747*,141118.

Berihun, M. L., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Fenta, A. A., 2021. Changes in ecosystem service values strongly influenced by human activities in contrasting agro-ecological environments. *Ecol. Process. 10*(1), 1–18.

de Vente J, Bautista S, Orr B: Preface: optimizing science impact for effective implementation of sustainable land management. J. Environ. Manage. 2017, 195:1–3.

Ebabu, K., Tsunekawa, A., Haregeweyn, N., Adgo, E., Meshesha, D.T., Aklog, D., Masunaga, T., Tsubo, M., Sultan, D., Fenta, A.A., Yibeltal, M., 2019. Effects of land use and sustainable land management practices on runoff and soil loss in the Upper Blue Nile basin, Ethiopia. Sci. Total Environ. 2019, 648, 1462–1475.

Ebabu, K., Tsunekawa, A., Haregeweyn, N., Adgo, E., Meshesha, D.T., Aklog, D., Masunaga, T., Tsubo, M., Sultan, D., Fenta, A.A., Yibeltal, M., 2020. Exploring the variability of soil properties as influenced by land use and management practices: A case study in the Upper Blue Nile basin, Ethiopia. Soil Till. Res. 200, 104614.

Ebabu, K., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Adgo, E., Fenta, A.A., Meshesha, D.T., Berihun M.L., Sultan, D., Vanmaercke, M., Panagos, P., Borrelli, P., Langendoen, E.J., Poesen, j., 2021. Global analysis of cover management and support practice factors that control soil erosion and conservation. Paper accepted in Int. Soil Water Conserv. Res.

FAO, 2009. Country Support Tool for Scaling-up Sustainable Land Management in Sub-Saharan Africa. Field Application TerrAfrica Partnership, TM Design Inc.

Fenta, A.A., Tsunekawa, A., Haregeweyn, N., Poesen, J., Tsubo, M., Borrelli, P., Panagos, P., Vanmaercke,M., Broeckx, J., Yasuda, H., Kawai, T., Kurosaki, Y., 2020. Land susceptibility to water and wind erosion risks in the East Africa region. Sci. Total Environ. 703,135016.

Fenta, A.A., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Yasuda, H., Shimizu, K., Kawai, T., Ebabu, K., Berihun, M.L., Sultan, D., Belay A.S., 2021a. Cropland expansion outweighs the monetary effect of declining natural vegetation on ecosystem services in sub-Saharan Africa. Ecosyst. Serv. 45,101154

Fenta, A. A., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Yasuda, H., Kawai, T., Ebabu, K., Berihun, M.L., Belay A.S., Sultan, D., 2021b. Agroecology-based soil erosion assessment for better conservation planning in Ethiopian river basins. *Environ.Res. 195*, 110786.

Fenta, A. A., 2021c. A novel integrated framework to evaluate impacts of alternative land use and management scenarios on ecosystem services. *Paper in preparation*.

Kebede, B., Tsunekawa, A., Haregeweyn, N., Mamedov, A.I., Tsubo, M., Fenta, A.A., Meshesha, D.T., Masunaga, T., Adgo, E., Abebe, G. and Berihun, M.L., 2020. Effectiveness of polyacrylamide in reducing runoff and soil loss under consecutive rainfall storms. *Sustainability*, *12*(4), 1597.

Kebede, B., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Mulualem, T., Mamedov, A. I., Meshesha, D.T., Adgo, E., Fenta, A. A., Ebabu, K., Masunaga, T., 2021. Effect of Polyacrylamide integrated with other soil amendments on runoff and soil loss: case study from Northwest Ethiopia. Paper accepted in Int. Soil Water Conserv. Res.

Haregeweyn N. 2021a. Progress and challenges in sustainable land management initiatives: A global review, Paper in preparation.

Haregeweyn, N., 2021b. A transdisciplinary approach to bridge the sustainable land management science–policy–development potential gaps: A global review, Paper in preparation.

Liniger, H., Harari, N., van Lynden, G., Fleiner, R., de Leeuw, J., Bai, Z., Critchley, W., 2019. Achieving land degradation neutrality: The role of SLM knowledge in evidence-based decision-making. *Environ. Sci. Policy*, *94*, 123–134.

Mekuriaw, S., Tsunekawa, A., Ichinohe, T., Tegegne, F., Haregeweyn, N., Nobuyuki, K., Tassew, A., Mekuriaw, Y., Walie, M., Tsubo, M., Okuro, T., 2019. Mitigating the anti-nutritional effect of polyphenols on in vitro digestibility and fermentation characteristics of browse species in north-western Ethiopia. *Tropical animal health and production*, pp.1–12.

Mekuriaw, S., Tsunekawa, A., Ichinohe, T., Tegegne, F., Haregeweyn, N., Kobayashi, N., Tassew, A., Mekuriaw, Y., Walie, M., Tsubo, M., Okuro, T., 2020. Effect of Feeding Improved Grass Hays and Eragrostis tef Straw Silage on Milk Yield, Nitrogen Utilization, and Methane Emission of Lactating Fogera Dairy Cows in Ethiopia. *Animals*, *10*(6), 1021.

Mihretie, F.A., Tsunekawa, A., Haregeweyn, N., Adgo, E., Tsubo, M., Masunaga, T., Meshesha, D.T., Tsuji, W., Ebabu, K., Tassew, A., 2021a. Tillage and sowing options for enhancing productivity and profitability of teff in a sub-tropical highland environment. *Field Crops Res. 263*,108050.

Mihretie, F.A., Tsunekawa, A., Haregeweyn, N., Adgo, E., Tsubo, M., Ebabu, K., Masunaga, T., Kebede, B., Meshesha, D.T., Tsuji, W., Bayable, M., Berihun, M. L., 2021b. Tillage and crop management impacts on soil loss and crop yields in northwestern Ethiopia. *Int. Soil Water Conserv. Res.2021*.

Mihretie, F.A., Tsunekawa, A., Haregeweyn, N., Adgo, E., Tsubo, M., Masunaga, T., Meshesha, D.T., Ebabu, K., Bayable, M., 2021c. Agro-Economic Evaluation of Alternative Crop Management Options for Teff Production in Midland Agro-Ecology, Ethiopia. *Agriculture*, *11*(4), 298.

Mulualem, T., Adgo, E., Meshesha, D.T., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Kebede, B., Mamedov, A.I., Masunaga, T. and Berihun, M.L., 2021a. Examining the Impact of Polyacrylamide and Other Soil Amendments on Soil Fertility and Crop Yield in Contrasting Agroecological Environments. *J. Soil Sci. Plant Nutr.* 1−14.

Mulualem, T., Adgo, E., Meshesha, D.T., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Ebabu, K., Kebede, B., Berihun, M.L., Walie, M. and Mekuriaw, S., 2021b. Exploring the variability of soil nutrient outflows as influenced by land use and management practices in contrasting agro-ecological environments. *Sci. Total Environ. 786*, 147450.

Mossie, M., Gerezgiher, A., Ayalew, Z., Nigussie, Z., 2021. Welfare effects of small-scale farmers' participation in apple and mango value chains in Ethiopia. *Agrekon*, 1–17.

Nigussie, Z., Tsunekawa, A., Haregeweyn, N., Adgo, E., Cochrane, L., Floquet, A., Abele, S., 2018. Applying Ostrom’s institutional analysis and development framework to soil and water conservation activities in north-western Ethiopia. *Land use policy*, *71*, 1-10.

Nigussie, Z., Tsunekawa, A., Haregeweyn, N., Adgo, E., Tsubo, M., Ayalew, Z., Abele, S., 2020. Economic and financial sustainability of an *Acacia decurrens*-based Taungya system for farmers in the Upper Blue Nile Basin, Ethiopia. *Land Use Policy*, *90*, 104331.

Nigussie, Z., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Adgo, E., Ayalew, Z., Abele, S., 2021a. The impacts of *Acacia decurrens* plantations on livelihoods in rural Ethiopia. *Land Use Policy*, *100*, 104928.

Nigussie, Z., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Adgo, E., Ayalew, Z. and Abele, S., 2021b. Small-Scale Woodlot Growers’ Interest in Participating in Bioenergy Market In Rural Ethiopia. *Environ. Manage. 68*(4), 553–565.

Nigussie, Z., 2021c. Effects of engaging poor framers in livelihood improvement activities in enhancing household welfare: Paper in preparation.

Schwilch, G., Bachmann, F., de Graaff, J., 2012. Decision support for selecting SLM technologies with stakeholders. Appl. Geogr. 34, 86−98.

Smyth, A.J. and Dumanski, J. 1993. FESLM: An international framework for evaluating sustainable land management. A discussion paper. World Soil Resources Report 73. Food & Agriculture Organization, Rome, Italy. 74 pp.

Taddese, G., 2001. Land degradation: a challenge to Ethiopia. *Environ. Manage. 27*(6), 815−824.

Teshager Abeje, M., Tsunekawa, A., Adgo, E., Haregeweyn, N., Nigussie, Z., Ayalew, Z., Elias, A., Molla, D., Berihun, D., 2019. Exploring drivers of livelihood diversification and its effect on adoption of sustainable land management practices in the Upper Blue Nile Basin, Ethiopia. *Sustainability*, *11*(10), 2991.

Tukahirwa J, M.B., Tenywa M., Kakuru W., Kamugisha R., Nampala, M.P., 2013. Establishing Functional Innovation Platforms for Scaling Sustainable Land Management. Handbook for Facilitators. ICRAF Publications Series.

Walie, M., Tegegne F., Mekuriaw, Y., Atsushi Tsunekawa, A., Kobayashi, N., Ichinohe, T., Haregeweyn, N., Tassew, T., Mekuriaw,S., Masunaga T., Okuro, T., Tsubo, M., Derege Tsegaye Meshesha, D.T., Adgo, E., Mulualem, T., 2021a. Biomass yield and nutritional value of Grazing land as influenced by farmyard manure and enrichment plantation with forage grasses in North Western, Ethiopia. Paper under review in Trop. Grassl.

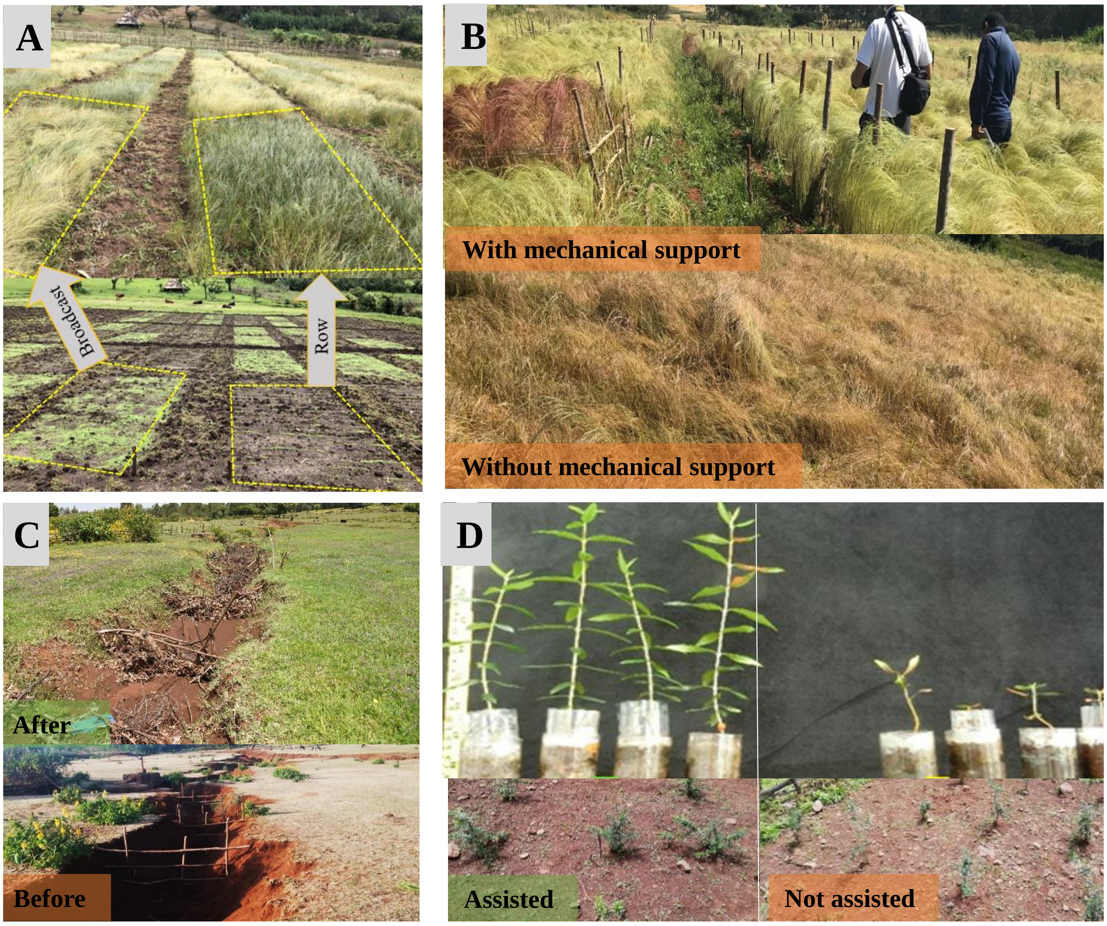
Walie, M., Tegegne, F., Mekuriawa, Y., Tsunekawac, A., Kobayashic, N., Ichinohed, T., Haregeweyne, T., Tassew, A., Masunaga, T., Okuro, T., Tsubo, M., Mekuriaw, S., Meshesha, D.T., Adgo, E., 2021b. Effects of farmyard manure and desmodium intercropping on growth and yield of forage grasses in contrasting two agro-ecologies of the Upper Blue Nile basin, Ethiopia. Paper under review Afr. J. Range Forage Sci.

Yayneshet, T., Eik, L. O., Moe, S. R., 2009. The effects of exclosures in restoring degraded semi-arid vegetation in communal grazing lands in northern Ethiopia. J. Arid Environ. 73 (4−5), 542−549.

Annexes

Annex 1: Seven of the 17 UN SDGs with one or more targets that are directly or indirectly related to aims of the SATREPS–Ethiopia Project: "Development of a Next-Generation Sustainable Land Management (SLM) Framework to Combat Desertification in Ethiopia".

Annex 2: Photos of selected SLM technologies evaluated by the SATREPS–Ethiopia project: (A) row planting and (B) lodging control for teff cultivation; (C) exclosure + check dams for gully rehabilitation in communal grasslands; and (D) microbial assisted seedling development for degraded lands.



Annex 3: List of proposed SLM technologies and their importance by land use type and impacts on key indicators; details are available in the user's manuals (in progress).

No.	Type of SLM technologies	Suitable land use type		Impact level on key indicators											
		Most suitable	Less suitable	Moisture conservation			Soil conservation			Improve land productivity			Improve livelihood		
				CL	GL	DH	CL	GL	DH	CL	GL	DH	CL	GL	DH
1	Soil bunds + grass	CL	GL	++	++	na	+++	+++	na	++	++	na	++	++	na
2	PAM + lime	CL		++	na	na	+++	na	na	++	na	na	++	na	na
3	Reduced tillage for teff	CL		++	na	na	++	na	na	++	na	na	++	na	na
4	Row planting for teff	CL		++	na	na	na	na	na	++	na	na	++	++	++
5	Irrigation for winter teff	CL		na	na	na	na	na	na	+++	na	na	+++	na	na
6	Teff lodging control	CL		na	na	na	na	na	na	++	na	na	++	na	na
7	Cover crops	CL		++	na	na	+++	na	na	++	na	na	++	na	na
8	Exclosure	GL, DH	CL	na	++	++	na	+++	+++	na	+++	+++	na	-/+	-/+
9	Stall-feeding	GL, DH	CL	++	+++	+++	++	+++	+++	++	+++	+++	++	+++	+++
10	Improved forage development	GL, CL	DH	+++	+++	++	+++	+++	++	+++	+++	+++	+++	+++	++
11	Exclosure + trenches	DH, GL	CL	na	+++	+++	na	+++	+++	na	+++	+++	na	-/+	-/+
12	Assisted seedling establishment	DH	GL	na	na	na	na	na	na	+++	+++	+++	na	na	na
13	*Acacia decurrens* plantation	All		+	+	+	++	++	++	+++	+++	+++	+++	+++	+++

CL: cropland; GL: grazing land; DH: degraded hillsides; -: negative; +: slightly positive; ++: positive; +++: very positive; -/+: neutral; na: not applicable.

Annex 4: List of proposed SLM approaches and their suitability by land use type and main objectives; details are available in the user's manuals (in progress).

No.	Type of SLM approaches		Suitable land use type	SLM objectives to be addressed			
				Moisture conservation	Soil conservation	Improve land productivity	Improve livelihood
1	Community-based participatory gully rehabilitation		CL, GL, DH	✓	✓	✓	✓
2	Developing alternative future land use and management scenarios		CL, GL, DH	✓	✓	✓	✓
3	Developing income-generating activities	3.1. Dairy farming	CL, GL, DH	na	na	✓	✓
		3.2. Poultry farming	Homestead	na	na	✓	✓
4	Facilitating SLM adoption by local farmers		CL, GL, DH	✓	✓	✓	✓

CL: cropland; GL: grazing land; DH: degraded hillsides; na: not applicable.