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Evidence Based Guideline for Implementing Sustainable Land Management (SLM) Technologies and Approaches

SATREPS-Ethiopia Project (2023)

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A Tool for Supporting the Implementation of Best SLM Practices Based on Research Results of the SATREPS (Science and Technology Research Partnership for Sustainable Development) – Ethiopia Project:

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

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Science and Technology Research Partnership for Sustainable Development (SATREPS)–Ethiopia Project

Evidence Based Guideline for Implementing Sustainable Land Management (SLM) Technologies and Approaches

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Cover photos

Left top: Soil bunds combined with grass strips substantially reduced both runoff and soil loss from cropland in the lowland agroecological zone of the Abay basin of Ethiopia; the trenches covered with plastic sheet were installed to monitor runoff and soil loss (photo by Prof. Atsushi Tsunekawa).

Left bottom: Napier grass integrated with Desmodium improved backyard forage production in the midland agroecological zone of the Abay basin of Ethiopia (photo by Dr. Kindiye Ebabu).

Right: Degraded hillsides rehabilitated following the implementation of soil and water conservation measures such as terracing and use of exclosures in the midland agroecological zone of the Abay basin of Ethiopia (photo by Mr. Anteneh Wubet).

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Water & Land Resource Centre Addis Ababa University	Shimane University

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Preface

This guideline was produced by the SATREPS-Ethiopia Project, which was jointly funded by the Japan International Cooperation Agency (JICA) and the Japan Science and Technology Agency (JST). It has been the flagship project of Bahir Dar University and ARARI (the Amhara Agricultural Research Institute) and has contributed greatly to capacity building, research, and development activities. The project identified a list of potential sustainable land management (SLM) technologies and evaluated their impact in reducing soil erosion and improving the productivity of three target land-use types (cropland, grassland, and degraded hillside). In addition to evaluations based on laboratory and plot experiments of specific SLM technologies, four approaches were developed and evaluated to support the large-scale implementation of best SLM practices. Best SLM technologies and approaches were then proposed on the basis of a comprehensive evaluation matrix containing multi-decision support criteria, including impacts on key ecological and socioeconomic indicators such as soil and water conservation and improvement of land productivity and livelihood.

Documenting proven best technologies and approaches should help to provide suitable information for relevant stakeholders who are engaged in developing and disseminating SLM practices. This guideline is therefore based on evidence produced through research and piloting activities, targeting mainly district level experts and farmers as immediate users. The scope and contents of the document have been evaluated through a series of consultative and stakeholder meetings. The guideline will help users in the sustainable use and management of land and water resources, while also improving the livelihoods of rural households in Ethiopia.

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Principal investigator of the SATREPS-Ethiopia Project
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Foreword

Land degradation caused by detrimental natural and human activities has been recognized as a major cause of the loss of ecosystem services in landscapes worldwide. This is particularly important in developing regions such as Ethiopia, where improper practices greatly threaten land productivity and food security. Several initiatives and programs have attempted to promote sustainable land management (SLM) practices with the goal of improving land productivity and achieving sustainable livelihoods. Nevertheless, little has been done to validate and document best practices and approaches through participatory and field-based research activities; moreover, the main actors in land management, such as district-level experts and farmers still lack appropriate information on environmentally sound, socially equitable, and economically viable SLM practices.

The aim of this guideline is therefore to provide a practical guide that can support and facilitate the implementation of promising SLM practices in different environmental settings of Ethiopia. The guideline provides procedures and illustrations for applying SLM technologies and approaches that can best improve land productivity and ensure sustainable livelihoods. The guideline was created for different SLM technologies, the effectiveness of which was evaluated and verified through laboratory and field-plot experimentation in three contrasting agroecological (highland, midland, and lowland) environments of the Abay basin of Ethiopia.

Many stakeholders have been involved at various stages (planning, monitoring, evaluation, and validation) of the creation of this guideline. Therefore, we strongly believe that the information it contains will substantially support existing knowledge and efforts to implement SLM at wider geographical scales.

Almaz Giziew (Dr.)
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Amhara Bureau of Agriculture, Ethiopia

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This guideline was prepared with financial support from the Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA). To provide a suitable knowledge tool for SLM, the guideline was developed through the proactive involvement of stakeholders and researchers with different areas of expertise from different partner institutions in Japan (Tottori University, The University of Tokyo, Shimane University) and Ethiopia (Bahir Dar University and Amhara Region Agricultural Research Institute).

The authors gratefully acknowledge the valuable inputs, support, and guidance received from stakeholders in Ethiopia (Amhara Bureau of Agriculture, Ministry of Agriculture, National Sustainable Land Management Programme, and Water and Land Resource Center of Addis Ababa University).

The ALRC (Arid Land Research Center) of Tottori University provided a safe and productive working environment for the researchers who contributed to this guideline, despite the challenges created by the COVID-19 pandemic. The authors also express great appreciation to the research assistants (Anteneh Wubet and Nigus Tadesse) of the SATREPS-Ethiopia project for the facilitation of research works and review workshops, as well as to the community members and target farmers of the three sites (Aba Gerima, Guder, and Dibatie) where research activities were conducted to evaluate and validate the SLM technologies and approaches included in this guideline.

Abbreviations/acronyms

ALRC	Arid Land Research Center
ARARI	Amhara Region Agricultural Research Institute
CL	Cropland
DA	Developmental agent
DH	Degraded hillsides
ETB	Ethiopian Birr
GL	Grassland
HI	Horizontal interval
HL	Highland
JICA	Japan International Cooperation Agency
JST	Japan Science and Technology Agency
LL	Lowland
ML	Midland
NPS	Nitrogen–phosphate–sulfur
PAM	Polyacrylamide
PD	Person-day
SBA	Soil bunds alone
SBG	Soil bunds with grass
SATREPS	Science and Technology Research Partnership for Sustainable Development
SHEP	Smallholder Horticulture Empowerment and Promotion
SLM	Sustainable land management
SLMP	Sustainable Land Management Programme
SWAT	Soil and water assessment tool
SWC	Soil and water conservation
VI	Vertical interval
WOCAT	World Overview of Conservation Approaches and Technologies

1. Introduction

1.1. Overview

Land degradation due to soil erosion by water is recognized as a major environmental problem in Ethiopia. Despite the implementation of different soil and water conservation interventions over the last decades, preventing land degradation, restoring degraded lands, and promoting sustainable use of terrestrial ecosystems remain major challenges for land managers, particularly in the highlands (Tadesse, 2001). The rapid depletion of ecosystem services associated with the increase in population pressure requires suitable countermeasures to protect, restore, and sustainably manage land and water resources. Proper planning and implementation of effective land management practices and approaches are essential to halt the detrimental effects of anthropogenic and natural factors on the functioning of natural ecosystems. This is particularly important in the Abay basin, where the livelihood of much of the population is essentially dependent on crop and livestock production using traditional practices that can cause severe land degradation.

In Ethiopia, sustainable land management (SLM) programs have been undertaken with the goal of reducing land degradation and improving land and livestock productivity and livelihoods. A tremendous number of SLM technologies and approaches have been introduced and implemented over the past several decades. Dissemination of these approaches for large-scale implementation, however, has mostly been done without well-defined guidelines, context-based practical details, and research-based evidence about the technologies and approaches. Furthermore, the adoption of some of the promising technologies by the immediate land users (farmers) has been very limited, mainly because of a lack of proper demonstration and validation. A lack of approaches that could allow the proactive involvement of relevant stakeholders and immediate actors in the development and dissemination of SLM technologies has also been recognized as a bottleneck in the effective adoption of best-performing SLM practices.

In addition to lack of knowledge among land users, some of the existing SLM guidelines and manuals for extension agents in Ethiopia have been adopted from abroad, and the approaches may not work well in the local contexts. A lack of research-based evidence and low levels of participation of relevant stakeholders in the development of SLM guidelines/manuals have also been reported as two important reasons for the failure or unsatisfactory adoption rates of promising SLM practices (Adimassu et al., 2016; Alemu et al., 2021).

This guideline, therefore, was developed by engaging relevant stakeholders at different levels (farmers to policy makers) and researchers and experts from various disciplines (e.g., crop production, livestock management, forestry/agroforestry, hydrology, irrigation, socioeconomics, soil and water conservation, watershed management) to ensure integrated and comprehensive evaluation and documentation of the best SLM technologies and approaches. To support and improve the existing knowledge and efforts towards achieving reduced land degradation, as well as improved land productivity and livelihoods, the necessary details and scientific evidence are provided for 13 selected SLM technologies. Evidence and remarks presented in this guideline are based on the results of laboratory and field-plot experiments of the technologies on three major land-use types (seven technologies on croplands, three on grasslands, two on degraded hillsides, and one for all three land-use types). This guideline also provides descriptions and evidence of four approaches developed to support the appropriate implementation of, and participation in, SLM at the watershed to larger spatial scales. The four approaches are (1) community-based participatory gully rehabilitation, (2) alternative future land-use and management scenarios, (3) SLM-based livelihood improvement activities, and (4) facilitation of farmers' adoption of SLM practices (technologies and approaches).

1.2. Purpose of the guideline

This guideline is intended to support future endeavors to implement improved SLM technologies and approaches in the Abay basin of the Amhara region, as well as in other regions of Ethiopia with similar environmental and socioeconomic settings. The aims of the descriptions and illustrations provided here are to visualize proposed SLM technologies and approaches and to demonstrate their impact in mitigating degradation and improving the productivity of three major land-use types (cropland, grassland, and degraded hillside). Homestead-based income-generating activities (backyard forage production and dairy/poultry farming) are also presented in relation to their contributions to SLM. The guideline particularly provides land-use-specific descriptions of SLM technologies and approaches that have been verified by multidisciplinary research performed in three different agroecological zones (lowland, midland, and highland) of the Abay basin of Ethiopia (**Figure 1**).

Overall, the information contained here is meant to support the appropriate implementation of SLM technologies and approaches that can help sustainable use and management of land and water resources and improve the incomes of rural households. The guideline also provides users with information about the ecological and socioeconomic impacts of proposed SLM technologies based on the results of case studies at three sites (Aba Gerima, Guder, and Dibatie; see **Figure 1**) representing three agroecological zones of Ethiopia (Hurni et al., 2016; Fenta et al., 2021b). The three agroecological zones are as follows: (1) lowland (*Kolla*) areas characterized by an elevation range of 500–1500 m above sea level (a.s.l.) and mean annual precipitation of < 900 mm; (2) midland (*Weyna Dega*) areas with an elevation of 1500–2300 m a.s.l. and mean annual precipitation of 900–1400 mm; and (3) highland (*Dega*) areas with an elevation of 2300–3200 m a.s.l. and mean annual precipitation of ≥1400 mm (**Figure 1**).

1.3. Target users of the guideline

The guideline was produced to target district- to *kebele (*small administrative unit*)* level experts and farmers, who are the immediate actors in the implementation of SLM technologies and approaches. The research-based evidence presented for selected technologies and approaches can also support higher level experts and policy- or decision-makers who are engaged in planning and scaling up of SLM practices. In general, this guideline will serve as a useful tool for agroecosystem-based implementation of SLM practices in the Abay basin of the Amhara region and beyond. The guideline is being presented in two languages (English and Amharic) to support its wider dissemination and easier applicability by experts and other stakeholders from different backgrounds.

1.4. Procedures followed to produce this guideline

The guideline was prepared by involving different stakeholders, researchers, and experts from various disciplines. The technical inputs and evidence used to develop the guideline were based on research activities supported by the SATREPS-Ethiopia Project (2017–2022). A total of 43 technologies and four approaches were investigated for their impacts on ecological and socioeconomic indicators; 13 technologies and all four approaches were selected and demonstrated with the involvement of relevant researchers and stakeholders. By using the WOCAT approach (https://explorer.wocat.net), a comprehensive evaluation matrix (**Annex 6)** was developed to document the necessary data obtained by laboratory or field-plot experiments and household surveys for the selected SLM technologies and approaches. The data from the matrix were then compiled and presented for use here as scientific evidence. The draft versions of the guideline were reviewed in a series of stakeholder meetings and editorial workshops and revised by a prominent expert (Lakew Desta) in SLM guideline development in Ethiopia. The final version was then edited in English, translated to Amharic (the local language), and endorsed by the relevant authorities for publication. **Figure 2** presents the steps involved in the development of the guideline: (1) planning and identification, (2) testing and verification by research, and (3) development of guidelines for the selected technologies or approaches, targeting suitable users.

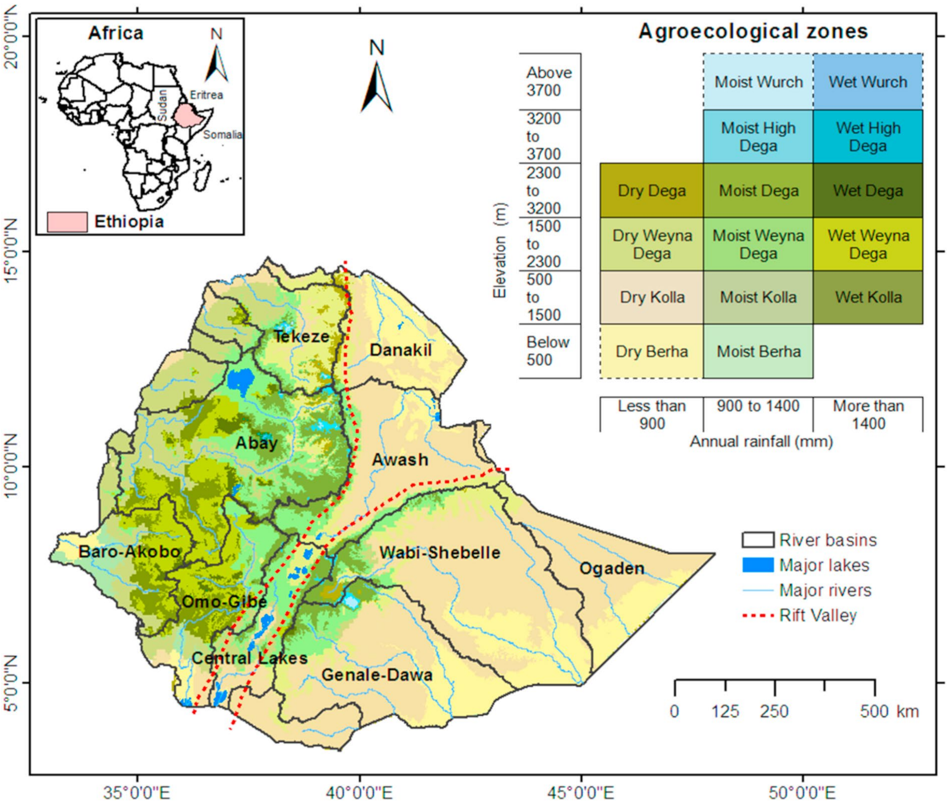

Figure 1. Map of major river basins and different agroecological zones of Ethiopia; Figure from Fenta et al. (2021b). Berha = warm, arid lowlands; Kolla = warm, semiarid lowlands, Weyna Dega = cool, humid highlands; Dega = temperate cool sub-humid highlands; Wurch = cold highlands (Fenta et al., 2021b)

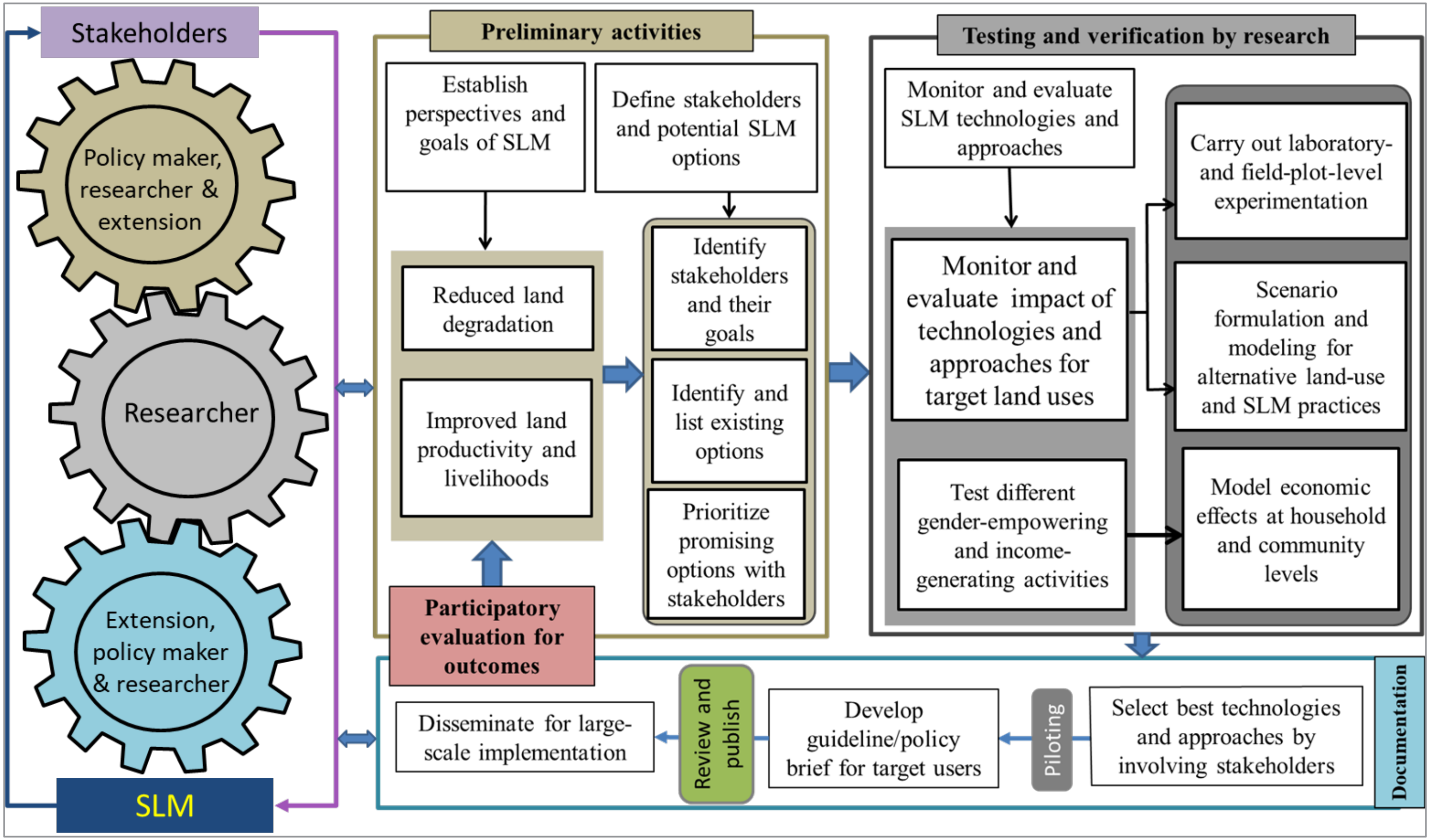

Figure 2. Overview of the procedures for developing the guideline: evaluation and documentation of selected SLM technologies and approaches with the involvement of relevant stakeholders at different stages (identification, testing, and documentation)

2. Land-use-based description of selected SLM technologies

2.1. SLM technologies for cropland

2.1.1. Soil bunds reinforced with forage grass or legumes

Description

A soil bund is an embankment of soil built along the land contour to control soil erosion by reducing the slope length and velocity of overland flow (Dehn, 1995). It is one of the most widely implemented physical soil and water conservation (SWC) measures for croplands in Ethiopia up to a slope steepness of 50% (Hurni et al., 2016). Reinforcing soil bunds with forage grass or legumes can substantially improve the efficiency of controlling runoff and soil loss as the grass or legume stabilizes the bunds and provides protection against raindrop impact (Herweg and Lud,1999; Amare et al., 2014; Ebabu et al., 2019). In addition, it offers other benefits, such as reduction of maintenance costs, provision of animal forage, and compensation for land loss by the bund structures. Different forage grass or /legume species, including Desho grass (*Pennisetum pedicellatum*), elephant grass (*Pennisetum purpureum*), vetiver grass (*Chrysopogon zizanioides*), tree lucerne *(Cytisus proliferus),* and sesban (*Sesbania sesban*), can be used to stabilize soil bunds, depending on the biophysical conditions of the target areas.

The layout and spacing of soil bunds can depend on several factors, including the purpose, slope, soil type, and rainfall. Bunds can be level for moisture stressed areas and graded (1% gradient) in high rainfall areas. As a rule of thumb, the vertical interval between two bunds is 1 m for slopes less than 15%, but it can be 2.5 times the soil depth for steeper slopes (Hurni et al., 2016). A case study in the midland agroecological zone (Demissie et al., 2022a) found that 12.7 m can be taken as an optimal spacing (horizontal interval) between two consecutive bunds on cropland with a 9% slope gradient. For general planning and allocation of resources on the basis of slope and rainfall regimes, however, the vertical interval (the difference in elevation) and horizontal interval (the horizontal distance) between two consecutive soil bunds can be computed by using the following formulas (Tripathi and Singh, 2008, refer to **Annex 2** for more details):

$$VI = 0.3\left(\frac{S}{a} + b\right), \quad (1)$$

where *VI* is vertical interval (m), *S* is land slope (%), and *a* and *b* are constants; *a* is 2 for low rainfall areas and 4 for high rainfall areas, whereas *b* is 1 for high rainfall areas and 3 for low rainfall areas.

$$HI = \frac{VI}{S} \times 100, \quad (2)$$

where *HI* is horizontal interval (m), *VI* is vertical interval (m), and *S* is land slope (%).

Depending on the soil stability, bunds can be 1–1.5 m wide at the base and 0.3–0.5 m at the top, and 0.5–0.75 m high. Ties (usually 0.2–0.3-m-wide structures that can be placed about every 10 m along the ditch) are required for level bunds. Because the excavated material of the embankment may fall back into the ditch, a berm (0.15–0.20 cm wide) is required at the lower edge of the ditch (**Figure 3**). A typical ditch could be excavated to about 1 m wide and 0.5 m deep and have a sediment storage capacity lifespan of about 5 to 10 years. However, backfill through sedimentation over time reduces the storage capacity, so regular repair is important for sustainable functioning (Taye et al., 2015).

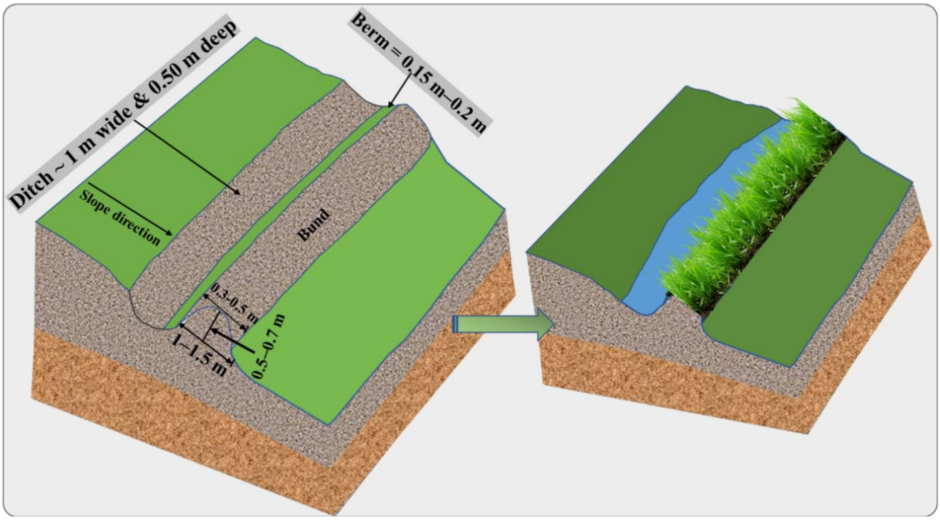

Figure 3. Schematic representation of the layout of soil bunds before (left) and after (right) being reinforced by grass or legumes

Classification and characteristics

According to the WOCAT standard, soil bunds reinforced with grass or legumes is categorized under cross-slope SWC measures (**Table 1**). The combination of bunds and grass can enhance the efficiency of mitigation and prevention of soil erosion by water.

Table 1. Characteristics of soil bunds reinforced with grass or legumes as an SLM technology for croplands

Criterion	Description
• SLM group	Cross-slope measures
• SLM measure	Combined (structural and vegetative) measures
• Type of degradation addressed	Soil erosion by water
• Stage/s of intervention	Mitigation and prevention

Practical specifications: activities, inputs, and suitable conditions

Establishment of a soil bund reinforced with grass or legumes requires rigorous routine activities and a wide range of inputs (**Tables 2 and 3**). In addition, it requires the careful identification of suitable agroecological and socioeconomic conditions before implementation (**Table 4**).

Table 2. Activities and their corresponding frequency and timing for establishing and maintaining soil bunds reinforced with grass or legumes

Activity	Annual frequency	Appropriate timing
Establishment		
• Planning	Once	Dry season
• Laying out	Once	Dry season
• Bund establishment	Once	Dry season
• Planting grass/legume	Once	Wet season
Maintenance		
• Bund maintenance	Depending on damages	As needed throughout the year
• Enrichment planting	Once	At the start of the rainy season
• Maintain zero-grazing	–	Throughout the year

Table 3. Inputs and costs (ETB ha^{-1} $year^{-1}$, 2020 price levels) for establishment and maintenance activities for soil bunds reinforced with grass

Input	Units	Quantity	Unit cost (ETB)	Total cost (ETB)
Establishment (construction of bunds)				
• Labor	PDs[a]	116	105	12,180
• 10% for hand tools and surveying				1280
Establishment (reinforcing with forage grass)				
• Grass purchase (20/bunch)	Bunch	75	105	7875
• Labor for transportation	PDs[b]	2	105	210
• Labor for planting	PDs	10	105	1050
Subtotal				**22,533**
Maintenance for bunds				
• Labor for maintaining bunds	PDs	6	105	630
Grass management				
• Grass purchase (20/bunch)	Bunch	1.5	105	157.5
• Labor for planting grasses	PDs	6	105	630
Subtotal				**1418**
Total				**23,951**

Remarks (in Table 3): Material costs are based on an average of prices for items of different types. Total length of bunds is 0.77 km ha^{-1}, calculated on the basis of the average of bund densities for different slope and rainfall conditions, as presented in **Annex 2**. PDs: person-days. [a]Labor for bund construction is based on the work norm documented by Desta et al. (2005) (i.e., 150 PD km^{-1} of bunds). [b]Transportation cost was estimated by assuming a 2-km distance from home. 1 ETB (Ethiopian Birr) = 0.029 US$ as of 3 July 2020 (considered as the average exchange rate of the year).

Table 4. Ecological and socioeconomic conditions suitable for implementing soil bunds reinforced with grass or legumes

Condition	Class or type
Ecological	
• Climate	Semi-arid to humid
• Landform	Mainly plains
• Average annual rainfall	750–2000 mm
• Slope	Mostly gentle (3%–8%) to steep (15%–50%)
• Soil depth	Moderate (51–80 cm) to very deep (>120 cm)
• Soil organic matter	Very low (1%–2%) to medium (2.1%–4.2%)
• Altitude	500–3000 m a.s.l.
Socioeconomic	
• Farming system	Smallholder
• Landholding size	More sustainable for relatively larger landholding size
• Level of mechanization	Manual work and animal traction
• Wealth class of land user	Not affected by wealth class
• Landholding rights	Mostly private
• Land-use rights	Mostly individual

Procedures/steps for implementation

Step 1. Identify the biophysical features of the target area (see Annexes 2 and 7 for examples)

- ✓ Identify agroecological zone and rainfall properties.
- ✓ Identify farming system (major crops, livestock grazing pressure/stocking rate, and agricultural practices).
- ✓ Identify the soil type and its susceptibility to erosion by water.
- ✓ Identify topographic characteristics, such as landform and slope, that determine bund parameters (gradient, spacing, and dimensions).

Step 2. Preparation and scheduling activities

- ✓ Identify areas that are suitable for implementing soil bunds reinforced with grass or legumes.
- ✓ Consider the catchment characteristics such as waterways, cut-off drains, and gullies that affect the layout of bunds.
- ✓ Decide on the bund layout, taking soil drainage properties into consideration. Bunds must be level if the soil has good infiltration capacity, whereas graded bunds are appropriate if the soil has poor infiltration capacity (e.g., clay soil). A gradient of 0.5%–1% can be provided for channels of graded bunds.
- ✓ Prepare the necessary materials (clinometer, tape measure, mattock, shovel, poles, rope, water level or A-frame, pegs, and manuals).
- ✓ Calculate the bund spacing and required amount of labor on a per-hectare basis.
- ✓ Select the appropriate season and prepare a suitable schedule of activities; the dry season (January to March) is most suitable for soil bund construction, whereas summer (late June to August) is most appropriate for planting grass or legumes on bunds.
- ✓ Provide practical training for experts, field assistants, and land users (farmers).
- ✓ Prepare a detailed activity plan and schedule.

Step 3. Layout and bund construction

- ✓ Determine the spacing between two bunds on the basis of the slope and rainfall (see **Annex 2**) and then mark lines of bund construction along contours; for example, 12.7 m is recommended as the optimal spacing between two consecutive soil bunds on croplands with a 9% slope gradient in the midland agroecological zone (Demissie et al., 2022a).
- ✓ Decide where to start the work (usually upslope of the target area).
- ✓ Make lines for the positions of the ditch, berm, and embankment of each bund (**Figure 3**).
- ✓ Dig and throw the excavated soil downhill to create an embankment 0.5–0.7 m high and 1.0–1.5 m wide at the bottom and 0.3–0.5 m wide at the top (**Figure 3**).
- ✓ Compact the soil embankment to avoid soil movement.

Step 4. Reinforcing bunds with grass or legumes

- ✓ At the start of the rainy season, sow or plant suitable and multipurpose grass or legume species on bunds at a proper spacing to strengthen the embankment and improve efficiency and sustainability, provided that free grazing is restricted.
- ✓ Provide orientation to farmers about the need to do regular monitoring and maintenance of bunds to repair any damage caused by farming activities and heavy rainfall and runoff events.
- ✓ If feasible, irrigate the grass or legume planting during periods of moisture stress (i.e., the dry season).
- ✓ Once the grass or legume is well established and ready for harvesting, it can be utilized through a cut-and-carry system for different purposes, such as for livestock feed.

Step 5. Maintaining and upgrading bunds

- ✓ Keep maintaining bunds when damage occurs.
- ✓ Annual maintenance is needed before the rainy season begins.
- ✓ Sediment deposited in the ditch can be used to maintain or raise the bund.

Impacts on key indicators

The efficiency of soil bunds reinforced with grass or legumes can be determined by different indicators, which can include ecological, economic, and sociocultural aspects (**Table 5**). For example, from an ecological viewpoint, soil bunds reinforced with grass reduce runoff by 28%–49% and soil loss by 66%–87%, and they improve soil fertility by 50%–220%.

Table 5. Impacts of implementing soil bunds reinforced with grass on selected ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Ecological benefits							
• Runoff reduction	++	++	++		49	28	31
• Soil loss reduction	+++	+++	+++		87	66	79
• Soil moisture increase	+++	+++	+++				
• Increase in soil cover	+++	+++	+++				
• Increase in soil organic matter	+++	+++	+++				
• Soil fertility improvement [a]	+++	+++	+++		121	220	50
• Flooding control	+++	++	++				
• Siltation reduction	++	++	++				
• Increase in soil infiltration/recharge	+++	+++	+++				
Economic benefits							
• Crop yield increase	++	++	++				
• Fodder production increase	++	++	++				
• Farm income increase	++	++	++				
• Increase in livestock productivity	++	++	++				
Sociocultural benefits							
• Improve knowledge of SLM	+	+	+				
• Help strengthen community institutions	+	+	+				
• Advance indigenous knowledge of farmers	+	+	+				
• Enhance community integration, communication, and collective work	+	+	+				
Benefit-cost ratio							
• In short term for establishment	+	+	+				
• In short term for maintenance	++	++	++				
• In long term for establishment	+++	+++	+++				
• In long term for maintenance	+++	+++	+++				

Remarks (in Table 5): Impact scale was based on expert judgement, and impact level was based on measurements made in three agroecological (lowland, midland, and highland) sites (Ebabu et al., 2019; 2020). Number of plus signs indicates extent of positive impacts: +, slightly positive; ++, positive; +++ very positive. [a]Based on the average of changes in total nitrogen, available phosphorus, and available potassium 3 years after establishment of soil bunds reinforced with grass (Ebabu et al., 2020).

Drawbacks of the technology and ways to overcome them

Although the use of soil bunds reinforced with grass or legumes is a vital SLM practice with multifaceted advantages, bunds have drawbacks that a practitioner should be well aware of (**Table 6**). Of these, loss of productive land and the high cost of construction are prominent.

Table 6. Drawbacks of implementing soil bunds with grass, and the corresponding solutions

Drawback	Solutions
• High cost of labor for establishment and maintenance	Improve culture of collective working
• Loss of cropland owing to construction of bunds	Apply optimum bund spacing, and plant multipurpose grass/legume and shrub species to compensate for the loss
• Hinders farming operations	Use suitable design and farm tools
• Prone to damage by free grazing	Restrict free grazing, use stall-feeding

2.1.2. Teff row sowing

Description

Teff (*Eragrostis tef*) is one of the major staple food cereal crops in the Ethiopian highlands, where it is utilized in the forms of *injera* (a pancake-like bread), porridge, soup, and alcoholic beverages. Traditionally, teff is sown by broadcasting seeds following compaction by using animal and human labor. Row sowing is a newly recognized technique that has been used for many reasons, such as to reduce the rate of seed-use from 25 kg ha^{-1} to 10–15 kg ha^{-1}, facilitate farm activities (fertilizer and herbicide applications, and weeding), and reduce lodging and associated yield loss. It can be practiced in all teff-growing areas except on heavy clay soils or Vertisols, where it is difficult to prepare well-defined rows under saturated moisture conditions. Also, the technique may not work well on stony fields. Seed application is possible by using locally available plastic bottles with a standard or otherwise suitable hole size to drop seeds, or by using a manufactured seed drill (a teff row seeder), which is easily pulled by one person (**Figure 4**). In addition to the benefits mentioned above, row planting has several advantages over broadcasting, including enhancing light interception, increasing the photosynthetic rate and tillering capacity, reducing lodging, reducing the seed-use rate, conserving soil moisture, and improving yield performance (**Figure 5**) (Mihretie et al., 2021a).

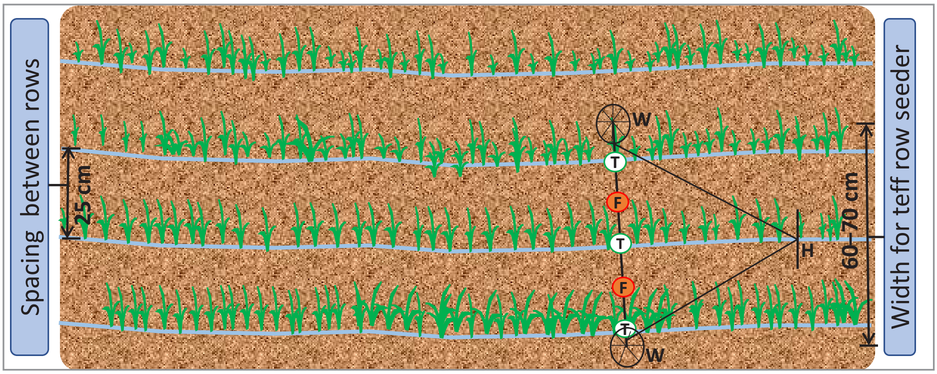

Figure 4. Simplified illustration of teff row planting: spacing between rows and total width covered by a teff row seeder that can be pulled by one person. Diagram redrawn from Gizaw (2014) and Gonite and Reda (2018). Letters represent the different parts of the row seeder: wheel (W), handle (H), and fertilizer (F) and teff (T) containers

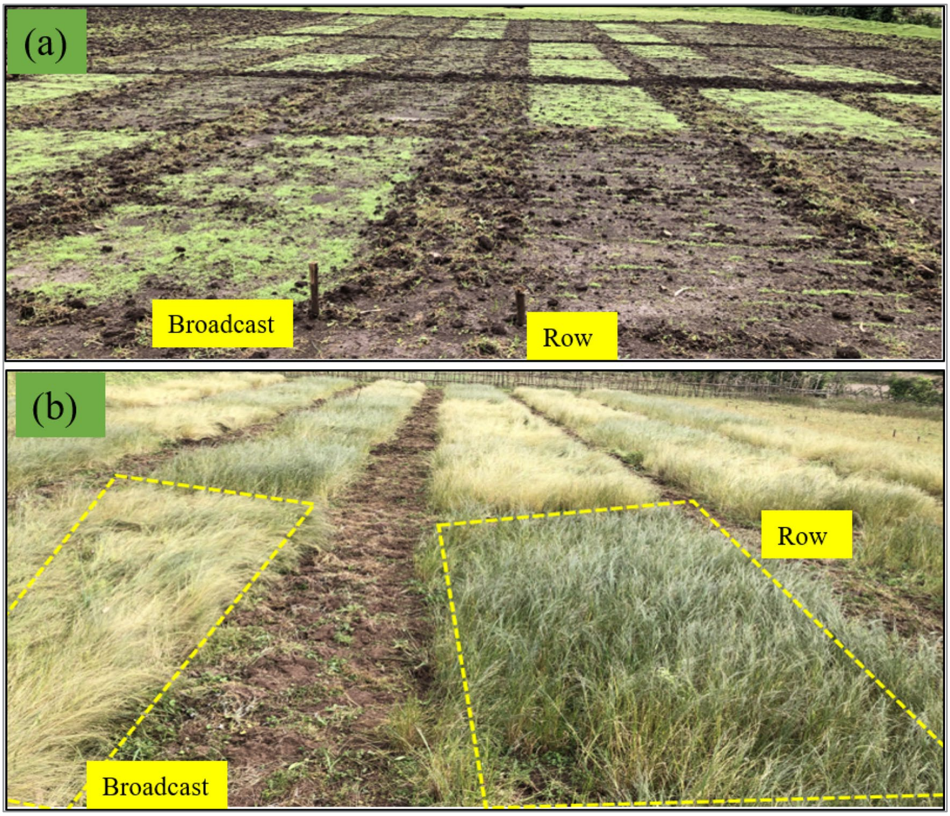

Figure 5. Difference in the performance of teff between row and broadcast sowing methods at the germination (a) and maturity (b) stages; Figure from Mihretie et al. (2021a)

Classification and characteristics

According to the WOCAT standard, teff row sowing is categorized under the crop management SLM group (**Table 7**). It is one of the agronomic measures implemented to improve land productivity and reduce runoff, soil erosion, and soil nutrient depletion.

Table 7. Characteristics of teff row sowing as an SLM technology for croplands

Criterion	Description
• SLM group	Crop management
• SLM measure	Agronomic
• Type of degradation addressed	Soil chemical degradation (nutrient depletion)
• Stage/s of intervention	Prevention/mitigation

Practical specifications: activities, inputs, and suitable conditions

Teff row sowing requires various routine activities and inputs (**Tables 8** and **9**) and careful assessment of ecological and socioeconomic conditions (**Table 10**). An understanding of the soil properties is very important for its suitability and effectiveness.

Table 8. Establishment and maintenance activities and their corresponding annual frequencies and timing for implementing teff row sowing

Activity	Frequency	Appropriate timing
Establishment		
• Land preparation (plowing/tillage)	4 times	1st immediately after harvesting and 2nd four weeks after the 1st plowing; 3rd and 4th after onset of rain
• Row seeder	Once	During planting (at sufficient soil moisture content)
• Row-making and sowing	Once	During planting (at sufficient soil moisture content)
• Apply NPS fertilizer	Once	At planting, as per recommendation
Maintenance		
• Weeding	3 times	1st at 15–18 days after planting, 2nd at 35–40 days after sowing, and 3rd as required
• Urea topdressing	Twice	1st half topdressing at 15–18 days after planting and the 2nd at 35–40 days after sowing, as per recommendation of Bureau of agriculture (see **Annex 7** for example)
• Disease and pest management	When required	At the time of disease and pest occurrences
• Harvesting	Once	At physiological maturity stage
• Drying	once	Immediately after harvest
• Threshing	Once	After proper drying in a well-cleaned yard or by using threshing machines
• Transporting	Once	Immediately after threshing

Table 9. Inputs and costs (ETB ha^{-1} $year^{-1}$, 2020 price levels) for establishment and maintenance (crop management) activities in implementing teff row sowing

Input	Units	Quantity	Unit cost (ETB)	Total cost (ETB)
Crop establishment				
• Labor for plowing/tillage	PDs[a]	68	105	7140
• Improved teff seed	kg	10	44	440
• Labor for planting	PDs[b]	9	105	945
• NPS fertilizer	kg	80	12	960
Subtotal				**9485**
Crop management after sowing				
• Labor for 3 weedings	No.	33	105	3465
• Urea fertilizer	kg	46	43	1978
• Labor for harvesting	PDs	12	105	1260
• Labor for fertilizer application	PDs	1	105	105
• Labor for harvesting				
• Labor for threshing	PDs	10	105	1050
Subtotal				**7858**
Total				**17,343**

Remarks (in Table 9): Only crop-management-related costs are considered. [a]PDs, person-days. Total cost is for tilling 4 times; [b]total sowing (planting) cost could be 2485 ETB if row seeder machine is used (Gizaw, 2014). 1 ETB = 0.029 US$ as of 03 July 2020 (considered as the average exchange rate of the year).

Table 10. Ecological and socioeconomic conditions suitable for implementing teff row sowing

Condition	Class/type
Ecological	
• Climate	Sub-humid to humid
• Average annual rainfall	1000–2500 mm
• Landform	Suitable for teff cultivation (mainly plains)
• Slope	Mostly gentle (2%–8%) to moderate (8%–15%)
• Soil depth	Moderate (51–80 cm) to very deep (>120 cm)
• Soil organic matter	Low (1%–2%) to medium (2.1%–4.2%)
• Altitude	500–2000 m a.s.l.
Socioeconomic	
• Farming system	Smallholder
• Landholding size per household	Small (0.5 ha) to large (>2 ha)
• Level of mechanization	Manual work and animal traction
• Wealth class of land user	Not affected by wealth class
• Landholding rights	Mostly private
• Land-use rights	Mostly individual or private

Procedures/steps for implementation

Step 1. Land preparation

✓ Prepare the cropland by using appropriate implements and number of tillage operations (up to four times, depending on the previous crop and soil conditions).
✓ During or after the last tillage, apply NPS fertilizer as per the site- or soil-specific recommendations (see **Annex 7** for example).

Step 2. Sowing

✓ Make rows at a spacing of 20–25 cm along contour lines and sow teff seeds at a rate of 10–15 kg ha^{-1}.

Step 3: Crop management (weeding, fertilizer application, disease and pest management, and harvest)

✓ Weed at appropriate frequency and timing.
✓ At 15–18 days after planting, apply half of the urea fertilizer, depending on the site-specific recommendation and soil fertility status.
✓ Apply the second half of the urea fertilizer 35–40 days after sowing.
✓ Protect from damage by diseases, pests, rodents, and lodging.
✓ After physiological maturity/ripening, cut the stand, dry properly, and make piles of appropriate size for threshing.

Impacts on key indicators

The impacts of teff row sowing on ecological, economic, and sociocultural indicators are summarized in **Table 11**. For example, it reduces soil loss by 19% and improves crop yield by 10%–20%, in addition to reducing the seed-use rate by 40% (Mihretie et al., 2022).

Table 11. Impacts of implementing teff row sowing on ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale			Impact level (%)		
	LL	ML	HL	LL	ML	HL
Ecological benefits						
• Runoff reduction	+	+	+			
• Soil loss reduction	+	+	+		19	
• Soil moisture increase	++	++	++			
• Increase in soil cover	+	+	+			
• Soil fertility improvement	++	++	++			
• Flooding control	–/+	–/+	–/+			
• Siltation reduction	+	+	+			
Economic benefits						
• Crop yield increase	++	++	++		10	20
• Fodder production increase	–/+	–/+	–/+			
• Farm income increase	++	++	++			
Sociocultural benefits						
• Improved knowledge of SLM	+	+	+			
• Strengthening of community institutions	+	+	+			
Benefit–cost ratio						
• In short term for establishment	++	++	++			
• In short term for maintenance	+	+	+			
• In long term for establishment	+++	+++	+++			
• In long term for maintenance	++	++	++			

Remarks (in Table 11): Impact scale was rated on the basis of expert judgement, and impact level was based on measurements made in the three agroecological (lowland, midland, and highland) sites (Mihretie et al., 2021; 2022). Minus/plus signs indicate extent of negative/positive impacts: –, slightly negative; –/+, neutral; +, slightly positive; ++, positive; +++, very positive; na, not applicable. The slightly positive impact on the cost–benefit ratio for maintenance is due to the high cost of weeding and related activities.

Drawbacks of the technology and ways to overcome them

Table 12 presents drawbacks of teff row sowing from the context of smallholder farmers. Small seed size, the need for a large amount labor for row making, and high weed infestation between rows are among the most important drawbacks.

Table 12. Drawbacks of implementing teff row sowing, and corresponding solutions

Drawback	Solutions
• Requires large amount of human labor for manual planting methods	Develop improved seeder and seeding techniques
• Improved seeder not available	Manual seeding
• Difficult to make straight rows and apply seed uniformly	Skill development through training and demonstration
• High level of weed infestation between rows	Use appropriate weed control methods
• Vigorous stalk growth, resulting in poor-quality straw for livestock feed	Use substitute feed or alternative feeding mechanisms

2.1.3. Reduced tillage for teff

Description

Reduced tillage in a teff cultivation system is a form of conservation agriculture applied to minimize the cost of labor and soil disturbance by reducing the frequency and intensity of tillage operations without compromising yield. Land preparation can be done only once—before or during planting/sowing—by using oxen-driven power. Reduced tillage has several advantages over intensive and continuous tillage systems: it improves soil structure, infiltration rate, and organic matter content, and it reduces soil and nutrient losses (Ebabu, et al., 2020; Mihretie et al., 2022). It is worth noting, however, that the use of appropriate weed-control strategies is essential to counter the disadvantage of reduced tillage and row sowing in promoting weed infestation (**Figure 6b**).

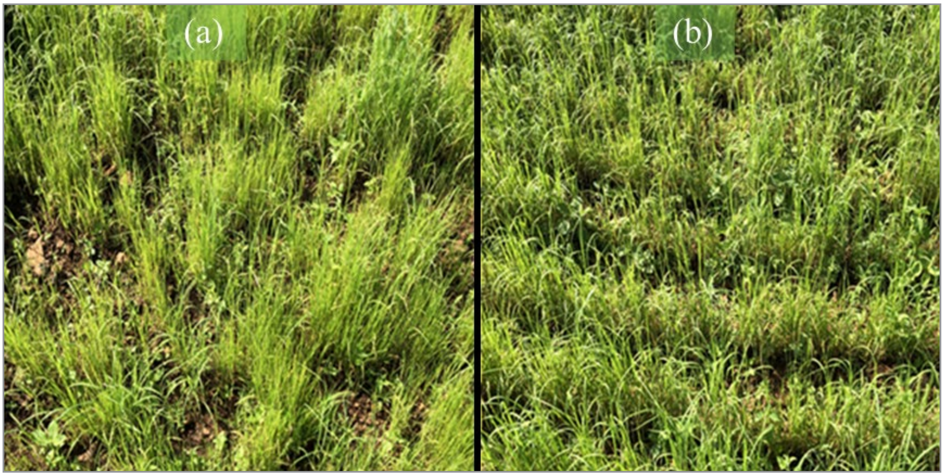

Figure 6. Differences in weed population from teff plots with (a) three tillage operations and broadcast sowing versus (b) with one tillage operation and row sowing

Classification and characteristics

Reduced tillage is one of the agronomic measures intended to reduce soil disturbance and enhance organic matter content. According to the WOCAT standard, this technology is categorized under the conservation agriculture SLM group (**Table 13**).

Table 13. Characteristics of reduced tillage for teff as an SLM technology for croplands

Criterion	Description
• SLM group	Conservation agriculture
• SLM measure	Agronomic
• Type of degradation addressed	Physical soil degradation and soil erosion by water
• Stage/s of intervention	Mitigation, prevention, restoration

Practical specifications: activities, inputs, and suitable conditions

Implementation of reduced tillage involves various routine activities and inputs (**Tables 14** and **15**) and careful identification of agroecological and socioeconomic conditions (**Table 16**). Understanding the timing of key activities is very important for its effectiveness.

Table 14. Establishment and maintenance activities and their corresponding frequencies and timings for implementing reduced tillage for teff

Activity	Frequency	Appropriate timing
Crop establishment		
• Protect from intervention of grazing animals	Always	During the off-crop season
• Apply cover crops/residue mulch	Always	During the off-crop season
• Apply herbicides (e.g., glyphosate)	Once	At about 10 days before planting
• Tillage	Once	At the time of sowing
• Seeding (row)	Once	During the rainy season
• Apply NPS fertilizer	Once	At sowing
Crop management		
• Weeding	3 times	1st at 15–18 days after planting, 2nd at 35–40 days after sowing, and 3rd as required
• Urea topdressing	Twice	1st half top-dressing at 15–18 days after planting; the 2nd at 35–40 days after sowing, as per the recommendation of Bureau of agriculture (see **Annex 7** for example)
• Disease and pest management	When required	At the time of disease and pest occurrences
• Harvesting	Once	At physiological maturity stage
• Drying	Once	Immediately after harvest
• Threshing	Once	After proper drying in a well-cleaned yard, or by using threshing machines
• Transporting	Once	Immediately after threshing
• Protect from intervention of grazing animals	Always	During the off-crop season

Remark (in table 14): Once the technology is adopted by land users, most of the agronomic activities can be done as maintenance activities, as they are repeated year after year.

Table 15. Inputs and costs (ETB ha^{-1} $year^{-1}$, 2020 price levels) for establishment and maintenance activities in implementing reduced tillage for teff

Input	Units	Quantity	Unit cost (ETB	Total cost (ETB)
Crop establishment				
• Herbicide (e.g., glyphosate)	Liters	2	280	560
• Labor for tillage	PDs	17	105	1785
• Improved teff seed	kg	10	28	280
• Labor for sowing	PDs[a]	9	105	945
• NPS fertilizer	kg	80	12	960
Subtotal				**4530**
Crop management				
• Labor for 3 weedings	PDs	33	105	3465
• Urea fertilizer	kg	46	43	1978
• Labor for 2 weedings	PDs	33	105	3465
• Labor for harvesting	PDs	12	105	1260
Subtotal				**10,168**
Total				**14,698**

Remarks (in Table 15): Only crop-management-related costs are considered. [a]Sowing cost is for manual row sowing; it otherwise could be only 105 ETB if broadcast sowing is used or 2485 ETB if a row seeder machine is used (Gizaw, 2014). 1 ETB = 0.029 US$ as of 3 July 2020 (considered as the average exchange rate of the year). PDs, person-days.

Table 16. Suitable ecological and socioeconomic conditions for implementing reduced tillage for teff

Condition	Class/type
Ecological	
• Climate	Sub-humid to humid
• Landform	Suitable for teff cultivation (mainly plains)
• Average annual rainfall	1000–2500 mm
• Slope	Mostly gentle (3%–8%) to moderate (8%–15%)
• Soil depth	Moderate (51–80 cm) to very deep (>120 cm)
• Soil organic matter	Low (1%–2%) to medium (2.1%–4.2%)
• Altitude	1500 – 2000 m a.s.l.
Socioeconomic	
• Farming system	Smallholder
• Landholding size	Not affected by landholding size
• Level of mechanization	Manual work, animal traction, and farm tools
• Wealth class of land user	Not affected by wealth class
• Land ownership	Mostly private
• Land-use right	Mostly individual

Procedures/steps for implementation

Step 1: Land preparation and sowing

- ✓ Prepare suitable cropland by tilling once at sowing (under the rainfed production system, teff is usually sown from late July to the first week of August in most parts of Ethiopia).
- ✓ Before the rainy season, tillage might be necessary to incorporate crop residues and improve the addition of soil nutrients from organic matter decomposition and mineralization.
- ✓ Immediately after the tillage at sowing, apply NPS fertilizer as per site-specific recommendations (see **Annex 7** for example).
- ✓ Space rows at 20–25 cm and sow teff seeds at a rate of 10–15 kg ha^{-1}.

Step 2: Crop management (weeding, disease and pest management, and harvesting)

- ✓ Weed as per recommendation (proper frequency and timing); application of herbicides might be necessary when weed infestation is expected to be high.
- ✓ At 15–18 days after planting, apply half of the urea fertilizer depending on the area-specific recommendation and soil fertility status. Add the second half at 35–40 days after sowing as per recommendation.
- ✓ Protect from damage by diseases, pests, rodents, and lodging.

Impacts on key indicators

The impacts of reduced tillage on ecological, economic, and sociocultural indicators are summarized in **Table 17**. For example, it reduces runoff by 19%–68% and soil loss by 86%–94%, and it improves soil fertility by 21%–202% (Ebabu et al., 2020).

Table 17. Impacts of implementing reduced tillage for teff on selected ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Ecological benefits							
• Runoff reduction	+++	+++	+++		67	48	19
• Soil loss reduction	+++	+++	+++		94	87	86
• Soil moisture increase	++	++	++				
• Increase in soil cover	++	++	++				
• Soil fertility improvement[a]	+++	+	+++		87	202	21
• Flooding control	++	++	++				
• Siltation reduction	++	++	++				
Economic benefits							
• Crop yield increase	+	+	+			27	2
• Fodder production increase	+	+	+				
• Farm income increase	+++	+++	+++				
Sociocultural benefits							
• Improved knowledge of SLM	+	+	+				
• Strengthened community institutions	+	+	+				
Benefit–cost ratio							
• In short term for establishment	++	++	++				
• In short term for maintenance	++	++	++				
• In long term for establishment	++	++	++				
• In long term for maintenance	+++	+++	+++				

Remarks (in Table 17): Impact scale was rated on the basis of expert judgement, and impact level was based on measurements made at three agroecological (lowland, midland, and highland) sites (Ebabu et al., 2019; 2020; Mihretie et al., 2021a, b, 2022). The number of plus signs indicates the scale of positive impact: +, slightly positive; ++, positive; +++, very positive. [a]Based on average of changes in total nitrogen, available phosphorus, and available potassium 3 years after the implementation of reduced tillage (Ebabu et al., 2020).

Drawbacks of the technology and ways to overcome them

Although implementation of reduced tillage for teff substantially reduces runoff and soil loss and improves soil fertility (**Table 17**), there are some drawbacks in terms of waterlogging and weeding (**Table 18**). High-level weed infestation is the most important drawback.

Table 18. Drawbacks of implementing reduced tillage for teff, and corresponding solutions

Drawback	Solutions
• Land is prone to high-level weed infestation	Apply herbicides before and after sowing or use other integrated weed-control methods
• Waterlogging may happen on poorly drained soils	Apply proper drainage mechanisms
• Less incorporation of crop residue into the soil	Apply proper residue-incorporation management practices (e.g., hand pulverization)

2.1.4. Irrigation for teff production in the dry season

Description

In Ethiopia, teff has been traditionally grown under a rainfed system during the long rainy season (*meher*), but the calendar and activities vary by location. For instance, sowing starts from mid-July and extends to early August, depending on the location, length of the growing period for the teff variety, soil type, and timing of onset of the rainy season. Teff cultivation under rainfed conditions requires several tillage operations, soil compaction, and sowing at saturated or high soil moisture conditions to control weed infestations and for good establishment. The grain yield of teff under rainfed conditions and traditional cultivation systems has been reported to be up to 1.8 t ha^{-1} $year^{-1}$ (CSA, 2019), whereas a grain yield of up to 2.6 t ha^{-1} can be obtained under irrigation when the crop is not subject to any nutrient and water stress (**Figure 7**).

Teff production under irrigation in the dry season can be practiced by applying an optimum amount of water and fertilizer for the crop, thus increasing crop productivity and farmers' incomes. The most appropriate sowing time for irrigated teff production in northwestern Ethiopia is from mid-December to mid-January. Irrigation amount and frequency should be based on the crop evapotranspiration for the entire growing period (299–342 mm) and taking into account the average total seasonal water requirement (319 mm) recommended by Hilemicael and Alamirew (2017). The teff cultivar to be selected for irrigation may vary depending on the soil type and climatic variables across locations.

Classification and characteristics

Teff cultivation under irrigation is an agronomic practice requiring soil and water management measures to improve land productivity. According to the WOCAT standard, this technology is categorized under irrigation management and economic efficiency (**Table 19**).

Table 19. Characteristics of teff irrigation as an SLM technology for croplands

Criterion	Description
• SLM group	Irrigation management and economic efficiency
• SLM measure/s	Agronomic and management
• Type of degradation addressed	Soil erosion by water and wind
• Stage/s of intervention	Mitigation and prevention

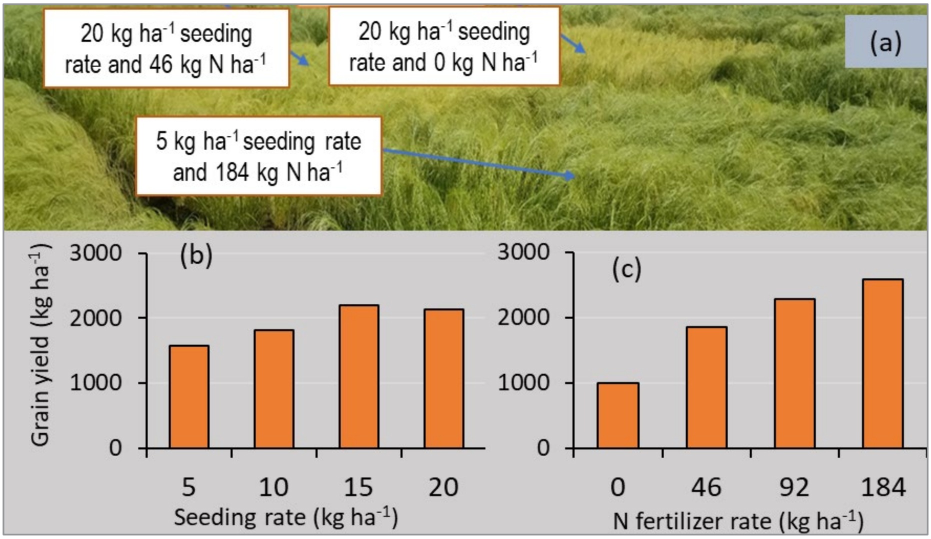

Figure 7. Performance of teff irrigation in northwestern Ethiopia: (a) partial view of teff stand under irrigation at the Dembia site, and variations in grain-yield performance as influenced by (b) seeding rate and (c) nitrogen (N) fertilization rate at the Koga site

Practical specifications: activities, inputs, and suitable conditions

Implementation of irrigation for teff production involves various routine activities and inputs (**Tables 20** and **21**) and careful analysis of agroecological and socioeconomic conditions (**Table 22**). Identifying the best timing for sowing and application of water and fertilizers is very important.

Table 20. Activities and their corresponding frequencies and timings for establishing and maintaining teff irrigation

Activity	Annual frequency	Appropriate timing
Establishment		
• Land preparation (tillage)	4 times	Starting immediately after harvesting the rainfed crop (*meher* crop); the 4th tillage is done at the time of sowing
• Prepare seed and fertilizers	Once	During land preparation
• Sowing	Once	Mid-December to mid-January
• Apply NPS fertilizer	Once	At sowing
Crop management		
• Irrigating the crop	Once a week for 4 months	From sowing to maturity
• Weeding	Twice	1st weeding at 15–18 days after planting; 2nd at 35–40 days after sowing
• Urea topdressing after weeding	Twice	1st half topdressing at 15–18 days after planting; the 2nd at 35–40 days after sowing as per recommendation of Bureau of agriculture (see **Annex 7** for example)

Table 20 (continued): crop management

Activity	Annual frequency	Appropriate timing
• Disease and pest management	When required	At the times of disease and pest occurrences
• Harvesting	Once	At physiological maturity stage (in April)
• Drying	Once	Immediately after harvest
• Threshing	Once	After proper drying in a well-cleaned yard or using threshing machines (from April to May)

Table 21. Inputs and costs (ETB ha^{-1} $year^{-1}$, 2020 price levels) for establishment and maintenance activities for teff irrigation

Input	Units	Quantity	Unit cost (ETB)	Total cost (ETB)
Crop establishment				
• Labor for tillage	PDs[a]	68	105	7140
• Improved teff seed	kg	10	44	440
• Labor for sowing	PDs[b]	9	105	945
• Apply NPS fertilizer	kg	100	12	1200
Subtotal				**9725**
Crop management				
• Labor for weeding twice	PDs	33	105	3465
• Urea fertilizer	kg	50	43	2150
• Labor for irrigating	PDs	20	105	2100
• Labor for harvesting	PDs	12	105	1260
• Labor for threshing	PDs	10	105	1050
Subtotal				**10,025**
Total				**19,580**

Remarks (in Table 21): Only crop-management-related costs are considered. [a]PDs, person-days. Total cost is for tilling 4 times; [b]total sowing (planting) cost could be 2485 ETB if a row seeder machine is used (Gizaw, 2014). 1 ETB = 0.029 US$ as of 3 July 2020 (considered as the average exchange rate of the year).

Table 22. Ecological and socioeconomic conditions suitable for implementing teff irrigation

Condition	Class/type
Ecological	
• Climate	Semi-arid to sub-humid
• Average annual rainfall:	500–1500 mm
• Landform	Mainly plains
• Slope	Mostly flat (0%–3%)
• Soil depth	Moderate (51–80 cm) to very deep (>120 cm)
• Soil organic matter	Low (1%–2%) to medium (2.1%– 4.2%)
• Altitude	1500–2500 m a.s.l.
Socioeconomic	
• Farming system	Smallholder
• Landholding size per household	Small (0.5 ha) to large (>2 ha)
• Level of mechanization	Manual work, animal traction and farm machinery
• Wealth class of land users	Not affected by wealth class
• Land ownership	Mostly private
• Land-use rights	Mostly individual

Procedures/steps for implementation

Step 1: Land preparation

- ✓ Prepare land by using appropriate methods and frequency of tillage operations; land may be tilled up to four times, depending on the soil characteristics.
- ✓ Immediately after the last tillage, apply irrigation water up to field capacity (the amount of water held in the soil after drainage of the water contained in the macropores by gravity action, while the smaller pores are still full of water).
- ✓ Apply NPS and urea fertilizers as per site-specific recommendations (see **Annex 7** for example).

Step 2: Sowing

- ✓ Sow teff seeds in rows at a spacing of 20–25 cm and at a seeding rate of 10–15 kg ha^{-1}; 15 kg ha^{-1} has been shown to be an optimum seeding rate for teff cultivation under irrigation and with suitable rates of N fertilizers (see **Figure 7**).

Step 3: Crop management (irrigation, weeding, fertilizer application, disease and insect pest management, and harvesting)

- ✓ Apply irrigation water at 4-day intervals until 20 days after sowing and at 6-day intervals after 20 days; irrigation might not be needed when unexpected rain events occur.
- ✓ Carry out weeding as per appropriate frequency and timing.
- ✓ At 15–18 days after planting, apply half of urea fertilizer depending on the area-specific recommendation and the soil fertility status. The second half should be applied 35–40 days after sowing as per recommendation.
- ✓ Protect from any damage and associated yield loss related to lodging, rodents, and pests.
- ✓ Prepare a proper schedule and methods of harvesting and threshing, accounting for conditions (e.g., time of maturity and occurrence of unforeseen rain events). After physiological maturity/ripening, cut the stand and dry properly; make piles of appropriate size for threshing.

Impacts on key indicators

Teff production under irrigation provides several benefits (**Table 23**). For instance, it increases crop yield by 56%–150% compared with rainfed teff cultivation. It also provides soil cover during the dry period and increases livestock feed.

Table 23. Impacts of implementing teff irrigation on selected ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Ecological benefits							
• Runoff reduction	++	++	++				
• Soil loss reduction	++	++	++				
• Soil moisture increase	++	++	++				
• Increase in soil cover	+++	+++	+++				
• Soil fertility improvement	–/+	–/+	–/+				
• Flooding control	na	na	na				
• Siltation reduction	na	na	na				

Table 21 (continued)

Key indicator	Impact scale			Impact level (%)		
	LL	ML	HL	LL	ML	HL
Economic benefits						
• Crop yield increase[a]	+++	+++	+++		56–150	
• Fodder production increase	+++	+++	+++			
• Farm income increase	+++	+++	+++			
Sociocultural benefits						
• Improved knowledge of SLM	+	+	+			
• Strengthened community institutions	+	+	+			
Benefit–cost ratio						
• In short term for establishment	+	+	+			
• In short term for maintenance	+	+	+			
• In long term for establishment	++	++	++			
• In long term for maintenance	++	++	++			

Remark (in Table 23): Impact scale was rated on the basis of expert judgement, and impact level was based on measurements made in the midland agroecological setting (Koga and Dembia sites). The impacts on the benefit–cost ratio are based on costs for establishment and maintenance and returns from teff straw and grain yields. Minus/plus signs indicate scale of negative/positive impacts: – slightly negative; –/+ neutral; + slightly positive; ++ positive; +++ very positive; na, not applicable. [a]Calculation assumes two teff crops in a year (rainfed + irrigation) and a grain yield of 1.8 t/ha (farmers' yield) as a reference/baseline (CSA, 2009).

Drawbacks of the technology and ways to overcome them

Table 24 presents the drawbacks of irrigation for teff from the viewpoint of smallholder farmers. Lack of access to irrigation facilities is the most important drawback, particularly in areas where irrigation water sources are limited, and topography is undulating.

Table 24. Drawbacks of implementing teff irrigation, and corresponding solutions

Drawback	Solutions
• High cost of inputs (labor and fertilizers)	Use of improved and cheaper technologies, such as improved cultivars and appropriate agronomic practices, can compensate for high costs by improving productivity
• Requires high level of knowledge/skills	Train/educate experts and farmers
• Shortage of access to irrigation water and facilities	Develop reliable sources of water and irrigation facilities
• May create conflict among farmers	Develop bylaws for sharing irrigation facilities
• Crop sensitive to damage by unexpected rain events at maturity	Establish suitable climate prediction facilities and early-warning systems
• Soil salinity problem may occur	Apply salinity management methods

2.1.5. Teff lodging control

Description

Lodging is defined as the permanent displacement of crop plants from their vertical appearance because of weak stalk and root conditions; it is a major yield constraint of cereal crops—particularly the gluten-free and panicle-bearing teff (Van Delden, et al., 2010). Therefore, controlling lodging by increasing the stem strength of cereal crops or using other mechanisms is crucial to increasing grain yield (Bayable et al., 2021). Using a semi-dwarf variety is one of the techniques widely used to control or reduce lodging in teff, although the desired impact to date has been minimal. A case study by Bayable et al. (2020), however, demonstrated that there is some potential in the use of lodging-resistant teff germplasm collections, which can be exploited under improved management practices (**Figure 8**).

Mechanical support can also be used as an alternative mechanism for teff lodging control under appropriate and feasible conditions. Results of rainfed- and field-based experiments have revealed that the use of mechanical support can increase grain yield of teff by 6%–36%, depending on the cultivar (**Figure 9e**). It was also confirmed that grain yield of teff can be increased by more than double if lodging is controlled and intensive management practices are applied (**Figure 8**). The mean grain yield under such intensive management was estimated at 4.6 t ha^{-1}, which is high as compared with 1.8 t ha^{-1} under conventional practices, indicating a potential yield gap of 156% (Bayable et al., 2020).

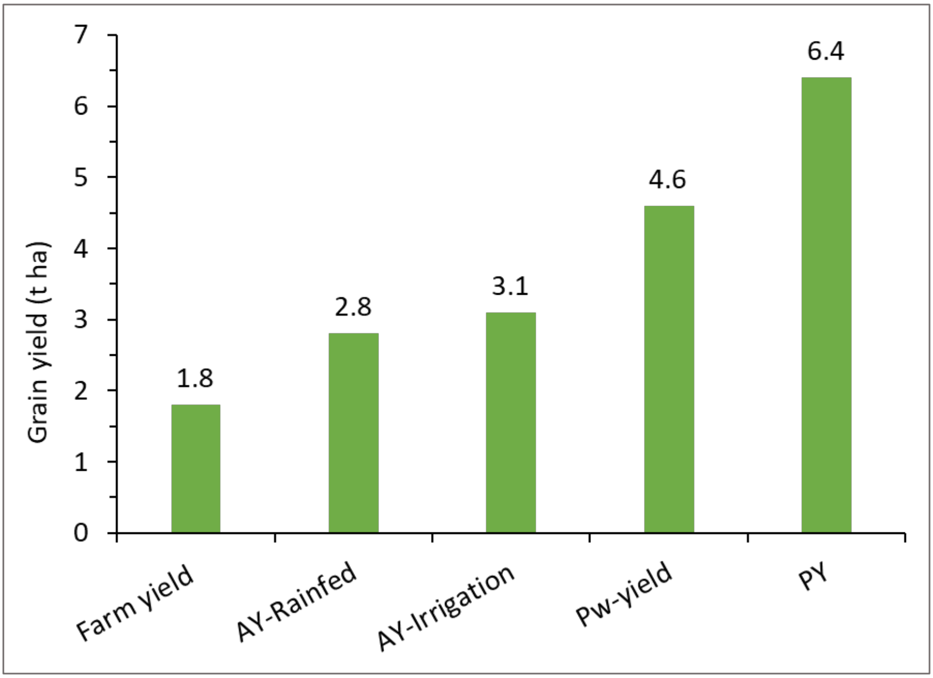

Figure 8. Teff yield gaps due to differences in management practices. Farm yield: average yield under rainfed conditions and farmers' conventional practices (CSA, 2019); AY-Rainfed: attainable yield under rainfed conditions (lodging not controlled), average yield of six improved varieties at two locations (at Adet and Bichena sites in northwestern Ethiopia) over 2 years (Bayable et al., 2021); AY-Irrigated: attainable yield under irrigated conditions, maximum yield obtained at the highest water treatment (Yihun et al., 2013); Pw-yield: water-limited potential yield under rainfed conditions with lodging controlled by providing mechanical support (Teklu and Tefera, 2005); PY: potential yield obtained under fully irrigated conditions, high fertilizer application, and lodging control in a pot experiment at the Adet site (Bayable et al., 2021).

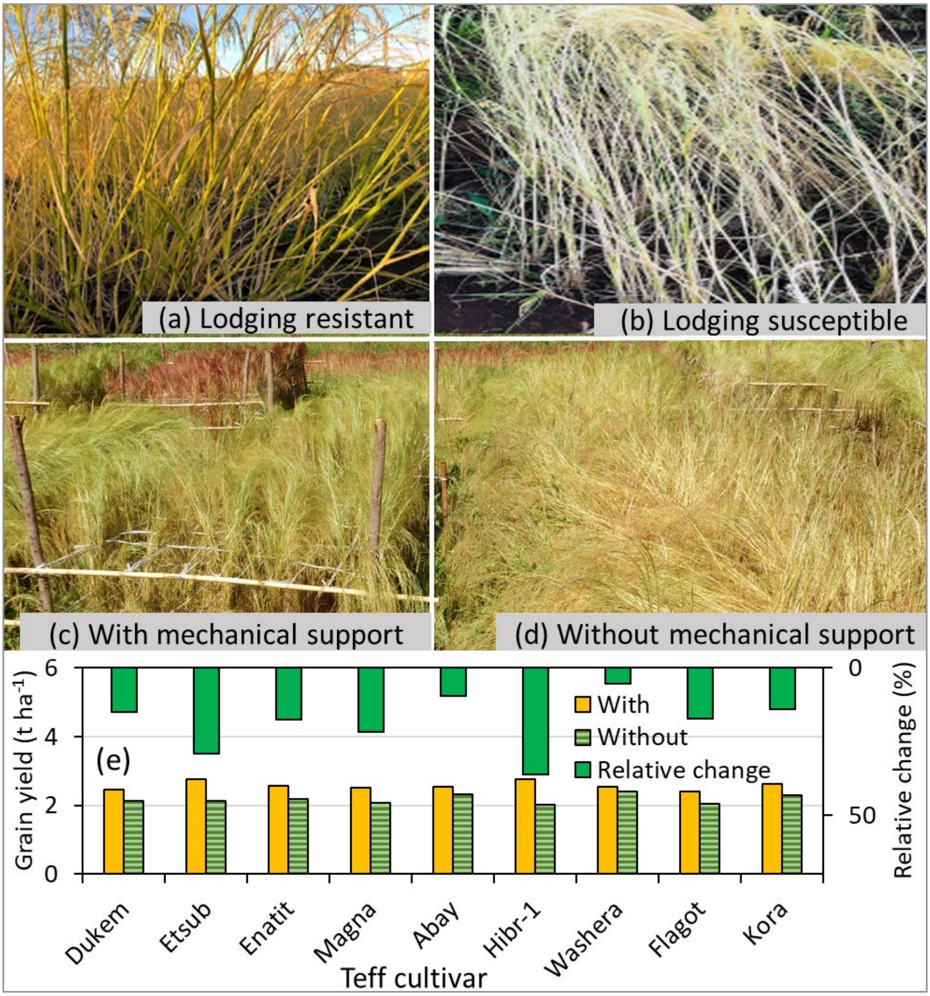

Figure 9. Differences in physiological features between (a) lodging-susceptible and (b) lodging-resistant teff cultivars, and between stands (c) with and (d) without mechanical support. (e) Variations in grain yield performance among nine teff varieties with and without mechanical support under rainfed and field conditions. The top photos (a and b) are adapted from Bayable et al. (2020)

Classification and characteristics

Teff lodging control is different from other SLM technologies: it is not directly related to managing the land, but it is all about managing the crop to reduce yield loss. According to the WOCAT standard, this technology is categorized under the economic efficiency SLM group (**Table 25**).

Table 25. Characteristics of teff lodging control as an SLM technology for croplands

Criterion	Description
• SLM group	Improved plant variety and economic efficiency
• SLM measure	Agronomic and management
• Type of degradation addressed	Not applicable
• Stage/s of intervention	Prevention and mitigation

Practical specifications

Establishment and maintenance activities and costs, and ecological and socioeconomic conditions suitable for this technology, are as the same as for row sowing (section 2.1.2), except for the additional costs of pegs, rope/string, and labor in the case of mechanical support (total cost is about 2800 ETB ha^{-1} $year^{-1}$, based on 2020 price levels). Activities and procedures for implementing lodging control by using a lodging-resistant variety or mechanical support, or both, are described below.

Procedures/steps for implementation

- ✓ Identify a lodging-resistant teff variety suitable for the target area and soil condition.
- ✓ Apply row sowing (section 2.1.2), because mechanical support will likely be implemented.
- ✓ Monitor the growth performance and check whether or not lodging is expected to occur.
- ✓ If lodging is likely to occur, prepare materials such as thin string or wire (~30,000 m ha^{-1}) and pegs (~400 ha^{-1}), each about 150 cm long.
- ✓ Put the pegs at 5–10-m intervals both along and across rows (**Figure 10**), by inserting them 30 cm deep into the ground.
- ✓ Stretch out the strings across and along the rows at two heights, considering the larger and average height classes of the teff plants (**Figure 9c**).
- ✓ At harvesting, remove the strings carefully to avoid shattering and related yield loss; pegs and strings can be used for the same purpose in the next growing season.

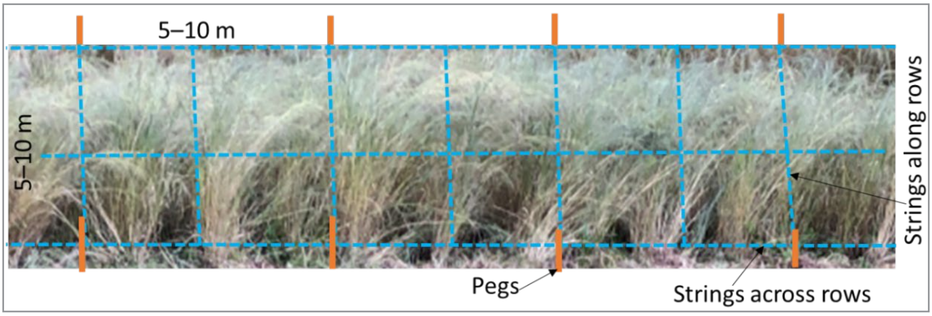

Figure 10. Simplified diagram showing the layout for mechanical support to control lodging in row-planted teff. The spacing between two strings along and across rows depends on the plant height and density

Impacts on key indicators

The impacts of teff lodging control on ecological, economic, and sociocultural indicators are summarized in **Table 26**. For example, mechanical support increases crop yield by 3%–29% compared with conventional practice [without control measures (**Figure 9e**)].

Table 26. Impacts of implementing teff lodging control on selected ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Ecological benefits							
• Runoff reduction	na	na	na				
• Soil loss reduction	na	na	na				
• Soil moisture increase	na	na	na				
• Increase in soil cover	na	na	na				
• Soil fertility improvement	na	na	na				
• Flooding control	na	na	na				
• Siltation reduction	na	na	na				
Economic benefits							
• Crop yield increase	+++	+++	+++				78
• Fodder production increase	–/+	–/+	–/+				
• Farm income increase	+++	+++	+++				
Sociocultural benefits							
• Improved knowledge on SLM	na	na	na				
• Strengthened community institutions	na	na	na				
Benefit–cost ratio							
• In short term for establishment	++	++	++				
• In short term for maintenance	+++	+++	+++				
• In long term for establishment	+++	+++	+++				
• In long term for maintenance	+++	+++	+++				

Remarks (in Table 26): Impact scale was rated on the basis of expert judgement, and impact level was based on measurements made for 2 years at the highland agroecological sites (Adet and Bichena sites). The impacts on short- and long-term benefit–cost ratios are based on the input costs and yield when using a lodging-resistant teff variety under improved agronomic practices. The minus and plus signs indicate the type and scale of impacts: –/+ neutral; ++ positive; +++ very positive; na, not applicable.

Drawbacks of the technology and ways to overcome them

Despite the substantial improvement of crop yield through the use of improved cultivars or mechanical support, there are some drawbacks in the context of smallholder farmers (**Table 27**). The high cost of inputs and obstruction of movement during harvest are particularly important drawbacks of lodging control by mechanical support.

Table 27. Drawbacks of implementing teff lodging control, and corresponding solutions

Drawback	**Solutions**
• Lack of knowledge among farmers to identify suitable variety	Create awareness by demonstration
• Lack of access to improved teff seed	Develop methods of accessing improved seed
• Poor quality of fodder because of strong stem developed to resist lodging	Use alternative feed source or use in mixture with other forages
• Labor and cost intensive to establish mechanical support	Work as a group work and use cheap materials such as wooden pegs and fiber ropes
• Difficult to harvest when many strings used for mechanical support are networked	Carefully remove strings immediately before harvest

2.1.6. Polyacrylamide combined with lime

Description

Polyacrylamide (PAM, **Figure 11**) is a water-soluble anionic polymer [$(CH_2{=}CH\text{-}CONH_2)_n$]. It has a long molecule of identical atom chains held together by covalent bonds that can bridge soil particles through cations in a soil solution (Seybold, 1994). PAM is applied to enhance soil aggregate stability and resistance to detachment by rainfall and surface runoff. Lime ($CaCO_3$) is an ionic soil amendment applied mainly to alter soil acidity and improve the availability of essential plant nutrients. The combined application of PAM and lime has been shown to effectively control soil erosion and improve the productivity of teff cropland by enhancing soil physical and chemical properties (Kebede et al., 2020; Mulualem et al., 2021a).

A case study under field conditions (Kebede et al., 2022) demonstrated that applying PAM alone at 40 kg ha^{-1} or integrated with other soil amendments reduced the seasonal soil loss by 13%–53%, with the highest reduction observed with PAM + lime followed by PAM alone. This implies that integrating PAM with lime can be used as an effective method to control soil erosion by water, as well as to improve soil fertility.

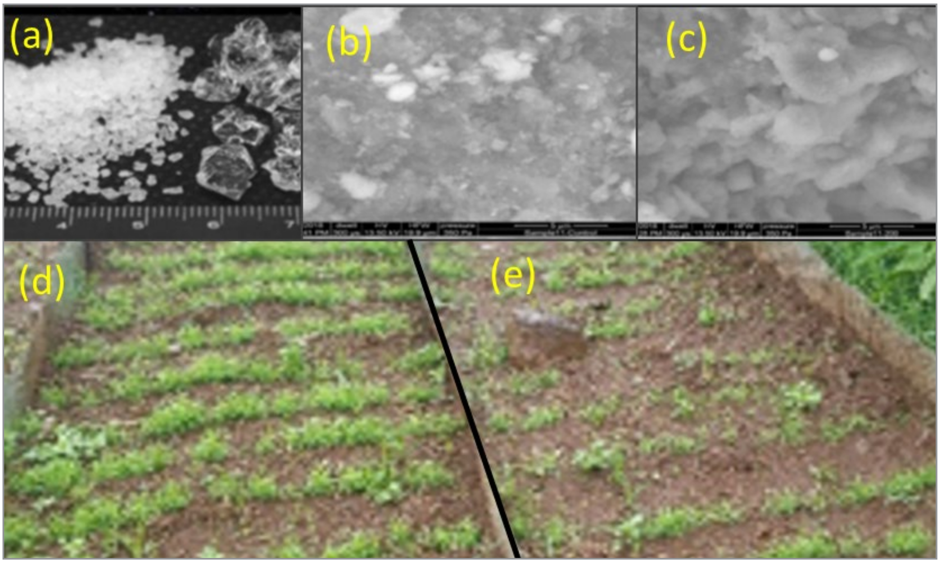

Figure 11. Illustrations of PAM and its effect on soil properties and erosion control: (a) granular PAM; (b) microscopic view of soil aggregates without PAM; (c) microscopic view of soil aggregates with PAM; (d) partial view of teff plot treated with PAM + lime amendment; and (e) partial view of teff plot not treated with PAM + lime amendment

Classification and characteristics

According to the WOCAT standard, combined application of PAM + lime belongs to the integrated soil fertility management SLM group (**Table 28**) and is regarded as a soil amendment measure to control soil erosion by water and improve soil properties.

Table 28. Characteristics of polyacrylamide combined with lime as an SLM technology for croplands

Criterion	Description
• SLM group	Integrated soil fertility management
• SLM measure	Soil management/amendment
• Type of degradation addressed	Soil erosion by water and soil acidification
• Stage/s of intervention	Mitigation and prevention

Practical specifications, taking teff as a target crop

Application of PAM + lime requires different activities that need to be accomplished during the establishment and maintenance phases (**Table 29**). These activities are conducted at specific times during the year and demand different inputs and costs (**Table 30**). The timing of activities may vary depending on the ecological and socioeconomic conditions (**Table 31**).

Table 29. Activities and their corresponding frequencies and timings for applying (establishing and maintaining) polyacrylamide combined with lime

Activity	Annual frequency	Appropriate timing
Establishment		
• Land preparation (tillage)	4 times	Before and at sowing
• Lime and PAM purchase	Once	Before sowing
• Apply lime	Once	At about 30 days before sowing
• Apply PAM	Once	At about 30 days before sowing
• Apply NPS fertilizer	Once	At time of sowing
• Teff row sowing	Once	Mid-July to early August
Maintenance (crop management)		
• Apply PAM	Once	At time of sowing
• Urea topdressing	twice	1st half topdressing at 15–18 days after planting; the 2nd at 35–40 days after sowing as per recommendation (e.g., see **Annex 7**)

Table 30. Inputs and costs (ETB ha^{-1} $year^{-1}$, 2020 price levels) for establishment and maintenance activities when applying polyacrylamide combined with lime

Input	Units	Quantity	Unit cost (ETB)	Total cost (ETB)
Establishment				
• Labor for land preparation	PDs	24	105	2520
• Lime	kg	4000	2	8000
• PAM	kg	20	70	1400
• Labor for PAM + lime application	PDs	24	105	2520
• NPS fertilizer	kg	80	12	980
• Teff seed	kg	15	46	690
• Labor for sowing and NPS application	PDs	3	105	315
Subtotal				**16,405**
Maintenance (soil and crop management)				
• Labor	PDs	106	105	11,130
• PAM	kg	20	70	1400
• Urea fertilizer	kg	46	43	1978
Subtotal				**14,508**
Total				**30,913**

Remarks (in Table 30): Labor cost is only for the human labor required for land preparation (tillage) and incorporating PAM + lime at establishment, as well as for teff cultivation and associated practices (application of PAM and fertilizers, row planting, and weeding) during maintenance (i.e., the costs for equipment are not included). 1 ETB = 0.029 US$ as of 3 July 2020 (considered as the average exchange rate of the year). PDs, person-days.

Table 31. Ecological and socioeconomic conditions suitable for applying PAM combined with lime

Condition	Class/type
Ecological	
• Climate	Sub-humid to humid
• Average annual rainfall	1000 to 2500 mm
• Landform	Mainly plains
• Slope	Mostly gentle (2%–8%) to moderate (8%–15%)
• Soil depth	Moderate (51–80 cm) to very deep (>120 cm)
• Soil organic matter	Low (1%–2%) to medium (2.1%–4.2%)
• Altitude	1500–3000 m a.s.l.
Socioeconomic	
• Farming system	Smallholder
• Landholding size per household	Small (0.5 ha) to large (>2 ha)
• Level of mechanization	Manual work and animal traction
• Wealth class of land users	Not applicable
• Landholding rights	Mostly private
• Land-use rights	Mostly individual

Procedures/steps for implementation, taking teff as target crop

Step 1: Land preparation and application of PAM and lime

- ✓ Test the pH of the soil to make sure it is suitable for applying lime.
- ✓ Prepare PAM and lime during the first tillage/plowing.
- ✓ After the second tillage in April to May, apply lime at 4000 kg ha^{-1} and PAM at 20 kg ha^{-1} over the ploughed surface and incorporate them into the soil by hoeing.

Step 2: Application of fertilizer and PAM at sowing

- ✓ During the last tillage, apply 20 kg ha^{-1} PAM, if necessary, in combination with a compound (NPS) fertilizer as per site-specific recommendation (e.g., see **Annex 7**).
- ✓ After applying PAM and fertilizers, make rows at a 20–25-cm spacing and sow teff seeds at a rate of 10–15 kg ha^{-1}.
- ✓ At 15–18 days after sowing, apply the first half of the urea fertilizer, depending on the area-specific recommendation and soil fertility status; apply the second half 35–40 days after sowing.

Step 3: Crop management (Weeding, disease and insect pest management, and harvesting)

- ✓ Weed as per the requirement and at appropriate timing.
- ✓ Protect the teff crop from damage by diseases, pests, rodents, and lodging.
- ✓ After physiological maturity/ripening, cut the stand, dry properly, and then make piles of appropriate size for threshing.

Impacts on key indicators

The efficiency of PAM combined with lime is determined by changes in different indicators, which can include ecological, economic, and sociocultural aspects (**Table 32**). For example, the use of PAM combined with lime reduces runoff by 26% and soil loss by 49%, and it improves crop yield by 10%–37% depending on the agroecological characteristics (Kebede et al., 2022; Mulualem et al., 2021a).

Table 32. Impacts of applying polyacrylamide combined with lime on selected ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Ecological benefits							
• Runoff reduction	++	++	++			26	
• Soil loss reduction	+++	+++	+++			49	
• Soil moisture increase	++	+	+			9	5
• Increase in soil cover	++	++	++			48	
• Soil fertility improvement	++	++	++				
• Flooding control	++	++	++				
• Siltation reduction	++	++	++				
• Increased infiltration rate	+++	+++	+++				
Economic benefits							
• Crop yield increase	++	++	++		10	32	37
• Fodder production increase	++	++	++		11	22	28
• Farm income increase	++	++	++				
Sociocultural benefits							
• Improved knowledge on SLM	+	+	+				
• Strengthened community institutions	+	+	+				
Benefit–cost ratio							
• In short term for establishment	++	++	++				
• In short term for maintenance	++	++	++				
• In long term for establishment	++	++	++				
• In long term for maintenance	++	++	++				

Remarks (in Table 32): Impact scale was rated on the basis of expert judgement, and impact level was based on measurements made at three agroecological (lowland, midland, and highland) sites (Kebede et al., 2022; Mulualem et al., 2021a). The impacts on short-and long-term benefit–cost ratios are based on input costs for establishment and maintenance and the levels of improvements in soil fertility and teff biomass (straw and grain) yields (Mulualem et al., 2021a). The number of plus signs indicates the scale of positive impacts: +, slightly positive; ++, positive; +++, very positive.

Drawbacks of the technology and ways to overcome them

Using polyacrylamide combined with lime as an SLM practice has drawbacks (**Table 33**) even though it has various advantages in terms of improving soil aggregate stability and decreasing soil loss. The major drawback is that it is not currently available in the local market and will require knowledge and labor for application.

Table 33. Drawbacks of using polyacrylamide combined with lime, and corresponding solutions

Drawback	Solutions
• Requires knowledge/skill for application	Provide training/demonstrations for experts and farmers
• Lack of access to PAM	Provide subsidy/market access for PAM and encourage importation by investors
• Labor-intensive establishment and crop-management activities	Use relatively easy and cheaper tools that reduce labor
• Effectiveness may be affected by soil properties	Do advance evaluations of important soil parameters, such as soil pH
• Difficult to transport lime to distant farmlands	Provide access to roads or use alternative options

2.1.7. Cover crops

Description

Cover crops (also known as green manures, catch crops, and living mulches) are grown to provide vegetative cover for soil (**Table 34**). They are then chopped and either left on the surface as a mulch or incorporated into the soil by tillage as a green manure (Weil and Brady, 2017). The benefits of using cover crops include reduced soil and water losses, increased infiltration and soil moisture, accumulation of organic matter and microbial biomass, reduced nutrient leaching, weed suppression, and improved soil fertility and productivity (Cercioglu et al., 2018; Daryanto et al., 2018). The methods and timing of establishing cover crops may vary depending on several factors, including the cover crop species, soil type, weather conditions, and types of previous and following regular crops. Generally, cover crops should be grown in early or late off-seasons or during fallow periods when soil and weather conditions favor good germination and root establishment. The cover crops presented in this guideline (white lupin, sweet lupin, vetch, and sesbania; **Figure 12**) can be established after regular non-row annual crops are harvested, or during the growing season between rows of both annual and perennial crops.

The results of field experiments (**Figure 12**) indicated that cover crops reduced runoff by 8%–11% and soil loss by 34%–46% as compared with control plots (plots with no cover crops), with the highest reduction efficiency by white lupin in both cases (in reducing runoff and soil loss) (Demissie, 2022c, paper in preparation).

Classification and characteristics

The use of cover crops is an important SLM practice to reduce runoff and erosion, as well as to enhance soil organic matter content and land productivity. According to the WOCAT standard, this technology is categorized under integrated soil fertility management (**Table 34**).

Table 34. Characteristics of cover crops as an SLM technology for croplands

Criterion	Description
• SLM group	Improved vegetation cover, integrated soil fertility management, and economic efficiency
• SLM measure	Agronomic and vegetative measures
• Type/s of land degradation addressed	Soil erosion by water, and physicochemical and biological soil degradation
• Stage/s of intervention	Restoration, mitigation, and prevention

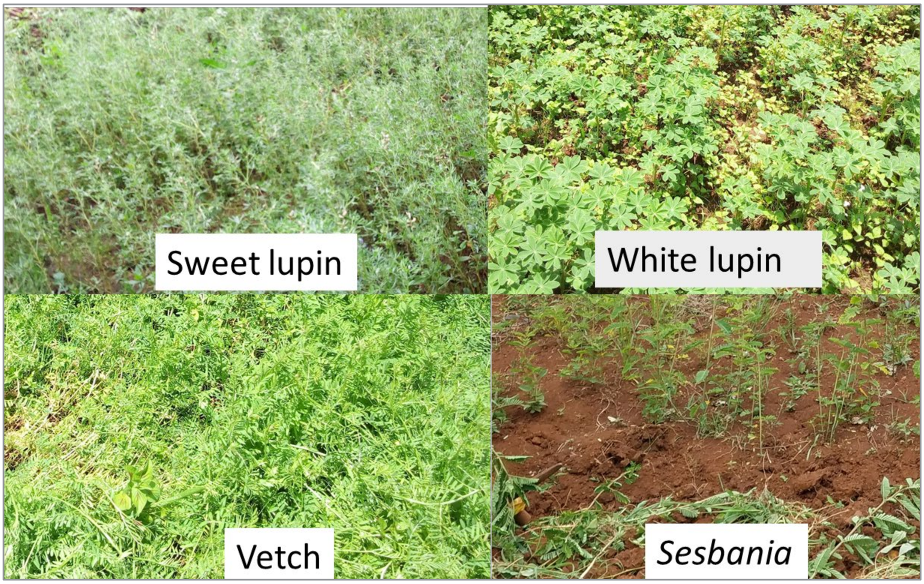

Figure 12. Partial view of cover crops at the stage suitable for incorporating them into the soil; photos taken at the Guder experimental site in the Abay basin of Ethiopia

Practical specifications

Using cover crops requires rigorous routine activities and a wide range of inputs (**Tables 35** and **36**). In addition, it requires careful selection of crop species and identification of suitable agroecological and socioeconomic conditions (**Table 37**).

Table 35. Activities and their corresponding frequencies and timings for establishing and maintaining cover crops

Activity	Annual frequency	Appropriate timing
Establishment		
• Seed/seedling preparation	Once	Before sowing/planting
• Land preparation	Once	At sowing/planting
• Sowing/planting	Once	When moisture levels are good following harvest of regular crops, or inter-seeding before harvest
• Protection from damage	Always	During the growing period
Maintenance (crop management)		
• Remove weeds	As required	At early stage of weed growth
• Harvest and incorporate into the soil as green manure	Once	At the stage of good nutrient content and relatively high decomposition rate; timing depends on type of cover crop

Table 36. Inputs and costs (ETB ha^{-1} $year^{-1}$, 2020 price levels) for establishment and maintenance activities for cover crops

Input	Units	Quantity	Unit cost (ETB	Total cost (ETB)
Establishment				
• Labor for land preparation	PDs	17	105	1785
• Purchase white lupin seeds	kg	50	27	1350
• Purchase sweet lupin seeds	kg	80	35	2800
• Purchase sesbania seeds[a]	kg	30	45	1350
• Purchase vetch seeds	kg	25	45	1125
Average of 4 seed types	kg	46	38	1656
Labor for sowing[b]	PDs	1	105	105
Subtotal[c]				**3546**
Maintenance				
• Labor harvesting/cutting	PDs	6	105	630
• Labor for mulching	PDs	17	105	1785
• Labor for incorporation by tillage	PDs	12	105	1260
Subtotal				**3675**
Total				**7221**

Remarks (in Table 36): Costs may vary depending on the type of cover crop and local conditions. [a]Seedling transplantation can be used for sesbania instead of direct seeding; [b]labor cost can be much higher if seedling transplantation is preferred for establishing sesbania; [c]average seed cost (1656 ETB) was assumed for calculation of total establishment cost. 1 ETB = 0.029 US$ as of 3 July 2020 (considered as the average exchange rate of the year). PDs, person-days.

Table 37. Ecological and socioeconomic conditions suitable for planting cover crops

Condition	Class/type
Ecological	
• Climate	Semi-arid to humid
• Average annual rainfall	750 to 3000 mm
• Landform	Anywhere suitable for crop cultivation
• Slope	Flat (0%–3%) to very steep (30%–50%)
• Soil depth	Moderate (51–80 cm) to very deep (>120 cm)
• Soil organic matter	Very low (<1%) to medium (2.1%–4.2%)
• Altitude	500–3000 m a.s.l.
Socioeconomic	
• Farming system	Smallholder
• Landholding size per household	Not affected by landholding size
• Level of mechanization	Manual work and animal traction
• Wealth class of land users	Not affected by wealth status
• Landholding rights	Mostly private
• Land use rights	Mostly individual

Procedures/steps for implementation

Step 1: Defining purpose and preparation

✓ Define purpose of establishing cover crops (i.e., for green manuring or mulching).
✓ Identify and prepare seeds/seedlings of suitable cover crop species on the basis of the defined purpose, agroecological characteristics, and soil properties.

✓ Prepare tools required for sowing/planting and related agronomic activities.

Step 2: Sowing or planting

✓ Conduct seeding/sowing by using an appropriate method (seed drilling in rows or surface broadcasting, depending on the type of cover crop); cover crops can be grown either by using residual moisture after harvesting the main crop or during the main rainy season.
✓ For seedlings, transplant either between rows of annual crops or immediately after harvesting the annual crops.

Step 2: Weeding, harvesting, mulching, and manuring cover crops

✓ After cover crops are well established, remove undesirable plants that may compete for resources (water, nutrients, and light).
✓ If necessary and applicable, harvest part of the cover crop and use it for stall-feeding.
✓ Once optimum cover has been attained, either chop and leave on the surface as a mulch or incorporate into the soil by tillage/hoeing (green manuring).

Impacts on key indicators

The efficiency of cover crops can be determined by changes in different indicators, which can include ecological, economic, and sociocultural aspects (**Table 38**). For example, the use of cover crops reduces runoff by up to 37% and soil loss by up to 63%, and it improves soil fertility by about 37% (Demissie, 2022c, paper in preparation).

Table 38. Impacts of using cover crops on selected ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Ecological benefits							
• Runoff reduction	++	++	++		37		10
• Soil loss reduction	+++	+++	+++		63		40
• Soil moisture increase	++	++	++				
• Increase in soil cover	+++	+++	+++				
• Increase in soil organic matter	+++	+++	+++				
• Soil fertility improvementa	+++	+++	+++		37		
• Flooding control	na	na	na				
• Siltation reduction	++	++	++				
Economic benefits							
• Crop yield increase	++	++	++				
• Farm income increase	+	+	+				
Sociocultural benefits							
• Improved knowledge on SLM	++	++	++				
• Strengthened community institutions	na	na	na				
Benefit–cost ratio							
• In short term for establishment	++	++	++				
• In short term for maintenance	++	++	++				
• In long term for establishment	+++	+++	+++				
• In long term for maintenance	+++	+++	+++				

Remarks (in Table 38): Impact scale was rated on the basis of expert judgement, and impact level was based on measurements made at the two agroecological sites (lowland and highland, e.g., Demissie, 2022c, paper in preparation). [a]Level of impact on soil fertility was based on the average of changes in available phosphorus levels after the application of sesbania and sweet lupin. Number of plus signs indicates level of positive impact: ++, positive; +++, very positive; na, not applicable.

Drawbacks of the technology and ways to overcome them

Applying cover crops as an SLM practice has its own drawbacks (**Table 39**), even though it has various advantages in terms of improving soil quality. The major drawback is that it will reduce crop production at the household level if it is implemented as a fallow system, mainly during the fallow year.

Table 39. Drawbacks of implementing cover crops, and corresponding solutions

Drawback	Solutions
• High cost of improved seeds	Produce seeds for the purpose
• High cost of labor for manual works	Use tools that can substitute for human labor
• Low productivity if soil moisture is limited under rainfed conditions	Complement with irrigation water if available and applicable
• May appear to be a source of conflict or inconvenience among neighboring farmers	Establish harmonized cropping systems among farms/farmers
• Susceptible to loss/damage from free-grazing animals	Apply zero-grazing and protect by fencing and other methods
• Increased weed population for the next cropping	Harvest before seed dispersal or use appropriate weed-control mechanisms
• May result in reduced crop production when implemented as a fallow system	Implement together with (in rows), or after harvesting of annual crops

2.2. SLM technologies for grazing land/forage development

2.2.1. Developing improved forage: the case of Napier grass *Desmodium* mixed cultivation

Description

Forage development consists of the use of agronomic practices of cultivating suitable forage species to increase the productivity of both land and livestock. It has been recognized as an effective strategy to solve feed scarcity and low livestock productivity in Ethiopia (Walie et al., 2022b). It can be best implemented in areas where stall-feeding (feeding and keeping animals in stalls, **Figure 13**) is well adopted by smallholder farmers or livestock farming enterprises. This guideline provides a description of, and insights into, improved forage development based on results from the combined cultivation of Napier grass (*Pennisetum purpureum*) and *Desmodium* (*Desmodium intortum*) on cultivable lands and homesteads by using farmyard manure as a fertilizer.

Napier grass is a perennial tropical C-4 grass, native to Africa, that can reach a height of 7–8 m and produce large amounts of forage, provided that low temperature and moisture stress are not limiting factors (Turano et al., 2016). *Desmodium* is a trailing or climbing perennial legume that forms very dense ground cover under favorable conditions. Both species are adaptable to a wide range of soils and are tolerant of slightly acidic soil. Applying farmyard manure, nitrogen fertilizer, and supplemental irrigation can improve forage biomass yield by modifying soil acidity. Planting *Desmodium* between rows of Napier grass is the best integration to control weeds, improve soil fertility, and increase land productivity. *Desmodium* can also be grown between rows of annual crops such as maize, or as a cover crop under orchard plantations. A case study in a subtropical environment (Walie et al., 2022a) indicated that combined cultivation of these two forage species with farmyard manure can yield up to about 40 t ha^{-1} of dry biomass per year. According to the daily feed requirement suggested by Bekele et al. (2005), this amount of biomass (40 t ha^{-1}) can feed about 3300 dairy cows or 57,140 growing sheep or goats a day. This practice can therefore support the adoption of stall-feeding and zero-grazing on pasturelands, which can in turn helps to prevent or reduce land degradation due to free grazing.

Figure 13. Photos showing three key activities to be performed for improved forage development and feeding: forage cultivation, cut and carry, and stall-feeding. Forage cultivation/production can be done under rainfed conditions or by using irrigation facilities

Classification and characteristics

Improved forage development is one of the best SLM technologies to increase land and livestock productivity. According to the WOCAT standard, this technology is categorized under different SLM groups (improved feeding, improved forage management, livestock management, and improved feed quality, **Table 40**). This technology can support the adoption of zero-grazing and rehabilitation of grazing lands.

Table 40. Characteristics of improved forage development as an SLM technology for grassland

Criterion	Description
• SLM group	Improved feeding, improved forage management and livestock management, and improved feed quality
• SLM measure	Agronomic, zero-grazing, and vegetative
• Type/s of land degradation addressed	Soil erosion by water and soil degradation
• Stage/s of intervention	Prevention, mitigation, and restoration

Practical specifications

Developing improved forage requires various activities and inputs (**Tables 41** and **42**) and careful selection of forage species on the basis of agroecological conditions (**Table 43**). Appropriate implementation of agronomic practices is very important to produce forage biomass of sufficient quality and quantity.

Table 41. Activities and their corresponding frequencies and timings for establishing and maintaining improved forage production

Activity	Annual frequency	Appropriate timing
Establishment		
• Fencing	Once	Before sowing/planting
• Land preparation	2 or 3 times	Dry season
• Seed/seedling preparation	–	Dry season
• Manure preparation	–	Whenever appropriate
• Manure transportation and application	Once	3 weeks before planting
• Planting Napier grass	Once	At the start of the rainy season
• Planting/sowing *Desmodium*	Once	After Napier grass is established
Maintenance		
• Maintaining fences	Once	Whenever necessary
• Weeding and harrowing	As needed	Whenever appropriate
• Watering	As needed	Dry season
• Applying manure or inorganic fertilizers	As needed	Whenever needed
• Silage-making	As needed	When necessary
• Cut, carry, and feeding	As available	Whenever appropriate

Table 42. Inputs and costs (ETB ha^{-1} $year^{-1}$, 2020 price levels) for establishment and maintenance activities for improved forage development

Input	Units	Quantity	Unit cost (ETB)	Total cost (ETB)
Establishment (fencing)				
• Wooden fence poles	No.	400	32	12,800
• Wooden fence panels	No.	500	50	25,000
• Nails (131/kg)	kg	20	105	2100
• Carpenter	PDs	2	175	350
• Daily labor	PDs	22	105	2310
Establishment (sowing/planting forage)				
• Napier grass seedlings	No.	20,000	1	20,000
• Seed of *Desmodium*	kg	10	455	4550
• Land preparation	PDs	5	105	525
• Transport and apply manure	PDs	16	105	1680
• Planting Napier grass	PDs	40	105	4200
• Sowing *Desmodium*	PDs	20	105	2100
• Seedling transportation	PDs	10	105	1050
Subtotal				**76,665**
Maintenance (forage management after sowing/planting)				
• Weeding and harrowing	PDs	40	105	4200
• Cutting and transportation	PDs	60	105	6300
• Maintaining fences	PDs	4	105	420
• Applying manure	PDs	10	105	1050
• Watering	PDs	60	105	6300
• Making silage	PDs	10	105	1050
Subtotal				**19,320**
Total [a]				**95,985**

Remarks (in Table 42): [a]This total cost is for the first implementation year; most of the costs may not be incurred in later years (after establishment). Establishing and maintenance of fences may not be required if livestock and destructive human interventions are prohibited by other mechanisms; thus, the total establishment cost could be reduced by 56% (i.e., the total cost could be 53,425 ETB). Seedlings of Napier grass should be planted in a single root split to reduce cost, but planting in two splits will increase the chance of survival. Frequency and timing of activities may vary from place to place, as influenced by soil and climatic factors. Costs of transportation were set by assuming a farm distance of up to 2 km from the home. 1 ETB = 0.029 US$ as of 3 July 2020 (considered as the average exchange rate of the year). PDs, person-days.

Table 43. Ecological and socioeconomic conditions suitable for implementing improved forage development (the case of Napier grass + *Desmodium*)

Condition	Class/type
Ecological	
• Climate	Semi-arid to humid
• Average annual rainfall	750–2800 mm
• Landform	Mostly plains and medium slope hillsides
• Slope	Flat (0%–3%) to moderate (8%–15%)
• Soil depth	Moderate (51–80 cm) to very deep (>120 cm)
• Soil organic matter	Medium (2.1%–4.2%) to high (>4.2%)
• Altitude	1500–3000 m a.s.l.
Socioeconomic	
• Farming system	Smallholder
• Landholding size per household	Not affected by landholding size
• Level of mechanization	Manual work and animal traction
• Wealth class of land users	Not affected by wealth class
• Land ownership	Mostly private
• Land-use rights	Mostly individual

Procedures/steps for implementation

Step 1: Preparation

- ✓ Select forage species to suit the site and soil conditions.
- ✓ Prepare seeds/seedlings of selected forage species (e.g., about 10 kg ha^{-1} of Desmodium seed and about 20,000 seedling splits per hectare of Napier grass).
- ✓ Seedlings of forage crops can also be produced at a nursery during the dry season; this requires seedbed preparation and sowing considering the optimum growth period from germination to transplantation.
- ✓ Prepare the land by tilling two or three times during the dry season, using human labor and animal traction.
- ✓ Apply dry farmyard manure (10–12 t ha^{-1}) by properly mixing it with the soil during tillage operations; inorganic fertilizers such as NPS (46% phosphorus and 18% nitrogen) can also be applied later during sowing/planting if farmyard manure is not available; urea can be added after the forage grass or legume is established.

Step 2: Transplanting/sowing

- ✓ At the beginning of the rainy season, when the soil moisture content is adequate, transplant Napier grass in rows at a spacing of 1 m between rows and 0.5 m between plants; under irrigation, the planting time may vary depending on several factors.
- ✓ Localized application of inorganic fertilizers may be required at transplanting to facilitate early establishment on low-fertility soils.
- ✓ One month after planting the Napier grass, remove weeds and sow Desmodium between the rows; Desmodium can also be established from root splits and cuttings.

Step 3: Weeding and protection

- ✓ Remove weeds whenever necessary during the growing season; some weed species may be invasive and may compete for resources (nutrients and moisture).
- ✓ Protect against damage by free-moving animals, rodents, pests, and diseases.
- ✓ Provide water during the period of moisture stress, or apply moisture-conservation measures such as mulching.

Step 4: Harvesting, storing, and feeding

- ✓ Harvest Napier grass when it reaches a height of about 1 m and at an interval of 4–6 weeks thereafter; after the grass is well established, the frequency of harvesting may depend on the available biomass volume and the need to feed livestock; leave stumps 10–15 cm above the ground when cutting.
- ✓ Harvest Desmodium about 4 months after sowing/transplanting (at 50% flowering) and at an interval of 3 months thereafter; leave stumps not less than 10 cm above the ground when cutting.
- ✓ Chop and mix Napier grass and Desmodium and feed to animals in a stall; the mixture can be mixed with other forage types, such as straws of teff, barley, finger millet, rice, and maize stover.
- ✓ Desmodium mixed with Napier grass can also be dried and baled as hay and silage, which can be used as a protein and energy supplement with other forages.

Impacts on key indicators

The impacts of improved forage development on ecological, economic, and sociocultural indicators are summarized in **Table 44**. This technology improves fodder production by 20%–54% (Walie et al., 2022a), depending on the agroecological characteristics, compared with conventional forage production system (natural pasture).

Table 44. Impacts of implementing improved forage development on selected ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Ecological benefits							
• Runoff reduction	++	++	++				
• Soil loss reduction	+++	+++	+++				
• Soil moisture increase	+++	+++	+++				
• Increase in soil cover	+++	+++	+++				
• Soil fertility improvement	++	++	++				
• Flooding control	++	++	++				
• Siltation reduction	++	++	++				
Economic benefits							
• Crop yield increase	na	na	na				
• Fodder production increase[a]	+++	++	++		54	24	20
• Animal productivity increase	++	++	++				
• Farm income increase	+++	+++	+++				
Sociocultural benefits							
• Improved knowledge of SLM	na	na	na				
• Increased awareness of stall-feeding/zero-grazing	++	++	++				
• Strengthened community institutions	na	na	na				
Benefit–cost ratio							
• In short term for establishment	+	+	+				
• In short term for maintenance	+	+	+				
• In long term for establishment	+++	+++	+++				
• In long term for maintenance	+++	+++	+++				

Remarks (in Table 44): Impact scale was rated on the basis of expert judgement, and impact level was based on measurements made at the three agroecological (lowland, midland, and highland) sites (Walie et al., 2022a, b). [a]Impact levels were calculated by taking biomass production from natural pasture as a baseline. The impacts on benefit–cost ratios are based on estimated returns from biomass yield and the costs incurred for establishment and maintenance. The numbers of plus signs indicate the level of positive impacts: +, slightly positive; ++, positive; +++, very positive; na, not applicable.

Drawbacks of the technology and ways to overcome them

Table 45 presents the drawbacks of implementing improved foraged development in the context of smallholder farmers. The high cost of inputs and a requirement for a moderate level of skills are among the most important drawbacks.

Table 45. Drawbacks of implementing improved forage development, and corresponding solutions

Drawback	Solutions
• High cost of labor and inputs	Use improved and cheaper technologies
• Requires moderate level of skills	Provide training for experts and farmers
• Competition for croplands	Use degraded areas, farmyards, and areas not suitable for crop production
• Prone to theft during critical feed shortages	Establish bylaws and other methods (fence and gate-lock systems)
• No, or insufficient, biomass in dry season	Complement rainfed system with irrigation water
• Not suitable for very high-altitude areas	Find alternative forage species

2.2.2. Stall-feeding with improved forage

Description

In Ethiopia and other tropical regions, free grazing is a major cause of soil erosion and severe land degradation. Furthermore, diets from free grazing have been characterized as being of poor quality and resulting in low animal productivity and high levels of methane emission (Mekuriaw et al., 2020). To mitigate this, stall-feeding (indoor-fed animal production with a cut-and-carry system) is being encouraged. To promote this, there is a need to develop improved feeds such as nutritionally rich forages or biochemically treated straw that can improve animal productivity and dietary energy and nitrogen utilization with reduced enteric methane emissions.

Although many forage species are adaptable to different agroecosystems, this guideline provides a description and evidence of stall-feeding by using two forage grass species (*Brachiaria* and Napier grass, **Figure 14**) as an example. *Brachiaria* and Napier grass are perennial tropical C-4 grasses, native to Africa, that have great potential for dairy production (Turano et al., 2016; Adnew et al., 2019). Both species are adaptable to a wide range of soils and are tolerant of slightly acidic soils (see the details for Napier grass in section 2.2.1). Mekuriyaw et al. (2020) reported that feeding Napier grass and *Brachiaria* grass hay as a basal diet to lactating dairy cows significantly improved nutrient intake, digestibility, milk yield, and nitrogen utilization efficiency, and reduced methane emissions, compared with feeding natural pasture hay.

Figure 14. Partial view of stall-feeding with Napier grass and *Brachiaria* forage grass, developed by using improved agronomic practices (applying manure, weeding, and proper spacing). The double green arrows indicate nutrient cycling (grass to manure and vice versa)

Classification and characteristics

According to the WOCAT standard, stall-feeding technology is categorized under various SLM groups (**Table 46**). It involves careful management of both livestock and forage and helps to mitigate or prevent land degradation due to free grazing. The technology can be applicable to all types of livestock, provided that there is a balance between the number of livestock and the available feed or water supply.

Table 46. Characteristics of stall-feeding as an SLM technology for grazing land

Criterion	Description
• SLM group	Improved feeding, zero-grazing, livestock management, economic efficiency, and mitigation of climate change
• SLM measure	Agronomic practices and livestock management
• Type/s of land degradation addressed	Soil erosion by water and soil degradation
• Stage/s of intervention	Prevention and mitigation

Practical specifications

Implementation of stall-feeding requires various activities and inputs (**Tables 47** and **48**), as well as a careful analysis of agroecological and socioeconomic conditions (**Table 49**).

Table 47. Activities and their corresponding frequencies and timings for establishing and maintaining stall-feeding

Activity	Annual frequency	Appropriate timing
Establishment		
• Land preparation	2 or 3 times	Dry season
• Seed/seedling preparation	–	Dry season
• Manure preparation	–	Whenever appropriate
• Transporting and applying manure	Once	At last tillage or planting
• Planting *Brachiaria*/Napier grass	Once	At the start of the rainy season
• Fencing of forage production area	Once	After planting
• Barn construction	Once	Whenever appropriate
• Feeding trough construction	Once	Whenever appropriate

Table 47 (continued)

Activity	Annual frequency	Appropriate timing
Maintenance		
• Weeding and harrowing	As needed	Whenever appropriate
• Watering	As needed	Dry period
• Applying manure or fertilizers	As needed	Whenever needed
• Cut-and-carry feed	As available	Whenever appropriate
• Farmyard manure preparation	As available	Whenever appropriate

Table 48. Inputs and costs (ETB ha^{-1} $year^{-1}$, 2020 price level) for establishment and maintenance activities for stall-feeding

Input	Units	Quantity	Unit cost (ETB)	Total cost (ETB)
Establishment of forage				
• Napier grass seedlings	No.	5000	1	5000
• *Brachiaria* seedlings	No.	5000	1	5000
• Land preparation	PDs	5	105	525
• Manure transportation and application	PDs	16	105	1680
• Planting of Napier grass	PDs	40	105	4200
• Planting of *Brachiaria*	PDs	40	105	4200
• Seedling transportation	PDs	10	105	1050
Establishment of fences				
• Wooden fence poles	No.	400	32	12,800
• Wooden fence panels	No.	500	50	25,000
• Nails (131/kg)	kg	20	105	2100
• Carpenter	PDs	2	175	350
• Daily laborer	PDs	22	105	2310
Feeding trough construction[a]				
• Wooden poles	No.	5	32	160
• Wooden panels	No.	30	56	1680
• Nails (different sizes)	kg	4	105	420
• Carpenter	PDs	1	175	175
• Daily laborer	PDs	2	105	210
Subtotal				**64,260**
Maintenance (forage management)				
• Weeding and harrowing	PDs	40	105	4200
• Cutting and transportation	PDs	60	105	6300
• Maintaining fence	PDs	4	105	420
• Preparing manure	PDs	45	105	4725
• Applying manure	PDs	10	105	1050
• Watering/irrigation	PDs	60	105	6300
Subtotal				**22,995**
Total[a]				**87,255**

Remarks (in Table 48): [a]The total cost is for the first implementation year; most of the costs may not be incurred for some years after establishment. Fencing may not be required if livestock and destructive human interventions in forage production areas are prohibited by other mechanisms; thus, total establishment cost could be reduced by 66% (i.e., total cost could be 44,695 ETB). Seedlings of Napier grass and *Brachiaria* grass should be planted in single root splits to reduce the cost of seedlings, but planting two splits increases the chance of survival. [a]The cost of inputs for a feeding trough assumes a trough large enough for use by four cattle. The frequency and timing of activities may vary from place to place, depending on the soil and climatic factors. Costs of transportation were set by assuming a farm distance of up to 2 km from home. 1 ETB = 0.029 US$ as of 3 July 2020 (considered as the average exchange rate of the year). PDs, person-days.

Table 49. Ecological and socioeconomic conditions suitable for implementing stall-feeding

Condition	Class/type
Ecological	
• Climate	All climate regions suitable for forage production
• Average annual rainfall	All rainfall regimes suitable for forage production
• Landform	Mostly plains/areas suitable forage production
• Slope	Flat (0%–3%) to moderate (8%–15%)
• Soil depth	Moderate (51–80 cm) to very deep (>120 cm)
• Soil organic matter	Medium (2.1%–4.2%) to high (>4.2%)
• Altitude	The range suitable for forage production
Socioeconomic	
• Farming system	Smallholder
• Landholding size	Not affected by landholding size
• Level of mechanization	Manual work and animal traction
• Wealth class of land users	Not affected by wealth classes
• Landholding rights	Mostly private
• Land-use rights	Mostly individual

Procedures/steps for implementation

Step 1: Seed/seedlings and land preparation

- ✓ Prepare seed/seedlings of Napier grass and *Brachiaria*.
- ✓ Seedlings of both Napier and *Brachiaria* grasses can be produced at a nursery site during the dry season by preparing seedbeds and sowing separately, considering the optimum growth period from germination to transplanting out into field conditions.
- ✓ Forage cultivation land must be prepared by tilling two or three times during the dry season.
- ✓ Apply dry farmyard manure (8–10 t ha^{-1}) and properly mix it with the soil during tillage operations before planting/sowing.
- ✓ Inorganic NPS fertilizers can also be applied at planting/sowing where farmyard manure is not available or applicable.

Step 2: Planting/sowing

- ✓ At the beginning of the rainy season, when soil moisture content is adequate, sow/transplant Napier grass in rows at a spacing of 2 m between rows and 1 m between plants.

- ✓ Localized application of fertilizers may be required at planting to facilitate early establishment in low-fertility soils.
- ✓ One month after planting the Napier grass, remove weeds and sow/transplant *Brachiaria* between the rows following the practice of intercropping.
- ✓ Both Napier grass and *Brachiaria* can also be established from root or stem cuttings at low cost.

Step 3: Weeding and protection

- ✓ Remove unwanted weeds whenever necessary during the growing season.
- ✓ Protect against damage by destructive agents such as free-moving animals, rodents, pests, and diseases.
- ✓ Provide water during the period of moisture stress or apply moisture conservation measures such as mulching.

Step 4: Harvesting

- ✓ Harvest Napier and *Brachiaria* grasses when their height reaches about 1 m and at an interval of 4–10 weeks thereafter, depending on available biomass and the feeding demand; leave stumps between 10 and 15 cm above ground when cutting.
- ✓ Napier and *Brachiaria* grasses can also be dried and baled as hay and used as a protein supplement.
- ✓ It is worth noting that Napier grass must be replaced 5 years after its establishment because its productivity decreases with time.

Step 5: Feeding and trough/barn management

- ✓ Chop Napier and *Brachiaria* grasses and mix with other forage, such as maize or teff straw.
- ✓ Feed to livestock in a feeding trough constructed for the purpose (**Figure 14**):
    - The feeding trough can be one- or two-sided, depending on the number of animals to be fed and the area of the barn.
    - A two-sided trough is suitable if it is to be constructed in the middle of a barn and the barn area is not limited (**Figure 14,** left), whereas a one-sided trough is convenient if it is to be attached to the wall of a barn or house and when the barn area is limited (**Figure 14,** right).
    - The length, width, and height of the trough depend on the number and breed type of animals to be fed.
- ✓ Clean the trough and the barn at a regular time interval or whenever necessary; frequent cleaning is required during periods of greater feed wastage.
- ✓ Prepare farmyard manure from the waste feed and animal dung and use it as an organic fertilizer; this may require labor to collect the waste feed and store it in a place designed for manure preparation.

Figure 15. Layout and dimensions of two-sided (left) and one-sided (right) feeding troughs for cattle. Depending on the economic status of the farmers or cooperatives, the barn roof can be made from locally available materials such as grass mat or from manufactured plastic and corrugated iron sheets. The length, width, and height are determined by considering the average size of cattle of different breeds

Impacts on key indicators

The impacts of stall-feeding on ecological, economic, and socio-cultural indicators are summarized in **Table 50**. Reduction of soil erosion and improvements in land and livestock productivity are among the main benefits.

Table 50. Impacts of implementing stall-feeding on selected ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Ecological benefits							
• Methane emission reduction	+++	+++	+++				
• Runoff reduction	++	++	++				
• Soil loss reduction	+++	+++	+++				
• Soil moisture increase	+++	+++	+++				
• Increase in soil cover	+++	+++	+++				
• Soil fertility improvement	+++	+++	+++				
• Flooding control	na	na	na				
• Siltation reduction	na	na	na				
• Reduced loss of indigenous forage species							

Table 50 (continued**)**

Key indicator	Impact scale				Impact level (%)		
	HL	ML	LL		HL	ML	LL
Economic benefits							
• Crop yield increase	na	na	na				
• Milk yield increase	+++	+++	+++			71	
• Meat yield increase	++	++	++				
• Fodder production increase	+++	+++	+++				
• Farm income increase	+++	+++	+++				
• Reduction of animal disease transfer	+++	+++	+++				
Sociocultural benefits							
• Improved knowledge of SLM	na	na	na				
• Strengthened community institutions	na	na	na				
• Enhanced education of children	++	++	++				
Benefit–cost ratio							
• In short term for establishment	+	+	+				
• In short term for maintenance	+	+	+				
• In long term for establishment	+++	+++	+++				
• In long term for maintenance	+++	+++	+++				

Remarks (in Table 50): Impact scale was rated on the basis of expert judgement, and impact level was based on measurements made in the midland agroecological zone (Mekuriaw et al., 2020). The number of plus signs indicates the level of positive impacts: +, slightly positive; ++, positive; +++, very positive; na, not applicable.

Drawbacks of the technology and ways to overcome them

Although stall-feeding is perceived to be effective as an SLM practice, there are some drawbacks constraining its adoption by smallholder famers (**Table 51**). Lack of access to water and insufficient feed during the dry season are the most important drawbacks.

Table 51. Drawbacks of implementing stall-feeding, and corresponding solutions

Drawback	Solutions
• High cost of inputs	Use locally available and cheaper inputs
• Requires a moderate level of skills	Provide training to land users and experts
• No, or insufficient, feed production in the dry period	Complement with irrigation; use alternative feed sources such as crop residues and agro-industrial byproducts
• Lack of access to drinking water in the dry period, particularly when livestock numbers are large	Develop reliable water sources and use efficient means of transporting water
• High cost of labor for transportation	Develop forage in a nearby area such as a backyard system

2.2.3. Exclosure

Description

Exclosure is a practice of excluding the human and animal interference that leads to damage to vegetation cover and deterioration of soil quality properties (Aerts et al., 2009). From the perspectives of protecting and restoring grazing lands, the objectives of establishing exclosures are to (1) allow native vegetation to regenerate while providing fodder and woody biomass, (2) enhance soil organic matter buildup, (3) increase rainwater infiltration, (4) control soil erosion and related impacts downstream, (5) promote stall-feeding of livestock through use of a cut-and-carry system and help sustain the natural functioning of grassland ecosystems, and (6) increase the seed bank of indigenous forage species (grasses, legumes, and shrubs). An exclosure can simply be established by fencing, but it must be integrated with other soil and water conservation measures such as moisture-conservation trenches and enrichment plantations in areas where fencing alone cannot bring about a significant reduction in soil erosion and improvements in vegetation cover.

The results of a plot-based experiment indicated that exclosure alone can reduce surface runoff from grazing lands by 14%–46% and soil loss by 23%–64% compared with conventional free-grazing practice (Ebabu et al., 2019). The substantial improvements in organic matter content and some soil quality parameters observed 3 years after the establishment of exclosures (Ebabu et al., 2020) suggest that degraded grazing lands can quickly be rehabilitated if they are well protected against destructive human activities.

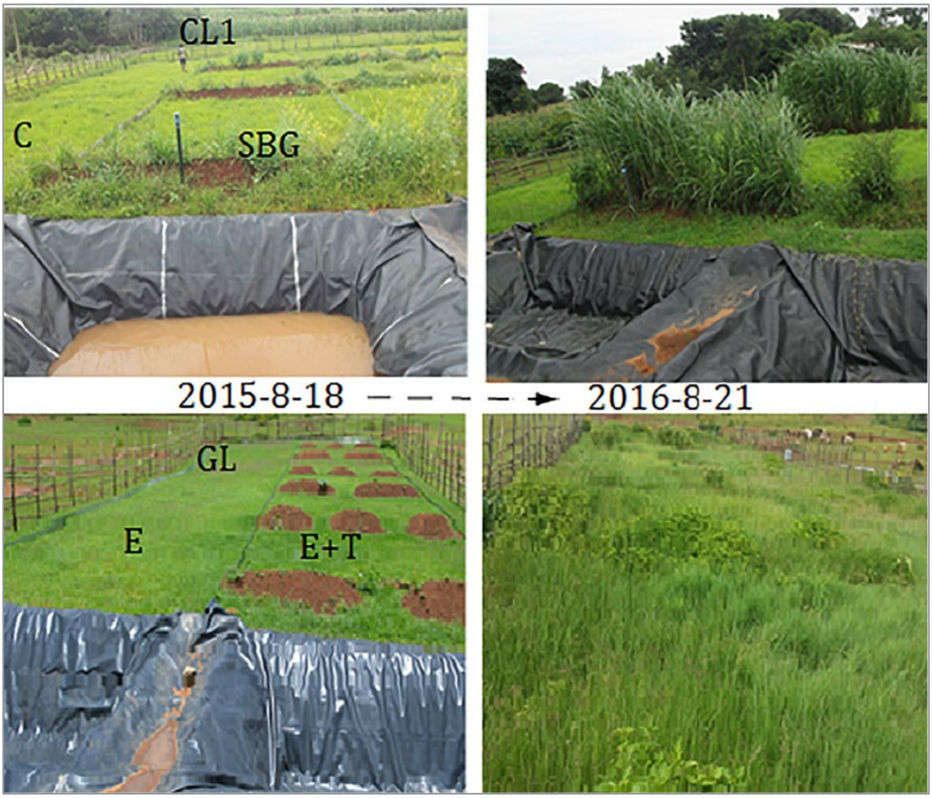

Figure 16. Noticeable improvement in vegetation cover and diversity observed shortly after an exclosure was established by fencing around 0.05 ha of cropland (CL, top photos) and grazing land (GL, bottom photos) at the midland agroecological site (Aba Gerima) in the Abay basin of Ethiopia. The photos were taken 3 months (August 2015, left) and 15 months (August 2016, right) after fencing part of the cropland and grazing land that had been under free/frequent and heavy grazing for several decades. Figure from Ebabu et al. (2019). C, Control; SBG, soil bunds with grass; E, exclosure; T, Trenches

Classification and characteristics

Grazing exclosure is one of the SLM practices recommended for rehabilitation and restoration of degraded grasslands. According to the WOCAT standard, this technology is categorized under vegetative soil and water conservation measures (**Table 52**).

Table 52. Characteristics of exclosure as an SLM for grazing lands

Criterion	Description
• SLM group	Exclosure and improved vegetation cover
• SLM measure	Livestock management and vegetative measures
• Type/s of land degradation addressed	Soil erosion by water, and physical and biological soil degradation
• Stage/s of intervention	Prevention, mitigation, and restoration

Practical specifications

Establishment of an exclosure requires various routine activities and inputs (**Tables 53** and **54**) and a careful analysis of the agroecological and socioeconomic conditions in the target area (**Table 55**). Understanding the sociocultural setting of the target communities is also very important for smooth implementation and sustainability.

Table 53. Activities and their corresponding frequencies and timings for establishing and maintaining an exclosure

Activity	Annual frequency	Appropriate timing
Establishment		
• Identify target grazing lands	Once	During dry season
• Hold community meetings	Once	During off-season
• Set bylaws for sharing responsibilities and benefits	Once	During community meetings and gatherings
• Establish fences, if necessary	Once	Before rainy season starts
• Enrichment sowing/planting	As needed	When appropriate
Maintenance		
• Repair damage to fences	As needed	Whenever appropriate
• Weeding	As needed	Whenever appropriate
• Community's awareness creation	As needed	Whenever appropriate
• Monitor changes and challenges	Regularly	Whenever appropriate

Table 54. Inputs and costs (ETB ha^{-1} $year^{-1}$, 2020 price levels) for establishment and maintenance of exclosure

Input	Units	Quantity	Unit cost (ETB)	Total cost (ETB)
Establishment				
• Wooden fence poles	No.	400	32	12,800
• Wooden fence panels	No.	500	50	25,000
• Nails (131/kg)	kg	20	105	2100
• Carpenter	PDs	2	175	350
• Daily labor	PDs	22	105	2310
Subtotal				**42,560**

Table 54 (continued)

Input	Units	Quantity	Unit cost (ETB)	Total cost (ETB)
Maintenance				
• Wooden fence poles	No.	40	32	1280
• Wooden fence panels	No.	40	91	3640
• Nails (131/kg)	kg	2	105	210
• Carpenter	PDs	1	175	175
• Daily laborer	PDs	4	105	420
Subtotal				**5725**
Total[a]				**48,285**

Remarks (in Table 54): [a]Cost could be zero if fencing were not required (i.e., total establishment and maintenance costs will be zero if zero-grazing is effectively adopted by the local community by making use of bylaws and other traditional rules). Quantities of input items for fence maintenance were determined by assuming 10% of the quantity required for establishment. 1 ETB = 0.029 US$ as of 3 July 2020 (considered as the average exchange rate of the year). PDs, person-days.

Table 55. Ecological and socioeconomic conditions suitable for implementing exclosure

Condition	Class/type
Ecological	
• Climate	Applicable to grazing lands in all climatic regions
• Average annual rainfall	Not affected by rainfall regime
• Landform	Applicable for grazing land in all landforms
• Slope	Flat (0%–3%) to moderate (8%–15%) unless integrated with cross-slope measures
• Soil depth	Moderate (51–80 cm) to very deep (>120 cm)
• Soil organic matter	Very low (<1%) to medium (2.1%–4.2%)
• Altitude	All altitudes where zero-grazing is to be applied
Socioeconomic	
• Farming system	Smallholder
• Landholding size	Not affected by landholding size
• Level of mechanization	Not affected by type of mechanization
• Wealth class of land users	Not affected by wealth status
• Landholding rights	Private and communal
• Land-use rights	Individual and communal

Procedures/steps for implementation

Step 1: Identification and discussion

✓ Identify grazing lands that need protection by excluding grazing and browsing animals, as well as regular foot traffic by humans.

✓ Assess some key characteristics of proposed grazing lands, such as the users, grazing history, soil type, and vegetation conditions.

✓ Hold meetings involving members of the surrounding community and other relevant stakeholders (local administrators and experts).

✓ Discuss and decide upon methods of establishing exclosures (i.e., by fencing around the target grazing land or using local community bylaws).

Step 2: Setting bylaws and establishing the exclosure

✓ Setup bylaws for roles and responsibilities during and after establishment of the exclosure and for forage utilization through a cut-and-share system.
✓ Explore and make use of best practices of the local community: for example, the norms/bylaws of traditional local institutions such as idir (an association of people that have the objective of providing social and economic insurance in the event of death, property damages, and accident) can be used for effective implementation and adoption of exclosures by local communities.
✓ If fencing is necessary to establish an exclosure, there is a need to prepare materials, plan activities, and make the fence a few months before the rainy season starts.

Step 3: Monitoring and evaluation

✓ Monitor situations at a regular time interval and document feedback/lessons for improvement.
✓ Whenever harvestable grass biomass is available in the excluded area, it can be cut and shared among users/members and used for different purposes, such as for stall-feeding of animals, or can be stored and used as a hay.
✓ Discuss challenges and opportunities for sustaining the practice with relevant stakeholders.

Impacts on key indicators

The efficiency of an exclosure is determined by changes in different indicators, including ecological, economic, and sociocultural aspects (**Table 56**). For example, exclosures reduce runoff by 14%–46% and soil loss by 23%–64%, and they improve soil fertility by 32%–216% and soil organic carbon by 10%–118% (Ebabu et al., 2020).

Table 56. Impacts of implementing exclosure on selected ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Ecological benefits							
• Runoff reduction	++	++	++		14	46	31
• Soil loss reduction	++	++	+++		23	42	64
• Soil moisture increase	++	++	++				
• Increase in plant cover and diversity	+++	+++	+++				
• Soil organic matter improve	++	+++	++		10	118	36
• Regeneration of lost forage species	+++	+++	+++				
• Soil fertility improvement[a]	++	++	++		216	66	32
• Flooding control	++	++	++				
• Siltation reduction	++	++	++				
Economic benefits							
• Crop yield increase	na	na	na				
• Fodder production increase[b]	+++	+++	+++		1050	928	1090
• Farm income increase	+	+	+				
Sociocultural benefits							
• Improved knowledge of SLM	++	++	++				
• Strengthened community institutions	++	++	++				
Benefit–cost ratio							
• In short term for establishment	+++	+++	+++				
• In short term for maintenance	+++	+++	+++				
• In long term for establishment	+++	+++	+++				
• In long term for maintenance	+++	+++	+++				

Remarks (in Table 56): Impact scale was rated on the basis of expert judgement, and impact level was based on measurements at three agroecological (lowland, midland, and highland) sites (Ebabu et al., 2019; 2020). The impacts on short- and long-term benefit–cost ratios are based on the establishment, maintenance, and scale of improvements in soil properties and land biomass productivity. [a]Calculated on the basis of the average of changes in total nitrogen, available phosphorus, and available potassium 3 years after establishment of the exclosure (Ebabu et al., 2020); [b]calculated by using annual biomass production (0.6 t ha^{-1}) from continuously grazed grassland (Yayneshet et al., 2009) as a baseline. The number of plus signs indicates the level of positive impacts: +, slightly positive; ++, positive; +++, very positive; na, not applicable.

Drawbacks of the technology and ways to overcome them

Although exclosure is an effective SLM practice in many respects, it has its some drawbacks (**Table 57**), particularly in the case of setting up exclosures on communal grazing lands. The fencing cost, even when shared, can be very high for poor farmers. Also, the unfair allocation of grass and other resources often leads to conflict among users.

Table 57. Drawbacks of implementing exclosures, and corresponding solutions

Drawback	Solutions
• High cost of inputs for fencing	Use best alternatives
• Affected by willingness of community members if grazing land is communal	Undertake participatory discussions and make decisions involving relevant stakeholders
• May result in conflicts of interest among community members	Set equitable bylaws for sharing responsibilities and benefits
• There may be theft of forage biomass	Set high monetary and other forms of penalties in the bylaws
• Closing one area increases pressure on neighboring areas	Introduce and promote improved forage, cut-and-carry, and stall-feeding (zero-grazing)

2.3. SLM technologies for degraded hillsides

2.3.1. Exclosure combined with trenches

Description

Implementing exclosures integrated with trenches is the best way to effectively control soil erosion and bring about improvements in vegetation cover and soil quality on degraded hillsides. This practice is recommended for areas where both soil erosion by water and degradation of natural vegetation are concerns and cannot be controlled or reversed simply by establishing an exclosure (section 2.2.3). The main purposes of integrating trenches with exclosures are to increase rainwater infiltration, reduce runoff and soil loss, and support the growth of vegetation planted in the vicinity. Moisture conservation by trenches can promote the quick recovery of natural vegetation, particularly in areas with a moisture deficit. Depending on the soil type and slope gradient, conservation trenches can be installed with the following specifications (illustrated in **Figure 17**): they should be 2–5 m long and 0.3–0.5 m deep, and they should have a spacing of about 2 m along the contour and an interval of 5–30 m between consecutive rows.

A plot-based experimental study (Ebabu et al., 2019) indicated that exclosures combined with staggered trenches reduced soil loss by 64%–94% in degraded bushland, whereas the soil-loss reduction due to exclosure alone was 35%–72%. As a result, noteworthy improvements in soil fertility were observed compared with those in plots with no conservation measures (Ebabu et al., 2020).

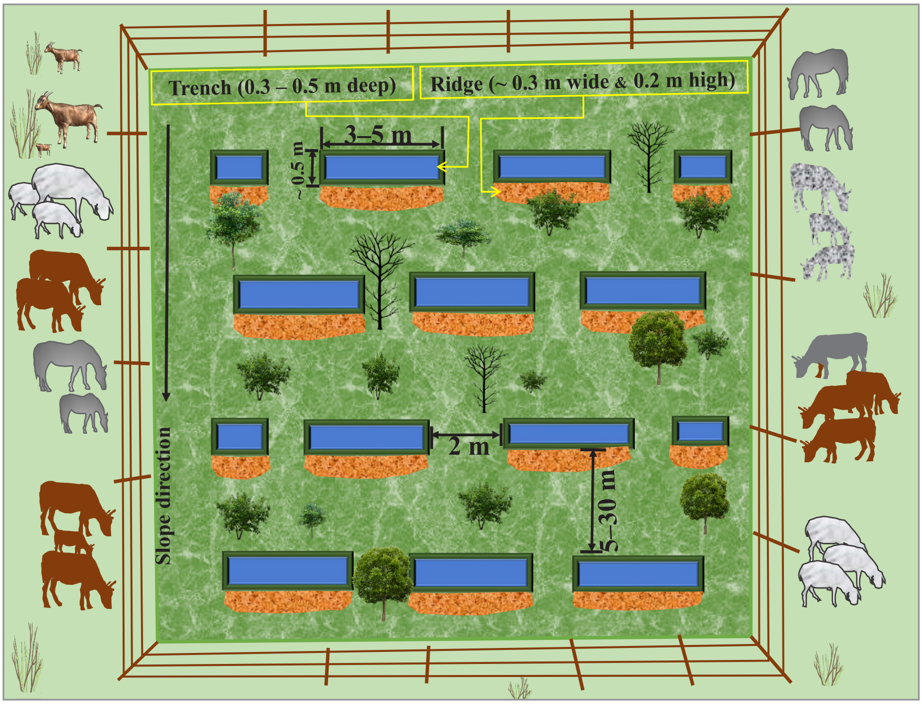

Figure 17. Schematic diagram representing establishment of an exclosure integrated with trenches (blue rectangles) on a hillside. Drawings on the deep green background represent the hypothesized gradual development of vegetation communities (grasses/herbs, shrubs, and trees) following exclosure and construction of trenches (dimensions and spacings shown); drawings on the light green background represent the fact that the use of an exclosure may result in a displacement effect of overgrazing unless zero-grazing or alternative livestock management/feeding practices are adopted

Classification and characteristics

The use of exclosures with trenches is recommended in areas where surface runoff and soil loss are concerns. According to the WOCAT standard, this SLM technology is categorized under vegetative and structural SWC measures (**Table 58**).

Table 58. Characteristics of exclosures integrated with trenches as an SLM technology for degraded hillsides

Criterion	Description
• SLM group	Exclosure, improved vegetation cover, plantation management, forest management, and grazing land management
• SLM measure	Structural measures and vegetative measures
• Type/s of land degradation addressed	Soil erosion by water, and physicochemical and biological soil degradation
• Stage/s of intervention	Prevention, mitigation, and restoration

Practical specifications

Establishment of an exclosure with trenches requires various routine activities and inputs (**Tables 59** and **60**). The technology is applicable in a wide range of agroecological settings and is not affected, or only barely affected, by socioeconomic conditions (**Table 61**).

Table 59. Activities and their corresponding frequencies and timings for establishing and maintaining an exclosure integrated with trenches

Activity	Annual frequency	Appropriate timing
Establishment		
• Hold community meetings	As needed	During farmers' off-season
• Identify target hillsides	Once	During farmers' off-season
• Set community bylaws	Once	During community meetings
• Establish exclosure	Once	Before rainy season begins
• Fence if necessary	Once	During farmers' off-season
• Construct trenches	Once	Before rainy season begins
• Enrichment plantation of forage species	As needed	Whenever appropriate
Maintenance		
• Repair fences	As needed	Whenever appropriate
• Repair trenches	As needed	Whenever appropriate
• Monitor and evaluate	As needed	At grass harvesting

Table 60. Inputs and costs (ETB ha^{-1} $year^{-1}$, 2020 price levels) for establishment and maintenance activities for exclosures integrated with trenches

Input	Units	Quantity	Unit cost	Total cost (ETB)
Establish exclosure by fencing				
• Wooden fence poles	No.	400	32	12,800
• Wooden fence panels	No.	400	91	36,400
• Nails (131/kg)	kg	20	105	2100
• Carpenter	PDs	2	175	350
• Daily labor	PDs	22	105	2310
Establish trenches (200 trenches ha^{-1})				
• Labor for trenching	PDs	133	105	13,965
• 10% for hand tools and surveying				1396
Subtotal				**69,321**
Maintenance				
• Wooden fence poles	No.	40	32	1280
• Wooden fence panels	No.	40	91	3640
• Nails (131/kg)	kg	2	105	210
• Carpenter	PDs	1	175	175
• Daily labor	PDs	4	105	420
• Labor for repairing trenches	PDs	28	105	2940
Subtotal				**8665**
Total[a]				**77,986**

Remarks (in Table 60): [a]Total cost could be reduced by 76% if fencing were not required (i.e., total cost for trench construction and maintenance could be only 18,301 ETB). The cost for trench construction was calculated by assuming a 1-ha area with a 400-m perimeter, with 200 trenches ha^{-1} on steeply sloped hillsides, and considering the smallest trench dimensions (3 m long, 10-m spacing between two consecutive rows, and 2-m spacing along contour). The amount of labor for trench construction is based on the work norm stated by Desta et al. (2005). 1 ETB = 0.029 US$ as of 3 July 2020 (considered as the average exchange rate of the year). PDs, person-days.

Table 61. Ecological and socioeconomic conditions suitable for implementing exclosures integrated with trenches.

Condition	Class/type
Ecological	
• Climate	All climatic regions where hillsides need restoration
• Average annual rainfall	All rainfall regimes where hillsides need restoration
• Landform	Mountain slopes/hillslopes
• Slope	Steep (15%–30%) to extremely steep (>50%)
• Soil depth	Not affected by soil depth
• Soil organic matter	Very low (<1%) to medium (2.1%–4.2%)
• Altitude	All altitudes where hillsides need restoration
Socioeconomic	
• Farming system	Smallholder
• Landholding size	Not affected by landholding size
• Level of mechanization	Not affected by level of mechanization
• Wealth class of land users	Not affected by wealth status
• Landholding rights	Private and communal
• Land-use rights	Individual and communal

Procedures/steps for implementation

Step 1: Identification and discussion

✓ Identify hillsides requiring rehabilitation by implementing exclosures integrated with trenches.
✓ Hold meetings involving members of the surrounding community and other relevant stakeholders (local-level officers and experts).
✓ Conduct community-based participatory planning to smoothly implement the practice.

Step 2: Setting bylaws and establishing the exclosure

✓ Create or update bylaws of sharing responsibilities and benefits among community members (see also section 2.2.3).
✓ Discuss and decide on the method of establishing the exclosure (i.e., by fencing targeted degraded hillsides or by making use of effective traditional practices such as rules or bylaws for church forest conservation/protection). For instance, in the context of Ethiopian history, many of the church forests are protected by their religious stewards and the communities around them.

Step 3: Installation of conservation trenches

✓ Calculate the number of trenches to be installed on the basis of the slope and rainfall conditions (see **Annex 5**).

- ✓ Prepare the required materials/tools and install the trenches, in a staggered arrangement, any time during the dry season, taking the following items into account:
  - When staggered trenches are installed in consecutive rows, the trenches in the upper row and the interspace in the lower row must be directly below each other (**Figure 17**) so that runoff and sediment from the interspaces of upper rows can be trapped by the trenches in the lower rows.
  - The excavated soil material should be thrown downhill of the trenches to create a ridge (bund) that is about 0.3 m wide and 0.2 m high, with a spacing (berm) of 0.2 m between the trench and bund.
  - The horizontal interval between two consecutive rows should be determined on the basis of the rainfall intensity, expected runoff, and land slope: rows can be as close as 5 m on steeper slopes and as far apart as 30 m on gentle slopes (FES, 2008; see also **Annex 5**).

Step 3: Monitoring and evaluation

- ✓ Regularly supervise the site and document information about challenges and opportunities for sustainability.
- ✓ Advise land users on when and how to harvest and share forage biomass.
- ✓ Maintain trenches in areas where runoff needs to be conserved in situ.
- ✓ Perform enrichment plantation of improved forage species if applicable.

Impacts on key indicators

The impacts of exclosures with trenches on ecological, economic, and sociocultural indicators are summarized in **Table 62**. For example, they reduce runoff by 34%–68% and soil loss by 84%–94%, and they improve soil fertility by 29%–135% and soil organic carbon matter by 1%–31% (Ebabu et al., 2020).

Table 62. Impacts of implementing exclosures integrated with trenches on selected ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Ecological benefits							
• Runoff reduction	+++	+++	+++		34	68	34
• Soil loss reduction	+++	+++	+++		86	94	84
• Soil moisture increase	+++	+++	+++				
• Increase in plant cover and diversity	+++	+++	+++				
• Soil organic matter increase	+	++	++		1	31	19
• Increased restoration of forage species	+++	+++	+++				
• Soil fertility improvement[a]	+++	++	+++		90	135	29
• Flooding control	+++	+++	+++				
• Siltation reduction	+++	+++	+++				
Economic benefits							
• Crop yield increase	na	na	na				
• Fodder production increase[b]	+++	+++	+++		833	500	100
• Farm income increase	–/+	–/+	–/+				
Sociocultural benefits							
• Improved knowledge of SLM	++	++	++				
• Strengthened community institutions	++	++	++				

Table 62 (continued)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Benefit–cost ratio							
• In short term for establishment	++	++	++				
• In short term for maintenance	+++	+++	+++				
• In long term for establishment	+++	+++	+++				
• In long term for maintenance	+++	+++	+++				

Remarks (in Table 62): Impact scale was rated on the basis of expert judgement, and impact level was based on measurements made at three agroecological (lowland, midland, and highland) sites (Ebabu et al., 2019; 2020). [a]Based on average of changes in total nitrogen, available phosphorous, and available potassium levels 3 years after establishment of an exclosure combined with trenches (Ebabu et al., 2020); [b] impact level was calculated by using the annual biomass production (0.6 t ha^{-1}) from continuously grazed land (Yayneshet et al., 2009) as a baseline. Plus/minus signs indicate type and level of impacts: –/+, neutral; +, slightly positive; ++, positive; +++, very positive; na, not applicable.

Drawbacks of the technology and ways to overcome them

Exclosure integrated with trenches is an effective SWC measure that can result in the quick restoration of vegetation cover. However, it has its own drawbacks that a practitioner should be aware of and take appropriate measures to overcome (**Table 63**).

Table 63. Drawbacks of implementing exclosures integrated with trenches, and corresponding solutions

Drawback	Solutions
• Demands a very large amount of labor for trench installation	Use alternatives and proper spacing between trenches
• High cost of inputs for fencing, when necessary	Make use of locally available fencing resources, such as live fencing (spiny shrubs/bushes), and bylaws
• Needs willingness of all community members and commitment of experts	Awareness creation and engaging of relevant experts and stakeholders
• May result in conflict of interest among community members	Set equitable bylaws for sharing responsibilities and benefits
• May result in high livestock stocking rates on untargeted areas	Apply zero-grazing and cut-and-carry systems
• Creates a fear of loss of access to resources if benefit-sharing mechanisms are not equitable	Ensure sustainable access to ecosystem services and benefits

2.3.2. Assisted vegetation establishment on degraded hillsides

Description

Assisted vegetation establishment refers to the practice of supporting the survival rate and growth performance of seedlings on degraded lands. This can be done in two ways: (1) by applying commercial soil inoculants (beneficial microbes—rhizobial bacteria and mycorrhizal fungi—collected, processed, and packed by companies) as seed coatings or directly to the roots of seedlings; and (2) by using the soil microbiome from well-protected and conserved sites (such as forests) as organic fertilizer inputs for nursery production and seedlings planted on degraded lands (**Figure 18**). For instance, Wassie et al. (2009)

suggested that soils from well-conserved sites such as the remnant church forests of Ethiopia could serve as potential sources of soil microbiome for the restoration of degraded lands using native tree species. This guideline provides a description and evidence of vegetation development at a greenhouse and under degraded field conditions by using soil microbiome from a remnant church forest (**Figure 18**).

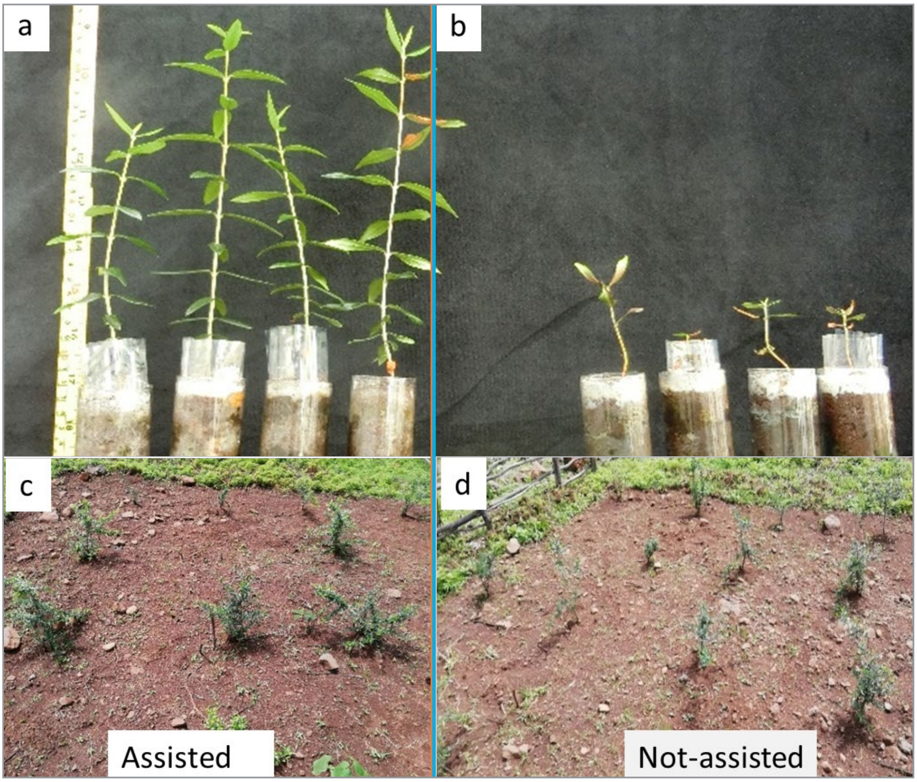

Figure 18. Partial view of *Olea europaea* seedlings assisted (left) and not assisted (right) by soil microbes from a church forest. (a) and (b) Growth performance of seedlings under greenhouse conditions (see Abebe et al., 2020b); (c) and (d) growth performance under degraded field conditions at the Aba Gerima site

Classification and characteristics

Assisted vegetation establishment can be categorized under diverse WOCAT SLM group categories (such as improved vegetation cover, plantation management, or soil fertility management) that enhance the survival and growth of vegetation and hence facilitate rapid restoration of degraded lands (**Table 64**).

Table 64. Characteristics of assisted vegetation establishment as an SLM technology for degraded hillsides

Criterion	Description
• SLM group	Improved vegetation cover, plantation management, soil fertility management, and forest management
• SLM measure	Vegetative and soil management
• Type/s of land degradation addressed	Biological soil degradation
• Stage/s of intervention	Rehabilitation and restoration

Practical specifications

Implementation of assisted vegetation establishment requires the undertaking of a wide range of activities (**Table 65**), the preparation of inputs (**Table 66**), and the identification of suitable ecological and socioeconomic conditions (**Table 67**).

Table 65. Activities and their corresponding frequencies and timings for establishing and maintaining assisted vegetation development on degraded hillsides

Activity	Annual frequency	Appropriate timing
Establishment		
• Excavate and transport soil	Once	Dry season
• Prepare seedling pots	Once	Dry season
• Sow	Once	Whenever appropriate
• Water during nursery period	Twice a week for 4–6 months	Early morning or night
• Establish exclosure (optional)	Once	Before planting
• Harden-off and transport	Once	At start of rainy season
• Plant	Once	At start of rainy season
Maintenance		
• Water	As needed	Early morning or night
• Cultivate to improve infiltration	As needed	Whenever appropriate
• Mulch to prevent moisture loss	As needed	Dry season
• Repair damage to fences (optional)	As needed	Whenever appropriate
• Protect saplings from any damage	As needed	Whenever appropriate

Table 66. Inputs and costs (ETB ha^{-1} $year^{-1}$, 2020 price levels) for establishment and maintenance activities for assisted vegetation establishment

Input	Units	Quantity	Unit cost (ETB)	Total cost (ETB)
Establishment of fences				
• Wooden fence poles	No.	400	32	12,800
• Wooden fence panels	No.	400	91	36,400
• Nails (131/kg)	kg	20	105	2100
• Carpenter	PDs	2	175	350
• Daily laborer	PDs	22	105	2310
Establishment of seedlings				
• Seed	kg	1	105	105
• Soil excavation and transportation	PDs	20	105	2100
• Seedling bags (100 pieces/pack)[a]	No.	5	105	525
• Preparation and sowing	PDs	40	105	4200
• Watering	PDs	20	105	2100
• Transportation and planting	PDs	100	105	10,500
Subtotal				**73,490**
Maintenance				
• Watering	PDs	100	105	10,500
• Mulching and cultivation	PDs	40	105	4200
• Repair fence and plant protection	PDs	2	105	210
Subtotal				**14,910**
Total				**88,400**

Remarks (in Table 66): Total establishment cost could be reduced by 73% if fencing were not required (see also section 2.3.1). [a]Size of seedling polyethylene tubes could be variable depending on several factors; for instance, polyethylene tubes should be sufficiently large to support survival and growth performance if seedlings are to be transplanted on severely degraded soils. 1 ETB = 0.029 US$ as of 3 July 2020 (considered as the average exchange rate of the year). PDs, person-days.

Table 67. Ecological and socioeconomic conditions suitable for implementing assisted vegetation establishment on degraded hillsides

Condition	Class/type
Ecological	
• Climate	All climatic regions
• Average annual rainfall	All rainfall regimes
• Landform	Hillsides
• Slope	Steep (15%–30%) to extremely steep (>50%)
• Soil depth	Not affected by soil depth
• Soil organic matter	Very low (<1%)
• Altitude	All altitudes
Socioeconomic	
• Farming system	Smallholder
• Landholding size	Not affected by landholding size
• Level of mechanization	Manual work
• Wealth class of land users	Not affected by wealth status
• Landholding rights	Private and communal
• Land-use rights	Individual and communal

Procedures/steps for implementation

Step 1: Identification and preparation

- ✓ Identify native tree species suitable for target sites of vegetation restoration.
- ✓ Identify potential sources/sites of soil inoculants/soil microbiome.
- ✓ Prepare materials and schedule activities for excavation and transportation of soil microbiome from conserved sites, or purchase from commercial sources.
- ✓ Import soil microbiome to the nursery site and prepare seedling pots by using appropriate sizes of polythene bags.

Step 2: Seedling production at the nursery

- ✓ Sow seeds on seedbeds, provide water, and transplant seedlings from seedbeds to prepared pots (or seeds can be sown directly to seedling pots).
- ✓ Supply water to seedlings at about 3-day intervals for 3–4 months.
- ✓ Protect from damage by diseases, pests, and extreme weather conditions.
- ✓ Remove weeds that can compete for valuable resources.

Step 3: Hardening-off and transporting seedlings

- ✓ To harden-off seedlings, remove sheds, reduce the frequency of watering, and finally expose the seedlings to field conditions for about a week before planting.
- ✓ Dig out planting holes (as deep as the seedling pots, and two to three times the diameter of the pot) along contour lines, considering the optimum spacing between plants and rows depending on the type of target plant species; note that planting holes could be prepared in advance (3–5 weeks before planting) and that topsoil must be

separated from the subsoil at digging.

- ✓ At the time of planting, put the seedlings into the holes; backfill the topsoil first, followed by the subsoil, and gently compact it by hand or using suitable tools; the root collar must be kept at the surface position or a bit over it, but not below it.

Step 4: Monitoring and nurturing

- ✓ Check the survival rate and growth performance of seedlings at a regular interval.
- ✓ Provide water to increase the rates of survival and growth during the dry season.
- ✓ Cultivate the soil around the seedlings to increase infiltration of rain/irrigation water.
- ✓ Apply mulch, if applicable, to prevent loss of moisture through evaporation.
- ✓ Remove weeds that may compete for water and available nutrients.
- ✓ After conducting a survival count, replant in locations where seedlings are dead or likely to die.

Impacts on key indicators

If properly implemented, assisted vegetation establishment offers a wide range of benefits (as indicated by positive to very positive impacts on key indicators) in the different agroecological zones (**Table 68**).

Table 68. Impacts of implementing assisted seedling development on selected ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Ecological benefits							
• Runoff reduction	+++	+++	++				
• Soil loss reduction	+++	+++	++				
• Soil moisture increase	na	na	na				
• Increase in plant cover and diversity	+++	+++	+++				
• Soil organic matter improve	+++	+++	+++				
• Soil fertility improvement	+++	+++	+++				
• Flooding control	na	na	na				
• Siltation reduction	na	na	na				
Economic benefits							
• Crop yield increase	na	na	na				
• Biomass production increase	+++	+++	+++			40–80	
• Farm income increase	na	na	na				
Sociocultural benefits							
• Improved knowledge of SLM	++	++	++				
• Strengthened community institutions	++	++	++				
Benefit–cost ratio							
• In short term for establishment	+	+	+				
• In short term for maintenance	+	+	+				
• In long term for establishment	+++	+++	+++				
• In long term for maintenance	+++	+++	+++				

Remarks (in Table 68): Impact scale is rated on the basis of expert judgement, and impact level is based on the results of a greenhouse experiment (Abebe et al., 2020b). The number of plus signs indicates the level of positive impacts: +, slightly positive; ++, positive; +++, very positive; na, not applicable.

Drawbacks of the technology and ways to overcome them

The implementation of assisted vegetation establishment has some drawbacks (**Table 69**), mainly related to the labor and material costs and the degradation of conserved sites such as church forests when commercial inoculum sources are not available.

Table 69. Drawbacks of implementing assisted vegetation establishment, and corresponding solutions

Drawback	Solutions
• May cause degradation of conserved sites (overexploitation)	Substitute with soils from construction sites or other suitable sources
• Requires a huge amount of labor for transportation from remote sites	Establish nursery sites close to source sites, or use other possible options
• Demands large polyethene tubes	Use cheaper and locally available biodegradable materials

2.4. SLM technology for all land-use types: *Acacia decurrens* plantations

Description

Acacia decurrens, an Australian species that is commonly known as black wattle or early green wattle, is a perennial fast-growing tree that grows to a height of up to 15 m (Hunde and Gizachew, 2003). This tree species was introduced into the highlands of Ethiopia in the early 1990s as a short-rotation forestry plant to counter urban firewood shortages. Although the main purpose of growing *A. decurrens* is to generate cash income from charcoal, and for use as a source of firewood and construction materials, it also improves soil fertility as a nitrogen-fixing species. It is a member of the Fabaceae family. Plantations can be established in different ways: through seedling recruitment from nurseries or direct sowing (seeding) at a site, or through natural seed dispersal agents (water, wind, and animals). In Ethiopia, suitable growing regions have elevations over 1500 m a.s.l and receive mean annual rainfall of between 1000 and 2500 mm (**see Figure 1**); i.e., the plant grows well in the Moist and Wet Weyna Dega and Dega agroclimatic zones.

According to Webb et al. (1984), *A. decurrens* cultivation is successful in regions with the following climatic conditions: mean annual rainfall between 900 and 2000 mm with a dry season that is 2–3 months long, uniform summer rainfall regime, mean annual temperature between 12 and 18 °C, mean maximum temperature of the hottest month between 16 and 24 °C, and mean minimum temperature of the coldest month between 2 and 10 °C. Ruskin (1983) noted that *A. decurrens* prefers deep, light to medium, and free-draining soils and that it occurs naturally on moderately fertile soils, including in acidic and neutral pH soil conditions.

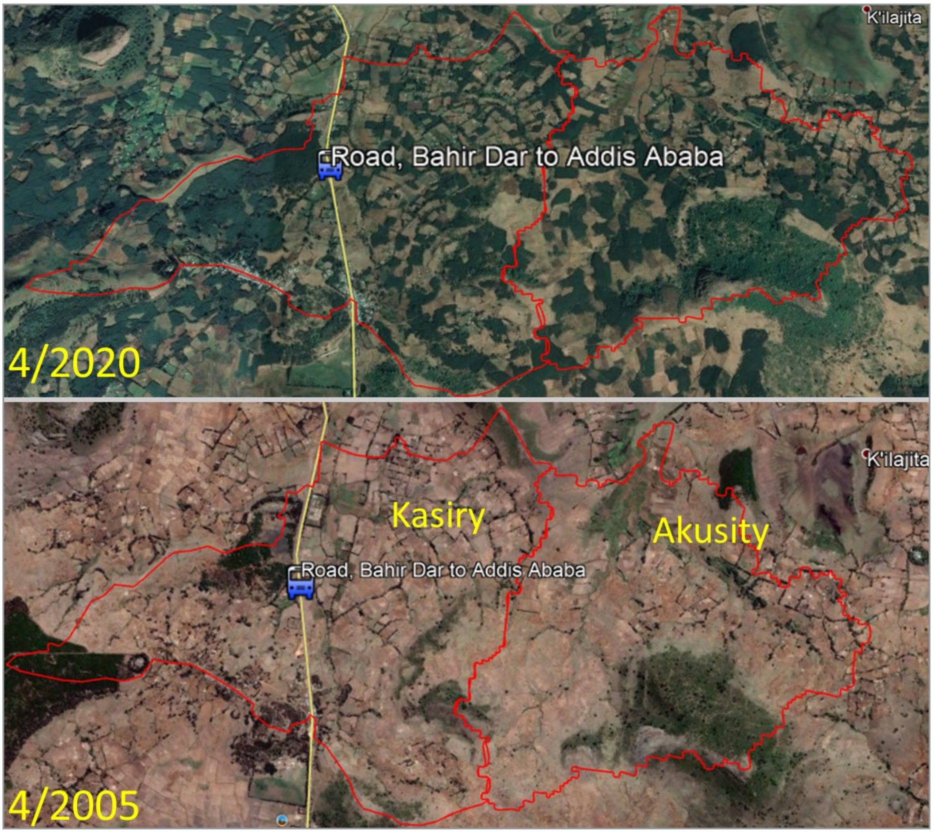

Figure 19. Google Earth images showing coverage of *Acacia decurrens* plantations (the change in green cover between 2005 (lower image) and 2020 (upper image)) in the humid highland agroecological zone (the case of Kasiry and Akusity watersheds in Guder site) of the Abay basin. The increase in coverage was greater later in the period (2014–2019; Danyo, 2014) as the result of rapid adoption of these plantations as an agroforestry practice

Classification and characteristics

According to the WOCAT standard, *A. decurrens* plantation can be categorized under different SLM groups (agroforestry, plantation management, rotational system, energy efficiency, economic efficiency, and improved vegetation cover) (**Table 70**). It provides multiple benefits, such as improving the incomes of land users, improving soil fertility, and reducing soil loss.

Table 70. Characteristics of *Acacia decurrens* plantations as an SLM technology for all land-use types

Criterion	Description
• SLM group	Agroforestry, rotational systems, improved vegetation cover, plantation management, economic efficiency, and energy efficiency
• SLM measure	Vegetative
• Type/s of land degradation addressed	Soil erosion by water, and soil fertility decline
• Stage/s of intervention	Prevention, mitigation, and restoration

Practical specifications

A number of different activities are needed to establish *A. decurrens* plantations as an SLM practice (**Table 71**). These include fulfilling inputs (**Table 72**) and identifying suitable ecological and socioeconomic conditions (**Table 73**).

Table 71. Activities and their corresponding frequencies and timings for establishing and maintaining *Acacia decurrens* plantations

Activity	Annual frequency	Appropriate timing
Establishment		
• Seed collection	Once	Whenever appropriate
• Nursery preparation	Once	Dry season or off-season
• Seeding	Once	Dry season or off-season
• Watering	Twice a week for 7–8 months	During nursery period
• Transplanting	Once	Summer season
• Fencing (optional)	Once	After planting
Maintenance		
• Maintaining fences	Once	After planting
• Weeding	As needed	Whenever appropriate
• Harvesting	Once	4–5 years after planting
• Charcoaling	Once	Dry season
• Transportation	Once	Dry season

Table 72. Inputs and costs (ETB ha^{-1} $year^{-1}$, 2020 price levels) for establishment and maintenance of an *Acacia decurrens* plantation

Input	Units	Quantity	Unit cost (ETB)	Total cost (ETB)
Establishing seedlings				
• Seed	kg	1	105	105
• Polyethylene tubes (100 pieces/pack)	No.	100	35	3500
• Bed/pot preparation	PDs	10	105	1050
• Seeding	PDs	1	105	105
• Watering	PDs	32	105	3360
• Planting	PDs	8	105	840
Establishing fence (optional)				
• Wooden fence poles		400	32	12,800
• Wooden fence panels	No.	500	50	25000
• Nails (131/kg)	No.	20	105	2100
• Carpenter	PDs	2	105	210
• Daily labor	PDs	22	105	2310
Subtotal				**51,380**
Maintenance				
• Stand cutting	PDs	30	105	3150
• Chopping	PDs	40	105	4200
• Pile-making	PDs	10	105	1050
• Charcoaling and packing	PDs	10	105	1050
• Transportation	PDs	20	105	2100
Subtotal				**11,550**
Total[a]				**62,930**

Remarks (in Table 72): [a]Total establishment cost could be reduced by 83% if fencing were not required (if free grazing is not a problem or when the target plot is bordered by a plantation that has a similar timing for establishment, or when crops are intercropped at the early stages of the plantation) (i.e., total cost could be 20,510 ETB). The amount of labor (PD) for each activity was determined arbitrarily, and the estimated corresponding cost was based on the work norm documented by Desta et al. (2005). 1 ETB = 0.029 US$ as of 3 July 2020 (considered as the average exchange rate of the year). PDs, person-days.

Table 73. Ecological and socioeconomic conditions suitable for implementing an *Acacia decurrens* plantations

Condition	Class/type
Ecological	
• Climate	Sub-humid to humid
• Average annual rainfall	1000–3000 mm
• Landform	All landforms that allow plant growth
• Slope	Flat (0%–3%) to very steep (30%–50%)
• Soil depth	Shallow (21–50 cm) to very deep (>120 cm)
• Soil organic matter	Very low (<1%) to high (>4.2%)
• Altitude	1500–3000 m above sea level
Socioeconomic	
• Farming system	Smallholder
• Landholding size	Not affected by landholding
• Level of mechanization	Manual work or animal traction
• Wealth class of land users	Not affected by wealth status
• Landholding rights	Private and communal
• Land-use rights	Individual and communal

Procedures/steps for implementation

Step 1. Seedling production

- ✓ Select an appropriate nursery site considering access to water and management.
- ✓ Prepare soil, seeds, seedbed, and seedling pots suitable for the purpose.
- ✓ Sow seeds directly to seedling pots or transplant seedlings germinated on seedbeds or other medium.
- ✓ Supply water twice a week for 7–8 months before planting.
- ✓ Harden-off seedlings before planting: stop watering and expose to sun, heat, cold, and wind for about a week until planting in the field.

Step 2. Planting and post-planting activities

- ✓ Transport seedlings to the planting site and prepare planting holes/furrows along the contour lines.
- ✓ Put seedlings into a hole or furrow in a straight-up position and at proper spacing between rows (about 2 m) and plants (about 1.5 m).
- ✓ Remove seedling bags if they are not biodegradable.
- ✓ Backfill the excavated topsoil, followed by the subsoil, and gently compact it.
- ✓ Remove competing weeds and protect against damage by diseases and pests.
- ✓ Thin and prune, when necessary, to facilitate maximum wood-volume production.
- ✓ If applicable, provide water during dry periods to enhance survival and growth rates, particularly in areas where soil-water-holding capacity is poor.

Step 3. Harvesting and charcoal production

- ✓ Prepare labor and materials for harvesting and charcoaling activities.
- ✓ Harvest the forest stand at the age of 4–5 years and during a dry season.
- ✓ Conduct debranching so that the main parts can be used to make charcoal (trunks and thick branches).
- ✓ Chop the trunks and large branches into smaller pieces (≤ 1 m) and make a pile (**Figure 20).**
- ✓ Cover the pile with twigs followed by soil and wait until it is ready for firing and charcoaling.
- ✓ Make the charcoal by firing (heating the piled wood in minimal oxygen to remove all water and volatile constituents).
- ✓ Process and pack the charcoal in bags appropriate for transportation; any remaining small particles can be used as biochar.

Figure 20. The four key activities for an *Acacia decurrens* plantation that produces charcoal: seedling production, plantation, harvesting, and charcoaling. It is worth noting that food or feed production is also possible during the early stages of the plantation

Impacts on key indicators

The impacts of implementing *A. decurrens* plantations as an SLM practice are presented in **Table 74**. Reduction in soil loss by up to 96% (Ebabu, 2016) and improvement in income by up to 158% (Nigussie et al., 2020) are the most notable positive impacts.

Table 74. Impacts of implementing an *Acacia decurrens* plantation on selected ecological and socioeconomic indicators at three agroecological sites (LL, lowland; ML, midland; and HL, highland)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Ecological benefits							
• Runoff reduction[a]	na	na	++				43
• Soil loss reduction	na	na	+++				96
• Soil moisture increase	na	na	–/+				
• Increase in biodiversity[b]	na	na	–				
• Soil organic matter improvement	na	na	+++				
• Soil fertility improvement	na	na	+++				
• Flooding control	na	na	–/+				
• Siltation reduction	na	na	–/+				
Economic benefits							
• Crop yield increase	na	na	+++				
• Fodder production increase	na	na	–/+				
• Farm income increase	na	na	+++				158

Table 74 (continued)

Key indicator	Impact scale				Impact level (%)		
	LL	ML	HL		LL	ML	HL
Sociocultural benefits							
• Improved knowledge of SLM	na	na	+++				
• Strengthened community institutions	na	na	+++				
• Improve sense of ownership	na	na	+++				
Benefit–cost ratio							
• In short term for establishment			–/+				
• In short term for maintenance			–/+				
• In long term for establishment			+++				
• In long term for maintenance			+++				

Remarks (in Table 74): Impact scale was rated on the basis of expert judgement, and impact level was based on measurements made at the highland agroecological (Guder) site (Ebabu, 2016; Nigussie et al., 2020). Plus/minus signs indicate type and level of impacts: –, slightly negative; –/+, neutral; +, slightly positive; ++, positive; +++, very positive; na, not applicable. [a]High runoff production can be a concern during the later stage of a plantation because of the formation of sealed surfaces and poor infiltration (Demissie et al., 2022b, paper in preparation; **Figure 21**). [b]The impact on biodiversity is negative when the planting density is high and at later stages of the plantation (**Figure 21**).

Figure 21. Changes in soil protective cover under an *Acacia decurrens* plantation: dense canopy and understory vegetation cover at an early stage (left) that can provide forage biomass and protection against soil erosion by rainfall or overland flow versus a bare and sealed ground surface at a later stage (right) of the plantation, which can result in high runoff and related impacts downstream (Ebabu, 2016; Sultan et al., 2018b)

Drawbacks of the technology and ways to overcome them

Although implementation of an *A. decurrens* plantation is largely beneficial, there are some drawbacks that the practitioner should be aware of and take appropriate measures to overcome (**Table 75**). Among these, high susceptibility of the plant to disease/insect damage and lack of understory vegetation at the later stages of the plantation are the most important drawbacks.

Table 75. Drawbacks of implementing an *Acacia decurrens* plantation, and corresponding solutions

Drawback	Solutions
• Nursery preparation and harvesting are labor intensive	Use alternatives or improved methods and materials/tools
• Requires quarry and transportation of soils of inoculum source	Use easily accessible and sustainable inoculum sources
• No understory vegetation, and formation of a sealed ground surface during later stages (**Figure 21**)	Use proper spacing and management practices to allow growth of grasses/shrubs and water infiltration
• Affects children's schooling because of their engagement in e.g., maintenance activities	Replace manual work with machinery or prohibit engagement of school children
• The existing species is highly affected by disease/insect damage	Apply appropriate disease-control measures or introduce an improved cultivar

3. Approaches to watershed-level SLM practices

3.1. Community-based participatory gully rehabilitation

3.1.1. Description

Community-based participatory gully rehabilitation is an approach in which members of a watershed community take on the main roles and responsibilities, with the support from relevant stakeholders (e.g., researchers and experts), for various activities (identification, planning, implementation, monitoring, and evaluation) of gully erosion prevention or control measures. In the Ethiopian highlands, gully formation and development are associated with high levels of runoff generated from intensively grazed fields, traditional ploughing practices, and improperly drained excess infiltration water from croplands (Yibeltal et al., 2019).

Several methods have been implemented to control runoff water from various sources and to enhance gully recovery (Desta and Adugna, 2012). The most widely implemented measures include (1) retention and infiltration ditches, (2) diversion ditches, (3) stone or wooden check dams, (4) gully reshaping and filling, (5) plantations, and (6) bans on free grazing through the use of exclosures and stall-feeding. This guideline describes an approach to improving community participation and ownership for gully rehabilitation. It is based on evidence from field experiments conducted through collaborative decision-making, proactive participation, and discussions with community members and other stakeholders (e.g., government officials, experts, and researchers). **Figure 22** illustrates the process and key activities of employing a participatory gully rehabilitation approach.

3.1.2. Procedures/steps for implementation: the case of gullies on communal grasslands

Step 1: Identification

- ✓ Identify areas prone to gully erosion and discuss the issue with community members and leaders.
- ✓ Gather information on areas where gully erosion has occurred and continues to be a major concern.
- ✓ Conduct a field visit involving key stakeholders (researchers, development agents, local administrators, and farmers); identify existing or potential gullies that require immediate action (**Figure 22**).
- ✓ Perform a detailed survey to collect baseline information. **Table 76** presents a list of parameters to be documented about five main factors controlling the rate/state of gully formation and rehabilitation.
- ✓ Propose potentially suitable measures, considering size and characteristics of the runoff contributing area (properties of upslope catchment area).
- ✓ Identify appropriate structures, such as check dams and diversion ditches.
- ✓ Propose suitable gully reshaping and plantation materials such as improved forage grass/legume or shrub species.

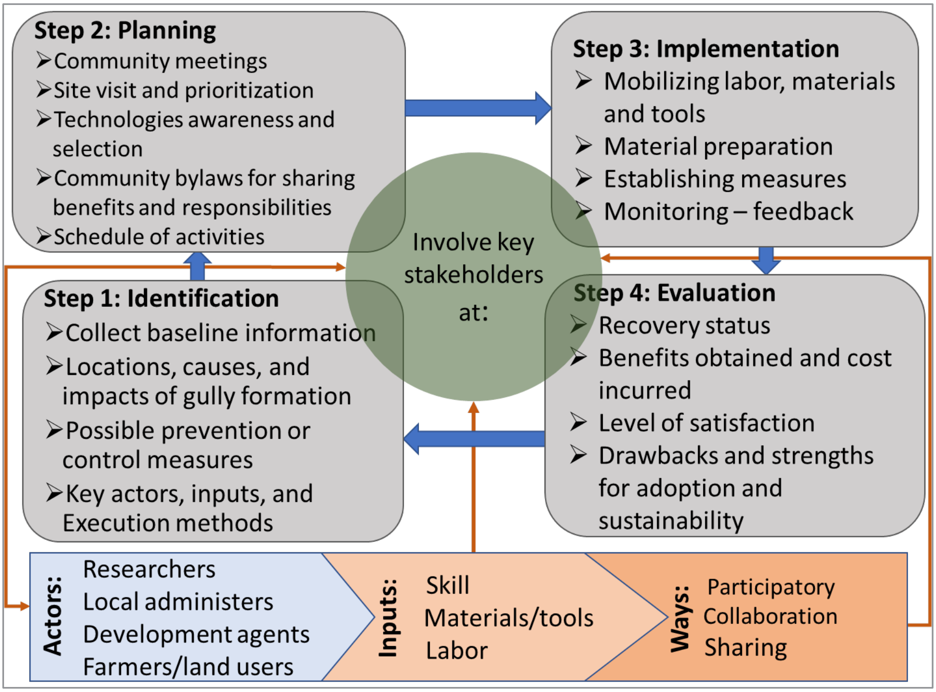

Figure 22. Schematic flowchart showing inputs and activities for a participatory gully rehabilitation approach: involving key stakeholders (actors), resources (inputs) to be effectively used, and ways (participation, collaboration, and sharing) to engage stakeholders in four steps/activities (identification, planning, implementation, and evaluation) of the whole process

Step 2: Planning

- ✓ Hold community meetings about key objectives.
- ✓ Create awareness of gully formation and control measures.
- ✓ Choose types of measures to be implemented, including in the upper catchment.
- ✓ Assign roles and responsibilities among members.
- ✓ Develop benefit-sharing bylaws and modalities.
- ✓ Plan activities and prepare a suitable schedule.

Step 3: Implementation of measures

- ✓ Mobilize labor, materials, and tools.
- ✓ Establish an exclosure through fencing or other methods.
- ✓ Promote stall-feeding through a cut-and-carry system.
- ✓ Establish selected measures as per the schedule.
- ✓ Document inputs used and contributions by members of the community (land users).
- ✓ Conduct regular monitoring and evaluation, maintain structures, and update bylaws about benefit sharing and responsibilities.

Step 4: Evaluation of outcomes

- ✓ Evaluate changes in vegetation cover, vegetation type, and soil properties by comparing gully areas before and after intervention.

- ✓ Collect data on gully characteristics and compare between before and after intervention.
- ✓ Estimate social, economic, and ecological benefits of the interventions.
- ✓ Identify key prospects and challenges for improvement and sustainability.
- ✓ Document best practices (lessons) for promotion to other areas.

Table 76. Baseline data to be collected about the main factors affecting gully formation and rehabilitation

Main factor	Parameters to be documented	Remarks
Gully characteristics	1. Location 2. Gully history (age and change over time) 3. Length 4. Width 5. Depth 6. Shape	Useful for implementation and evaluation
Biophysical conditions	1. Rainfall (amount and intensity) 2. Soil type 3. Vegetation type 4. Size of gully erosion affected area 5. Contributing area and its features (e.g., number of users, size, SWC density, slope, land use/cover; see **Figure 23**)	Useful for planning and selection of appropriate measures
Socioeconomic and cultural conditions	1. Number of users/farmers 2. Wealth status of farmers 3. Household characteristics 4. Landholding status 5. Religious issues 6. Farming practices 7. Embedded institutions	Useful for resource mobilization and selection of improved technologies
Livestock type, population, and grazing intensity	1. Total number of livestock in the area 2. Number of livestock by type 3. Number of livestock per household 4. Type of animal breed 5. Grazing frequency and timing	Useful to propose alternatives
Awareness of local community about improved practices	1. Improved forage development 2. Stall-feeding 3. Livestock management	

3.1.3. Showcase: Research evidence on the impact of community-based participatory gully rehabilitation in the midland agroecological site (Aba Gerima)

As shown in **Figure 23**, sediment transport through the gully channel can be effectively controlled by installing combined stone and brushwood check dams. Improved vegetation cover following exclosure can also provide suitable evidence that gully erosion control is possible through implementing zero-grazing (with a cut-and-carry system) integrated with structural measures. For instance, farmers harvested and shared the dry biomass of 3000 kg in the first year (11/2021) and 8200 kg in the second year (10/2022) of the experiment. This encouraged them to continue and adopt the practice at the community and individual levels.

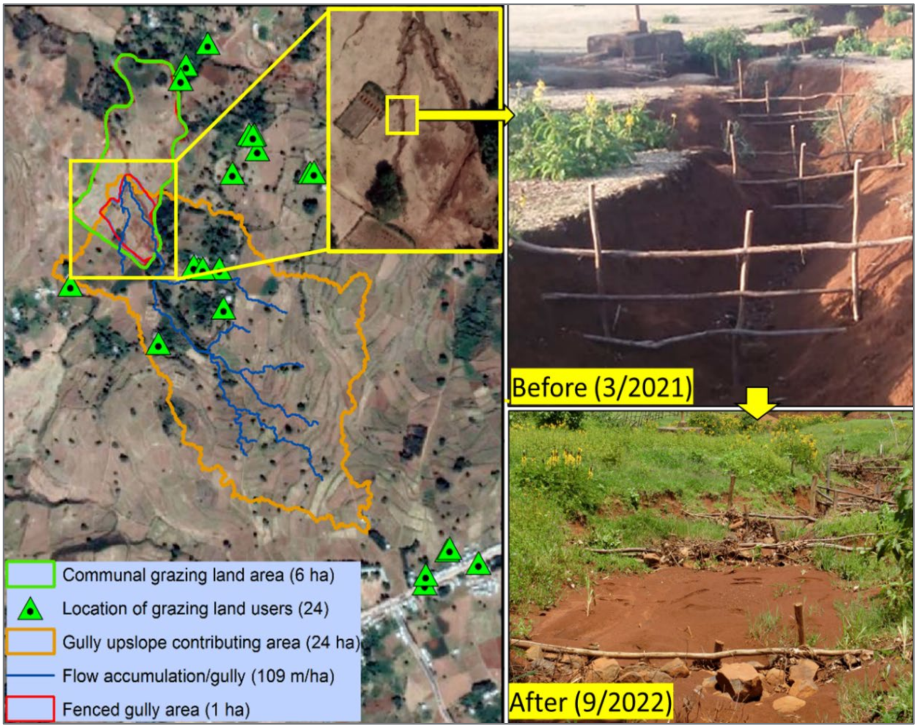

Figure 23. Effects of community-based participatory gully rehabilitation. Improvements in vegetation cover after fencing (exclosure) of 1 ha of grazing land affected by gully erosion, as well as the sediment-trap efficiency of stone and brushwood combined check dams, can be seen in the "after" photo. A total of 24 farmers who were direct users of the grazing land (6 ha) were engaged at different stages (planning, implementation, and evaluation) of the rehabilitation experiment. Note: flow direction was to the north; information on the upper contributing area and flow accumulation/potential gully were extracted from very high resolution (0.5-m) digital elevation model data

3.2. Developing alternative land-use and management scenarios

3.2.1. Description

Developing alternative land-use and management scenarios is an effective approach to evaluating possible options by exploring the implications of implementing these scenarios at watershed to basin levels. It involves integrating land-use and management options on the basis of land capability classification (i.e., the grouping and mapping of land units into various classes based on inherent limitations for sustainable use; these are associated mainly with soil attributes, topography, drainage, and climate) and the efficiency of selected technologies verified through field-plot experiments (Fenta et al., 2022, paper submitted for publication). The approach provides possible future land-use and management options coupled with their estimated impacts on the natural environment and economic return. It facilitates stakeholders' decision-making when selecting and scaling-out suitable land-use and management practices (**Figure 24).**

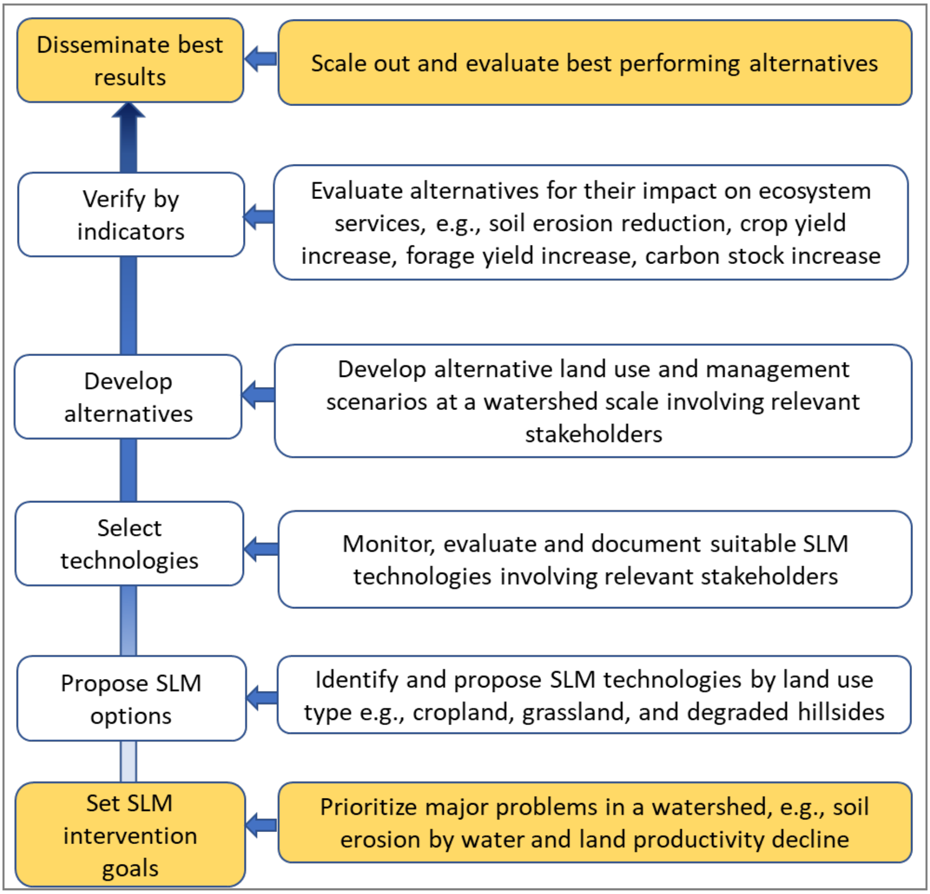

Figure 24. Methodological flowchart for land use-based evaluation and scaling out of best watershed management practices

The approach for developing alternative future land use and management scenarios comprises six complementary steps (**see section 3.2.2**): (1) land-use-problem identification and objective setting, (2) identification of best-performing land-use options, (3) formulation of alternative future scenarios and modeling of key indicators, (4) cost–benefit analysis, (5) monitoring and evaluation of alternative future scenarios through stakeholder workshops, and (6) communication of the alternative future scenarios to relevant stakeholders for institutional and financial support for implementation (Fenta et al., 2022, paper submitted for publication).

3.2.2. Steps to develop and evaluate alternative land-use and management scenarios

Step 1: Problem identification and objective setting

- ✓ Perform baseline surveys followed by extensive field-based experiments to identify the mainland-use problems in the target watershed.
- ✓ Identify the type of farming system and activities that are the main sources of livelihood.

- ✓ Identify land-use types and coverage that have high levels of soil erosion.
- ✓ Characterize the target watershed in terms of land and livestock productivity.
- ✓ Identify potential land-use and management practices to reduce soil erosion and improve land productivity specific to the target watershed.
  - In the context of this approach, "land productivity indicates the value of agricultural products per unit area of land".

Step 2: Identification of best solutions on the basis of land use

- ✓ Evaluate potential land management practices to reduce runoff and soil loss and improve land productivity.
- ✓ Identify the best-performing land-use and management practices to formulate land use and management scenarios.

Step 3: Formulation of alternative future scenarios and modeling of key indicators

a. Developing alternative future land-use and management scenarios

- ✓ Develop land-use options based on the land capability classification (LCC) proposed by the Federal Democratic Republic of Ethiopia Ministry of Agriculture (FDRE MoA, 2020).
- ✓ Create the proposed LCC map and superimpose it on the existing land-use map to check whether or not each land capability unit is suitable for the existing land use.
- ✓ When a land unit is suitable for the existing land use, identify and check appropriate land management practices.
- ✓ Once the land-use options are identified, incorporate the best-performing land-management options for specific land-uses based on the research results.

b. Modeling key indicators

- ✓ Identify main land use problems in the target area, which in this case, are severe soil erosion and poor land productivity.
- ✓ Model the ecosystem services related to erosion reduction and land productivity improvement compared with the baseline scenarios.

c. Estimation of changes in soil organic carbon stocks

- ✓ Study changes in the soil organic carbon (SOC) stocks to assess the impacts of land-use and management alternatives.
- ✓ Evaluate changes in the SOC stocks on the basis of a laboratory analysis of soil samples from different land uses before and after the implementation of management practices.
- ✓ Calculate the total SOC in the top 20 cm of soil for specific land uses at the watershed scale in accordance with the method of Ellert and Bettany (1995).

d. Estimation of changes in runoff and soil loss

- ✓ Evaluate the potential impacts of alternative future land-use and management scenarios on runoff and soil erosion by integrating plot-scale and watershed-scale measurements.
- ✓ Evaluate the individual and combined impacts of land-use change by using suitable

models such as the SWAT (Soil and Water Assessment Tool) (Berihun et al., 2022).

- ✓ Propose alternative future land-use and management scenarios on the basis of research results regarding the impacts on runoff and soil erosion in the target watershed.
- ✓ Present the scenarios by using models (e.g., SWAT) and modifying the appropriate values of parameters to reflect the effects of alternative future scenarios on runoff and soil erosion.

e. Estimation of changes in land productivity

- ✓ Estimate land productivity (ETB ha^{-1} $year^{-1}$) for target products (crop and livestock), i.e., analyze the grain and straw yield of food crops from croplands, and biomass yield of feed resources from all land uses in the watershed.
- ✓ Estimate the monetary values (ETB ha^{-1} $year^{-1}$) of the feed resources on the basis of the number of target livestock type.
- ✓ Estimate watershed-scale land productivity (ETB ha^{-1} $year^{-1}$) on the basis of the area-weighted productivity of all land uses under the baseline and alternative future scenarios.

Step 4: Cost–benefit analysis

- ✓ Translate the monetary units of land productivity into a net present value (NPV), because investments in future land-use and management scenarios generate their full potential only after a number of years have passed.
- ✓ Set a decision criterion to compare the economic profitability of the alternative future land-use and management scenarios on the basis of the NPV values.
- ✓ Compute the NPV as the sum of the difference between the present values of the benefits and associated costs (all discounted net cash flows) over an investment period (Kay et al., 2003; Godsey et al., 2009).
- ✓ Compare the financial profitability over a given period.
- ✓ Analyze the sensitivity of the cost–benefit analysis of the investment alternatives with respect to the main indicators of land productivity by varying the price levels of the target products.

Step 5: Evaluate alternative future land-use and management scenarios with stakeholders

- ✓ Select relevant stakeholders representing local communities, policymakers, researchers, and development professionals.
- ✓ Conduct stakeholder workshops to evaluate the alternatives according to multiple objectives related to the ecological, economic, and sociocultural benefits.

Step 6: Communicate alternative future land-use and management scenarios to stakeholders to gain institutional and financial support for implementation

- ✓ Present the alternative options to all relevant stakeholders (e.g., farmers, experts, policy makers, researchers).
- ✓ Communicate the selected alternatives to stakeholders through workshops, discussions involving the community, and brochures, and investors.
- ✓ Make sure that all stakeholders understand the proposed scenarios and the ultimate outcome of implementing them (see for example **Tables 77** and **78**).

3.2.3. Showcase: Research evidence on the impacts of alternative land-use and management practices at the highland agroecological site (Guder)

Taking the Kasiry watershed of Guder in the northwest of Ethiopia as a case study, results indicated that the proposed alternative land-use and management practices could bring about substantial reductions or improvements in key ecological and economic indicators (runoff, soil loss, soil organic carbon, land productivity, and profitability). For instance, a change in land use combined with the implementation of best-performing SLM practices reduced runoff by 71%–95% and soil loss by 75%–96%, and improved soil organic matter by 2%–51%, compared with the baseline condition (**Table 77**). Improvements in land productivity and profitability were also evident for the proposed changes in land use and the implementation of suitable land management practices **(Table 78**).

Table 77. Estimates of changes in watershed-scale annual runoff, soil loss, and SOC stocks for alternative land-use (LU) and management scenarios (SC-I to SC-V), based on the results of case studies for the Kasiry watershed in the highland agroecological zone of the Abay basin

Indicator	Scenario	Type of change		Change (%)[a]	
		LU	LU + SLM	LU	LU + SLM
Runoff (mm)	Baseline	719.6	–	–	–
	SC-I	548.3	207.6	-23.8	-71.2
	SC-II	493.2	115.9	-31.5	-83.9
	SC-III	382.3	80.1	-46.9	-88.9
	SC-IV	267.5	34.9	-62.8	-95.2
	SC-V	318.8	62.3	-55.7	-91.3
Soil loss (t ha^{-1})	Baseline	49.9	–	–	–
	SC-I	19.1	12.6	-61.6	-74.9
	SC-II	15.2	8.1	-69.5	-83.8
	SC-III	7.4	6.0	-85.2	-88.1
	SC-IV	3.3	2.0	-93.4	-96.1
	SC-V	4.8	2.7	-90.4	-94.6
SOC stock (Mg ha^{-1})	Baseline	52.9	–	–	–
	SC-I	52.9	57.6	0	9
	SC-II	59.1	67.5	12	27
	SC-III	50.5	53.8	-5	2
	SC-IV	62.2	66.8	17	26
	SC-V	74.6	80.2	41	51

[a]Change (%) = ((A-B) ÷ B)) × 100, where *A* is the runoff/soil/SOC value from the alternative scenario (SC-I to SC-V) and *B* is the runoff/soil loss/SOC value from the baseline (current land use and farmers' practices); Baseline is current land use and existing conventional farmers' practices; SC-I is current land use plus SLM practices; SC-II is No crop cultivation on steep slopes (>30%) plus SLM practices; SC-III is acacia plantation on suitable areas plus SLM practices; SC- IV is forage production on suitable areas plus SLM practices; SC-V is reforestation on degraded bushland and on hilly croplands plus SLM practices.

Table 78. Cash flows and NPVs (ETB ha^{-1} year^{-1}, 2020 price levels) for the proposed alternative future land-use and management scenarios (r = 10%) for a 10-year investment period for the Kasiry watershed

Scenario	Gross revenue	Gross cost	Net cash flow	Mean annual net cash flow	NPV
Baseline	273,369	180,417	92,953	9295	54,088
SC-I	443,050	196,015	247,035	24,703	145,183
SC-II	424,474	215,850	208,624	20,862	128,609
SC-III	425,500	187,910	237,590	23,759	136,836
SC-IV	500,428	249,245	251,183	25,118	151,711
SC-V	406,216	209,580	196,636	19,664	115,779

3.3. Developing an approach to SLM-based livelihood improvement

3.3.1. Description

Promoting inclusive watershed development approaches could largely contribute to the sustainability of SLM program efforts. As a result, an SLM-based livelihood improvement approach requires buy-in from watershed communities through all of its phases, which is particularly important in ensuring inclusive approaches to rehabilitating degraded watersheds. **Figure 25** shows a general practical framework for developing an SLM-based livelihood improvement system and five activity phases (**section 3.3.2**).

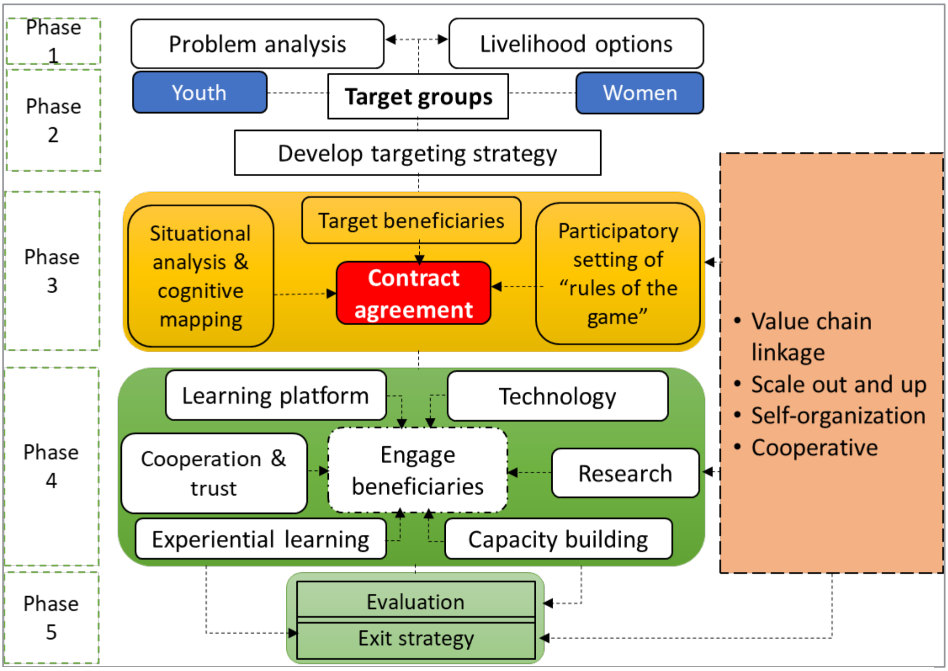

Figure 25. Practical flowchart for developing an SLM-based livelihood improvement system

3.3.2. Phases/steps to developing an inclusive livelihood improvement system

Phase 1: Understanding the local livelihood system of the target population

Livelihood analysis can be done by clearly profiling the "target groups" by detailing their available resources, livelihood activities, capacities and priorities, and constraints and opportunities (e.g., Abeje et al., 2019). The facilitator can start this activity by collecting baseline information through the combined use of formal (e.g., questionnaires) and informal (e.g., key informant interviews and focus group discussions) surveys (**Figure 26**). To implement this, the facilitator can involve a multidisciplinary team involving researchers with expertise in livestock, crops, horticulture, economics, extension, and natural resource management. After the information has been compiled, preliminary findings should be presented in a stakeholders' workshop. This type of workshop is important to get the community's feedback and validate the findings. This stage enables the facilitator to understand the local conditions and existing problems and their depths; identify appropriate target groups (youth, women, and the landless); explore opportunities on the basis of local contexts; and help build the interest of watershed communities.

Figure 26. Key informant interviews (top photos) and stakeholder meetings (bottom photos) to identify and engage appropriate targets (youth, women, and the landless)

Phase 2: Implementing effective targeting

Effective targeting can be done in two steps: (1) setting beneficiary selection criteria and procedures to follow on the basis of the local context, and (2) targeting specific beneficiary households. Both steps should be implemented with the involvement of the local community and the district-level watershed development team to understand the sociocultural context and create a sense of ownership (i.e., use a community-based approach). For effective community engagement, the facilitator can ask *district* -level agriculture experts to invite a range of villagers within the watershed to attend stakeholder meetings. The social composition of the groups (e.g., age, gender, wealth, and social and religious positions), expertise (e.g., development agents), and local administrative position (e.g., *kebele* administrators, watershed development committee members, and community police officers) can be considered when calling for local stakeholder participation. Meetings should be facilitated by local experts.

Attendees should be encouraged to list targeting criteria for beneficiaries and their corresponding weights (i.e., their relative importance). A possible list of targeting criteria that can be used and applied by the community includes: (a) gender composition, (b) age composition, (c) access to resources, (d) potential to take advantage of any extension support, and (e) potential to be a model for other individuals. At the meeting, the facilitator should summarize the objectives of the selection activity but assume only a facilitation role to the extent possible and refrain from creating unnecessary expectations. The meeting can be concluded by asking participants to assign an ad hoc committee with up to five members to come up with list of potential beneficiaries that is based on the set criteria.

The facilitator should ask this newly formed committee to come up with a preliminary list of beneficiaries (more than the required minimum number) and assign weighted values for each on the basis of the criteria set by the community. The facilitator then should be given the unweighted preliminary list of beneficiaries. (The assigned weighted values should remain with the committee.) Depending on the manageability of the process, the facilitator can then plan a door-to-door visit of each listed beneficiary and assign weighted values for each. The facilitator should then ask local experts to call for a community meeting to present the findings of both by himself and the committee, solicit feedback, and finalize a list of beneficiaries. This process will help to introduce transparent targeting, reach consensus on a list of beneficiaries, create trust, and minimize any potential risks of conflict within the community. At this stage, care should be taken to avoid the problem of "elite capture" (i.e., the biased allocation of public resources to benefit only a few individuals of superior social status, to the detriment of the rest of the population). In addition, the facilitator can initiate a general discussion of the potential livelihood opportunities within the watershed.

Phase 3: Evaluating existing situations and prospects for change

Depending on the feasibility, the facilitator can meet with beneficiaries individually or in a group. The facilitator should begin by broadly asking about each beneficiary's background and life experiences before getting into specific details. The facilitator can then proceed with profiling the specific circumstances of beneficiaries and highlighting available resources and livelihood activities. They can also ascertain their interest in engaging in various livelihood diversification options, as well as any constraints and opportunities and prospects for change. The facilitator should allow beneficiaries the chance to reflect on any new insights, ideas, or solutions that may have become evident during the process and that could inform possible actions.

Phase 4: Supporting and monitoring activities

At this stage, the facilitator should have a short list of specific livelihood options that have been suggested by individuals or the group. The facilitator can proceed with establishing a regular discussion platform that will create a space for collaborative learning among the beneficiaries. Through this platform, it is important to ignite their interest and motivation so as to enable them to widen their scope of activities, and arranging an experiential visit is one possible option. In an experiential visit, the facilitator identifies two or three model farmers who are engaged in similar activities in the same or neighboring villages. These model farmers explain their livelihood trajectories, thus potentially inspiring the visiting farmers. In addition, to enable beneficiaries to observe potential markets, the facilitator can arrange similar visits to commercial farms (e.g., poultry, dairy, food processors).

After the experiential visits, the facilitator should engage beneficiaries in problem diagnosis, enable them to suggest possible solutions, and motivate them to put forward their own solutions. It is important to enable beneficiaries to prioritize and undertake their own desired actions and develop improved livelihood aspirations. After potential actions (e.g., income-generating activities) have been carefully defined, criteria should be established for each activity before final selection. These criteria could include technical feasibility, skill requirements, profitability, social acceptability, cost of inputs, marketability, and self-sufficiency. After setting valid criteria in a participatory manner, the facilitator can call for a meeting of beneficiaries and ask them to assign scores (e.g., between 1 (very low) and 5 (very high)) to each of the criteria. Then, the final selection can be done on the basis of the score attained by each income-generating activity.

If the planned action requires resources, ask the beneficiaries to propose possible sources. Depending on the situation, the facilitator may need to look for support mechanisms, but the support should be extended on a cost-sharing basis between beneficiaries and support providers. The level of cost-sharing can be determined on the basis of the situation and the resource availability. The cost-sharing scheme must be established in a written contract that states clear terms for all parties. It is good to prepare the contract in collaboration with the beneficiaries and have both parties sign the contract.

The facilitator needs to look for additional ways to keep the beneficiaries engaged in their planned activities. The facilitator should make farmers active partners in the action research (identification, monitoring, and evaluation activities) to enable them to witness objectively measurable changes resulting from the activities they have been pursuing. This can be achieved through the following mechanisms:

a. **Technology promotion:** Introduce farmers to innovations (e.g., improved forage species, improved animal breeds, improved land-management practices, feed treatment, improved feeding troughs, compost preparation, and crossbreed bull services; **Figure 27**).
b. **Training (capacity development):** Provide farmers with hands-on training on new technologies and practices.
c. **Implementation:** Implement technologies in accordance with appropriate procedures and technical standards.
d. **Monitoring and evaluation:** Set up continuous monitoring mechanisms and tools (e.g., for evaluating weights, yields, biomass) and provide feedback, both individually and during discussion platforms.
e. **Experience-sharing and motivation:** As part of experiential learning, beneficiaries should physically evaluate each other’s activities and exchange feedback; they could be motivated by introducing “awards” for good performers. The type of incentive does not have to necessarily be something of high value.
f. **Provide access to markets:** Link activities with markets.
g. **Scaling-out**: Encourage beneficiaries to disseminate technologies and practices to their fellow non-beneficiary farmers. Organizing field days for stakeholders within and outside the watershed can enable them to disseminate their experiences with improved technologies and practices.
h. **Farmers’ business organizations:** Encourage beneficiaries to establish organizations (e.g., saving groups, users’ associations, cooperatives)

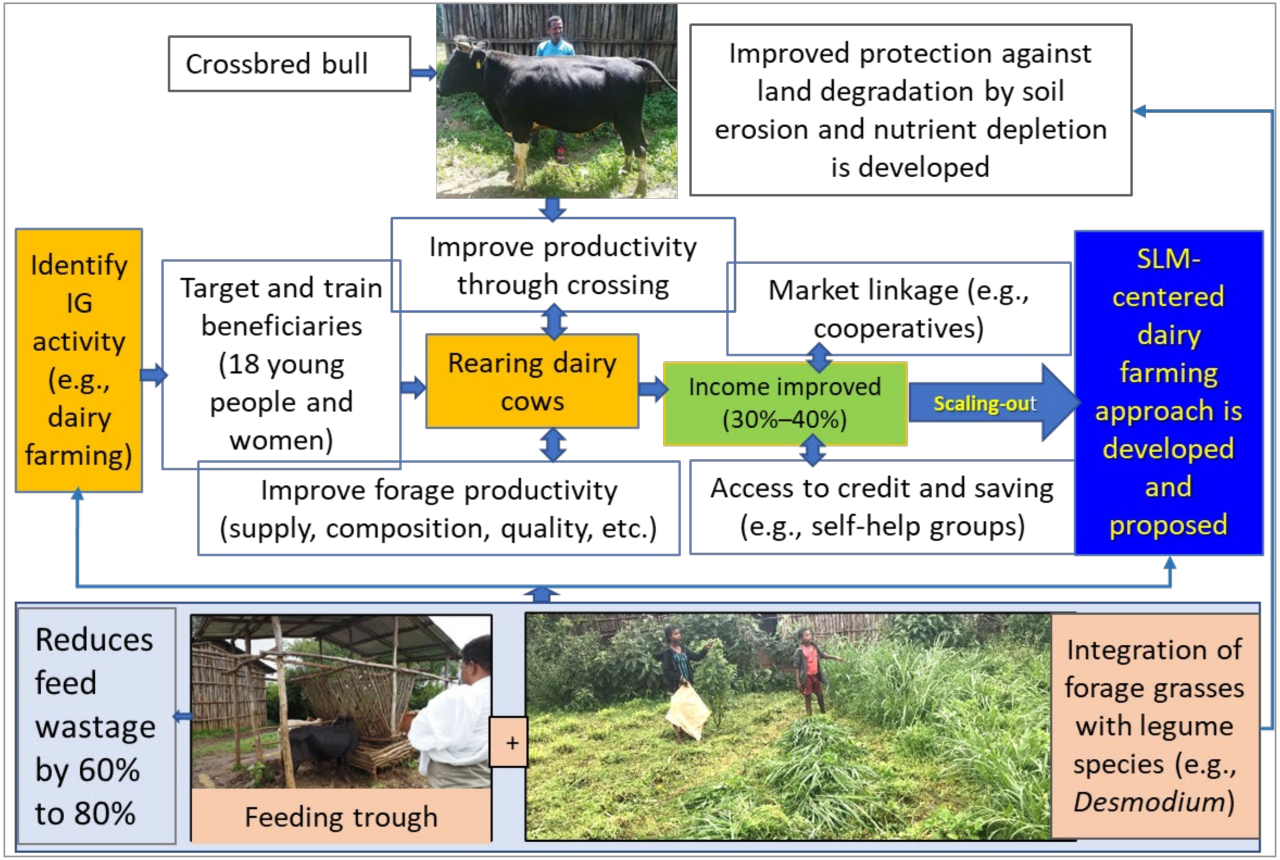

Figure 27. SLM-centered dairy farming developed by involving key components for income-generating (IG) activities

Phase 5: Evaluation and designing sustainability strategies

Facilitators need to proactively evaluate activities at different stages and enable the beneficiaries to make collaborative decisions. From the early stages, the facilitators need to think about "sustainability" issues to ensure continuity of outcomes. One possibility could be to enable the beneficiaries establish an institution—for example, a savings and credit group (**Figure 28**). Beneficiaries can decide by themselves on the modalities of this group and its management. Here, the facilitator should only identify gaps and extend support through capacity-development activities (e.g., record keeping, writing minutes and contracts, financial management). This type of group can play a critical role by promoting a culture of saving, bringing access to financial services, and teaching financial skills in rural areas. The facilitator can use this type of platform to engage farmers in continuous learning.

Figure 28. Bimonthly meetings among members to collect monthly savings and share lessons and challenges

3.3.3. Showcase: Evidence of improvement in the livelihoods of beneficiaries engaged in income-generating activities

Two income-generating activities were implemented and monitored with financial support from the SATREPS-Ethiopia Project: dairy farming, which involved 24 selected beneficiaries (women and young people) at the midland agroecological site (Aba Gerima watershed); and poultry farming, which involved 12 selected beneficiaries (women/youth) at the highland agroecological site (Guder). The estimated changes in annual income are shown in **Figure 29**. The incomes of the beneficiaries who implemented dairy farming were improved by 39.6% compared with the baseline (Nigussie, 2021c, paper in preparation). Similarly, poultry farming improved the livelihood of women and youth by 37.6% (Nigussie, 2021c, paper in preparation). The results imply that engaging and supporting less-advantaged people in the community (e.g., landless people, women, and young people) can bring about positive outcomes and support ongoing integrated watershed development programs. For example, improved forage development based on dairy farming has been scaled out because of improved forage production by farmers who have implemented it at the farmyard and small-plot levels (**Figure 29**).

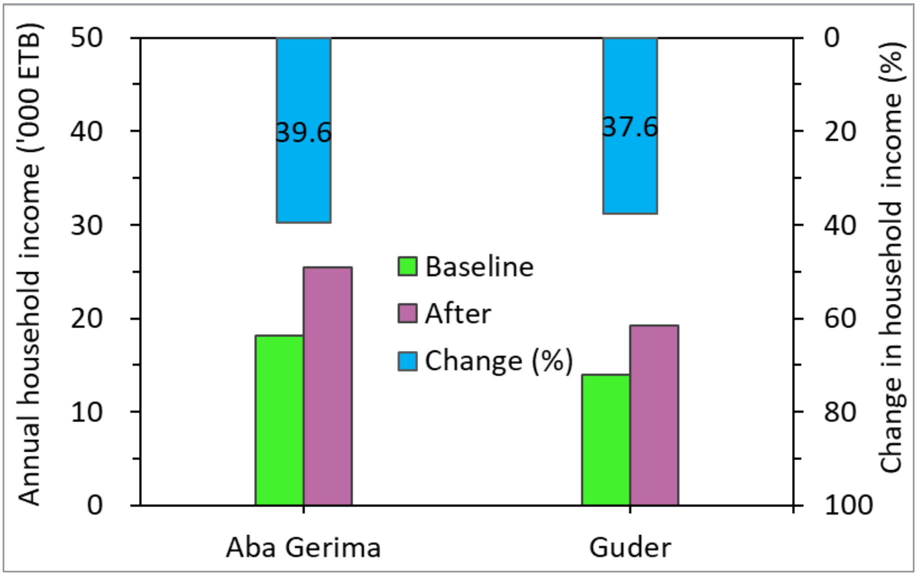

Figure 29. Changes in household income after implementing income-generating activities: dairy farming at Aba Gerima (midland) and poultry farming at Guder (highland) (Nigussie, 2021c)

3.4. Facilitating farmers' voluntary adoption of SLM technologies

3.4.1. Description

Currently, various SLM technologies and approaches have been developed in Ethiopia under many projects or programs by using existing guidelines and manuals. However, there have been few occasions where farmers have voluntarily wanted to adopt SLM technologies by themselves. Usually, the farmers prefer external support. With this reality in mind, the project recognizes that self-implementation of SLM is one of the possible keys to improving sustainability. Therefore, there is a need to devise a way to enhance self-motivation. Such an approach was developed by the project to catalyze the willingness of farmers to adopt improved SLM practices on their farmlands. Under this approach, the project formulated a group exercise tool and used it in several trials. It is expected that the tool (a pocket-sized handbook: "A Guide to Starting Profitable and Sustainable Land Management") will help farmers to (1) understand that SLM methods will bring long-term benefits and improve their livelihoods, so that they will want to try these methods, (2) choose the appropriate SLM activities on the basis of their status and capacity, and (3) make realistic action plans to lower costs and increase benefits.

Aims

The main aim of this approach (and the tool) is to increase the willingness of farmers to adopt SLM practices on the basis of the following three concepts: simplification, monetization, and scientific evidence.

Simplification: The simplification concept means that anybody can follow the approach and take the initiative in planning SLM very easily. For farmers autonomously starting

SLM activities, the contents and steps of the tool should be extremely easy to follow. This is especially important when those who do not have much knowledge and experience with SLM want to take new actions. After the developmental agents (DAs, extension workers or critical actors in the agricultural sector of Ethiopia) and farmers efficiently select only the necessary activities out of the vast selection on offer, the tool (the guidebook) also introduces other extension materials (guidelines and other materials) as a reference for farmers to have options to access more detailed information on SLM technologies. Furthermore, the simplification of the tool is aimed at extending its use to different *districts* or *kebeles* to have more impacts over a wider area and with greater cost efficiency.

Monetization: This concept states that planning based on economic value increases farmers' willingness to start SLM activities. When people realize they can gain monetary benefits, they are more willing to take on an activity without external support. For example, in some areas where *A. decurrens* plantations have proliferated in recent years, farmers who have seen neighboring farmers' profitability increase by producing and selling wood or charcoal have also adopted this practice. However, this type of dissemination is limited to a few visible practices, and it is also limited to those who have easy access to information. Therefore, it is important for farmers to see wider SLM practices and their pros and cons, including the long-term benefits, for sustainable productivity. They also need to gather realistic information on input costs and output sales for their plans. Inside the tool, cost–benefit information is explored through self-exercises by farmers to try to visualize the profitability of SLM technologies. The tool also emphasizes that the benefits are for the farmers' children, grandchildren, and future generations.

Scientific evidence: Scientific evidence lowers uncertainty, thereby encouraging farmers to invest in long-term activities. Many farmers are reluctant to use their own money or labor for SLM activities if the benefits or effectiveness are unclear and the desired effects will occur in the long term. If farmers are presented with scientifically proven SLM options, their willingness to take up SLM practices could increase. The tool provides information that is based on the research results of the SATREPS-Ethiopia Project, including the effectiveness of selected SLM technologies. There are, however, trade-offs between the goals of presenting scientific evidence and simplification. Therefore, research results must be demonstrated clearly and in easy-to-understand terms.
The tool is also referred to by JICA as the "Smallholder Horticulture Empowerment and Promotion (SHEP) Approach." This has been expanded by JICA from its original use in Kenya to Ethiopia and other African countries as one of the pillars of "Agricultural Cooperation in Africa." The SHEP approach has succeeded in increasing farmers' incomes on the basis of two basic concepts: promoting farming as a business and empowering and motivating farmer/s. The approach is also supported by the academic theories of markets with asymmetric information and self-determination theory. (Please refer to the following link for more information on this topic:
https://www.jica.go.jp/english/our_work/thematic_issues/agricultural/shep/shep_now_09.html).

By incorporating the abovementioned three concepts, the project carefully configured the order and structure of the contents of the tool, with reference to both SHEP's approach and existing theories—particularly those related to nourishing farmers' autonomy. Whereas SHEP targeted horticulture, this SLM approach focuses on the management of land and its natural resources, emphasizing the importance of long-term benefits and improved livelihoods.

3.4.2. Features of the tool (a guide to starting profitable and sustainable land management by farmers)

Purpose

To enhance farmers' desire to plan and implement SLM-related activities that can improve their livelihoods without external financial or material support.

Contents

The guide contains a cover page with a "problem-solution sheet," an introduction, three key activities (understanding the present status, exploring for improvement, and action planning), and three tips and references (**see Figure 30**).

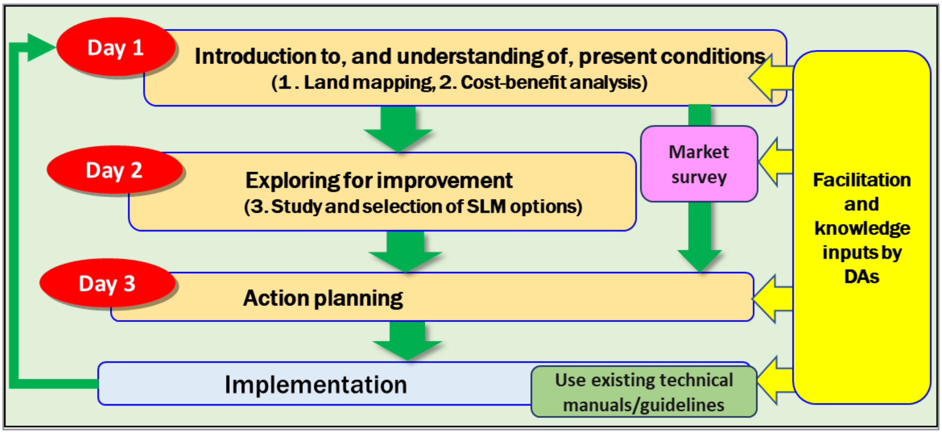

Figure 30. Schematic showing how to implement the SLM exercise tool: cycle of activities and required inputs (knowledge and tools)

Target users (beneficiaries)

The approach is for farmers or groups of farmers who want to voluntarily adopt new SLM technologies without any external financing or other materials. This approach focuses mainly on the residential community (small village [*mender*]) level. It is important to go through the planning process of organizing water users' associations or cooperatives at the watershed or sub-watershed levels across multiple working or development groups, because they have already been promoted by other existing community-based programs. Harmonizing with these programs or the ordinary NRM (natural resources management) extension system adds value as part of the voluntary adoption concept.

Expected outcomes and impacts

Through this package, farmers are expected to build the capacity to make appropriate action plans considering their current situation and the pros and cons of various SLM methodologies and new crop cultivars. A simplified and streamlined package can easily be distributed in digital or paper form, not only to farmers but also to DAs as an extension tool; this should have an immediate impact at wider scales. **Figure 31** shows the vertical flow of information for and from the extension of the SLM exercise tool.

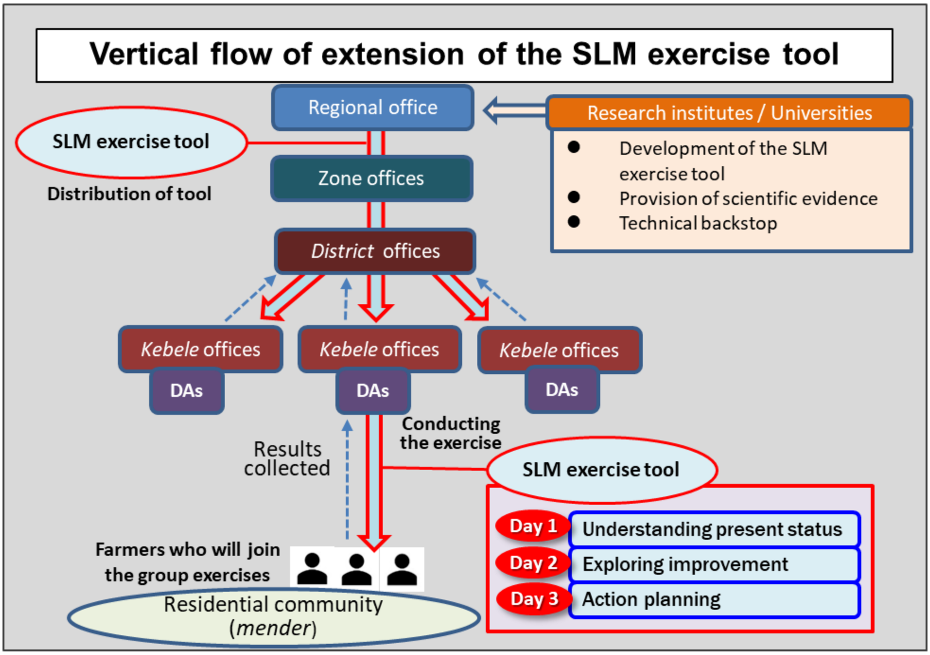

Figure 31. Upward and downward flows of information in the course of distributing the SLM exercise tool (i.e., the flows of inputs and feedback from farmers to higher officials and vice versa)

3.4.3. Procedures/steps of exercises in the tool

Step 1: Understanding present status

- ✓ Land-mapping (exercise 1): Draw a rough map of the surrounding land area of the participants and indicate the major problems related to SLM for the purpose of visualizing the current status of different land-use types (**Figure 32**).
- ✓ Cost–benefit analysis (exercise 2): Describe each element of production, including the name, area size, yield, sales, cost, and income, on the format sheet to help gain an understanding of the costs and benefits of the latest harvested products (crops, trees, and livestock products), and to realize the different levels of profitability among different products and different farmers.
- ✓ Market survey (exercise 3): Nominate two to four members (considering gender balance) from the group who will research market information by using the survey format sheet to better understand the price and demand trends of different products among buyers in the market or other places.

Step 2: Exploring improvement

- ✓ Study of potential SLM options: Understand the existing land-degradation risks and the importance of SLM technologies, and study the potential options among them.
- ✓ Selection of SLM options: On the basis of the study of potential SLM options, discuss and select practical SLM options and actions corresponding to the major issues identified on the land map.

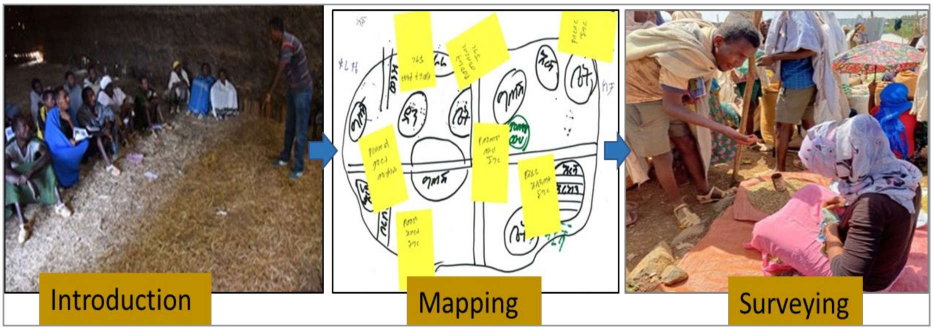

Figure 32. Three key activities involved in exercises in the SLM toolset: introduction of the purpose, land mapping, and market survey for cost benefit analysis from farmers to higher officials and vice versa)

Step 3: Preassessment and action planning

- ✓ Feedback of market survey results: Obtain the market survey results from surveyors.
- ✓ Activity selection: Select activities for products (e.g., crops, livestock, trees) in the next season on the basis of the information in steps 1 and 2 and additional factors such as expected costs and sales of products, potential risks, and opportunities.
- ✓ Group activity: On the survey format sheet, fill out information on how to obtain input materials and expected benefits. This will help prepare for the next steps (action planning and implementation).
- ✓ Action planning: Nominate a subgroup leader and participants for each selected production type or SLM option, and prepare the necessary work schedule, including meetings, training sessions, and other necessary work.

Step 4: Implementation

- ✓ During implementation of selected activities, DAs will help farmers by providing technical support, referring to existing guidelines or manuals. (Reference documents are recommended in the presentation materials.)
- ✓ DAs will also provide printouts of the needed parts from the guidelines or manuals and will train farmers if necessary.

Step 5: Data survey after implementation

- ✓ To capture and evaluate the results from farmers, DAs may conduct a cost–benefit analysis involving selected farmers.
- ✓ DAs may also conduct interviews of target farmers about their perceptions and expectations about the SLM activities they are implementing, so that they can learn about any behavioral changes (positive or negative).

4. Challenges and solutions in adopting SLM technologies and approaches

In Sub-Saharan countries such as Ethiopia, the implementation and sustainability of promising SLM technologies and approaches have been facing several challenges (FAO, 2008). For instance, major challenges in the achievement of food security are related to (1) an insufficient policy environment to boost SLM and unsuccessful scaling-up of project and community efforts; (2) a lack of capacity at the institutional, community, and stakeholder levels; (3) insufficient partnership and alliance across institutions and sectors to boost investments in land and water management; and (4) a lack of clearly defined roles and responsibilities among different institutions and sectors involved in the implementation of SLM interventions. **Table 79** presents some of the most important challenges and corresponding possible solutions for the implementation of SLM practices (technologies and approaches) in Ethiopia.

Table 79. Existing challenges for adopting SLM practices, and proposed solutions

Existing challenge	Proposed solutions
Insecurity of rural land-use and tenure systems	• Ensuring land ownership and sustainable land-use rights for rural communities through land certification.
Lack of uptake of new technologies and approaches and failure of previous attempts and interventions	• Learn lessons from previous interventions (failures and successes). • Develop improved management practices and enhance their adoption by creating awareness through training and field demonstrations. • Develop flexible extension strategies that facilitate access to the inputs and services (demonstrations, help from appropriate experts, finance, and credit) needed for effective adoption of SLM technologies and approaches at the grassroots level.
Diversity in agroecological and sociocultural settings and farming systems across landscapes, requiring different types/designs of SLM technologies and approaches	• Develop alternative land-use and management options relevant and specific to local conditions.
Lack of integration among policy, research, and development	• Establish an appropriate planning platform and a system for integrating or bridging research and developmental works to achieve effective resource management. • 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. • Establish a forum that considers policy, research, and the development aspects of SLM.

Table 79 (continued)

Existing challenge	• Proposed solutions
Duplication of efforts and lack of proper exit strategies for SLM projects	• Properly evaluate the goals and outcomes of previous and ongoing SLM projects involving relevant stakeholders. • Set proper intervention and exit strategies for SLM projects. Project interventions in a specific geographical area should be based on a multi-disciplinary and stakeholder evaluation of common goals and possible areas of collaboration with existing projects. • Before intervention, current environmental and socioeconomic conditions must be assessed and documented for successful planning and implementation of suitable SLM-related activities. • Termination of SLM projects should always be based on best exit strategies that can ensure the project results will continue to benefit targeted beneficiaries. • The exit strategy of a given project must be considered during the planning, implementation, monitoring, and evaluation processes.
Lack of attention by local stakeholders (officials and communities) to supporting the sustainability of best SLM practices	• Link the implementation of SLM practices with social and religious institutions. The principles and implementation of promising SLM practices should be supported by community bylaws through which members are governed and dedicated to shared responsibilities (e.g., *idir:* an association of people with the objective of providing social and economic insurance in the event of death, property damages, and accident).
Lack of suitable bylaws at the watershed or community level and lack of community ownership of bylaws	• Develop new or update existing bylaws that take the local contexts into account, and ensure that the members of the target community are aware of the principles and contents of the documents. • Create awareness and build consensus among community members on the significance of SLM.
Traditional farming activities causing destruction of structural SLM measures	• Use appropriate design of structural measures and develop suitable farm implements. • Provide training to land users.

Table 79 (continued)

Existing challenge	Proposed solutions
Prevalence of free grazing	• Develop improved livestock production systems. For instance, a ban on free grazing can support farmers to keep small numbers of livestock suitable to apply stall-feeding. • Replace cropping practices (e.g., teff cultivation) requiring animal traction with other appropriate alternatives to reduce the numbers of livestock and hence the pressure on grazing lands. • Rear high-yielding livestock breeds. Introduce productive forage species.
Increasing demand for arable land due to population growth	• Develop and implement technologies that can substantially improve the productivity of existing croplands. For instance, making use of high-yielding crop cultivars and best-fit agronomic practices can support adequate and sustainable food production. This can, in turn, reduce the conversion of vegetated lands to croplands. • Promote the development of agroforestry practices that provide diverse products such as fruits, crops, forage, timber, and non-timber products. • Support farmers to engage in additional income-generating activities such as bee keeping, poultry farming, dairy, and other off-farm activities. Develop irrigation facilities to increase crop production.
Financial constraints for rural households. SLM practices require labor and financial resources. Consequently, they have not been easily implemented by individual farmers. Most SLM interventions are funded (financially and materially) from foreign sources.	• Develop mechanisms to provide financial support and other rewards for farmers implementing improved SLM practices. • Encourage community collective efforts to increase financial effectiveness. • Provide access to credit (short- and long-term). Encourage farmers to use available financing mechanisms while using the selected technologies.
Mobilization-based SLM implementation	• Emphasize regular extension approaches in implementing SLM.
Lack of pre- and post-harvest mechanization technologies	• Develop appropriate pre- and post-harvest mechanization technologies.

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Annexes

Annex 1. Summary of selected SLM technologies, their importance by land-use type, and impacts on key indicators based on expert judgment

No.	Type of SLM technology	Suitable land-use type		Impact on key indicators											
		Most suitable	Less suitable	Moisture conservation			Soil conservation			Improved land productivity			Improved 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	CL		++	na	na	++	na	na	++	na	na	++	na	na
4	Row planting	CL		++	na	na	na	na	na	++	na	na	++	++	++
5	Irrigation for teff production	CL		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	Improved forage (N+D)	CL, GL	DH	+++	+++	++	+++	+++	+++	+++	+++	+++	+++	+++	++
10	Exclosure + trenches	DH, GL	CL	na	+++	+++	na	+++	+++	na	+++	+++	na	–/+	–/+
11	Stall-feeding	CL, GL	BH	++	+++	++	++	+++	++	++	+++	++	na	++	++
12	Assisted v. establishment	DH	GL	na	na	na	na	+++	+++	na	+++	+++	na	na	na
13	Acacia plantation	CL, GL, DH		–/+	–/+	–/+	++	++	++	+++	+++	+++	+++	+++	+++

CL: cropland; GL: Grassland; N+D: Napier grass + *Desmodium;* DH: degraded hillsides; Acacia: *Acacia decurrens*; assisted v.: vegetation; –: negative; +: slightly positive; ++: positive; +++: very positive; -/+: neutral; na: not applicable.

Annex 2. Slope-and rainfall-based calculation of spacing and density of soil bunds in 1 ha of land

Features of soil bunds are shown for different slopes of cropland in areas with low (>900 mm) and high (≥ 900 mm) average annual rainfall. Vertical and horizontal intervals (VI and HI, respectively) are calculated on the basis of the following empirical equations (FES, 2008): $VI = 0.3(S/(a+b))$ and $HI = VI/S \times 100$, where S is land slope (%), and a and b are constants.

Slope (%)	Low-rainfall areas ($a = 2$, $b = 3$)					High-rainfall areas ($a = 4$, $b = 1$)				
	VI (m)	HI (m)	Density[a] (km ha^{-1})	Labor (PDs[c])	LOS[b] (%)	VI (m)	HI (m)	Density (km ha^{-1})	Labor (PD)	LOS[b] (%)
5	1.65	33.0	0.30	45	8	0.68	13.5	0.74	111	20
10	2.40	24.0	0.42	63	11	1.05	10.5	0.95	143	26
15	3.15	21.0	0.48	71	13	1.43	9.5	1.05	158	28
20	3.90	19.5	0.51	77	14	1.80	9.0	1.11	167	30
25	4.65	18.6	0.54	81	15	2.18	8.7	1.15	172	31
30	5.40	18.0	0.56	83	15	2.55	8.5	1.18	176	32
35	6.15	17.6	0.57	85	15	2.93	8.4	1.20	179	32

[a]The density represents the total length of bunds constructed in a unit area; the number of bunds in a given area can be calculated by dividing the total length of bunds in an area by the horizontal interval (HI) between two successive bunds. [b]LOS: land occupied by structures. This represents the fraction of the land area that is out of crop production (i.e., occupied by bunds, berms, and ditches) (Adimassu et al, 2014; Ebabu et al, 2019); it is based on maximum values of dimensions (i.e., bund width =1.5 m, ditch width =1 m, berm = 0.2 m).
[c]PD: Person-day, the work of 1 person in 1 day (150 PDs per km of bunds; Desta et al., 2005).

Note: The information provided in this table can be used as a general guide for planning at larger scales. In certain circumstances, however, calculating the spacing by using empirical formulas may result in either an under- or overestimation of the number of bunds. For instance, the use of closer bund spacing may result in the loss of productive land, higher input costs, and hinder agricultural operations, whereas wider spacing can result in lower effectiveness in reducing runoff and soil loss. A rule of thumb combined with expert or farmer judgment could be used for reasonable spacing and effective design of bunds, while at the same time generally following the practical standards.

Annex 3. Effects of reinforcing soil bunds with grass: cases studies at three sites

Effectiveness of soil bunds alone and reinforced with grass in reducing seasonal runoff and soil loss from croplands in the three agroecological zones of the Abay basin of Ethiopia. The percentage reduction values are the average values observed during two rainy seasons (2015 and 2016; see the photos and descriptions below (Ebabu et al., 2019).

Agroecological zone (site)	Slope (%)	Soil texture	Number of bunds in 30 m	Runoff reduction (%)		Soil-loss reduction (%)	
				SBA	SBG[a]	SBA	SBG[*]
Highland (Guder)	5	Clay loam	3	42	33	78	80
	15	Clay loam	4	27	26	67	77
Midland (Aba Gerima)	5	Clay loam	3	30	34	61	65
	15	Sandy loam	4	20	22	60	66
Lowland (Dibatie)	5	Clay	3	51	55	86	87
	15	Clay	4	35	43	63	86

SBA: soil bunds alone; SBG: soil bunds stabilized with different grass species.
[a]The species used to stabilize soil bunds were Desho grass (*Pennisetum pedicellatum),* elephant grass (*Pennisetum purpureum*) and vetiver grass (*Chrysopogon zizanioides*), respectively, at the Guder, Aba Gerima, and Dibatie sites.

Soil bunds stabilized with elephant grass constructed on cropland with a ground slope of 5%; photo taken on 18 August 2015. Seasonal runoff was reduced by 31% and soil loss by 56%. The plots were planted with finger millet (*Eleusine coracana*).

A photo of the same bunds taken 1 year later, on 21 August 2016. Seasonal runoff was reduced by 46% and soil loss by 73%. The plots were planted with teff *(Eragrostis tef)*.

Annex 4. Effects of bund spacing: case study at two sites

Effects of spacing on the performance of soil bunds in reducing runoff and soil loss from croplands at two sites (Aba Gerima and Dibatie) representing two agroecological zones (midland and lowland, respectively) in the Abay basin, Ethiopia (see also **Annex 3**).

Spacing (HI, m)	No. of bunds in 30 m	Density (km ha^{-1})	LOS (%)	Runoff reduction (%)		Soil-loss reduction (%)	
				Aba Gerima	Dibatie	Aba Gerima	Dibatie
5	4	1.30	35	58	53	79	84
8	3	1.00	27	44	40	66	68
13	2	0.70	19	32	25	33	51
27	1	0.30	8	12	8	13	23

LOS: Land occupied by structures, representing the fraction of the land area occupied by the bunds and ditches per hectare; a detailed description is given in **Annex 2**. The relative runoff and soil loss reduction values are the ratios of actual values from plots with bunds to the actual values obtained from the plot where no bunds were implemented (control plot) (Ebabui et al., 2019; Demissie et al., 2022a).

Annex 5. Slope-and infiltration capacity-based calculation of spacing and number of trenches in 1 ha of land

Features of trenches for different slope and rainfall infiltration conditions are shown; vertical interval (VI) and horizontal interval (HI) are calculated on the basis of empirical equations (FES, 2008): $VI = 0.3(S/(a+b))$ and $HI = VI/S \times 100$, where S is land slope (%), and a and b are constants.

Slope (%)	Soils with good infiltration ($a = 3$, $b = 2$)					Soils with poor infiltration ($a = 4$, $b = 2$)				
	VI (m)	HI (m)	Rows (no. ha^{-1})	Density[a] (no. ha^{-1})	Labor (PDs[b])	VI (m)	HI (m)	Rows (no. ha^{-1})	Density[a] (no. ha^{-1})	Labor (PD[b])
5	1.1	22.0	4	80	53	1.0	19.5	5	100	66
10	1.6	16.0	6	120	80	1.4	13.5	7	140	93
15	2.1	14.0	7	140	93	1.7	11.5	8	160	106
20	2.6	13.0	7	140	93	2.1	10.5	9	180	120
25	3.1	12.4	8	160	106	2.5	9.9	10	200	133
30	3.6	12.0	8	160	106	2.9	9.5	10	200	133
35	4.1	11.7	8	160	106	3.2	9.2	10	200	133
40	4.6	11.5	8	160	106	3.6	9.0	11	220	146
45	5.1	11.3	8	160	106	4.0	8.8	11	220	146
50	5.6	11.2	9	180	120	4.4	8.7	11	220	146

[a]The number represents the total number of trenches to be constructed per hectare by assuming a total of 20 trenches in one row (each tranche is 3 m long with an interspace of 2 m).

[b]PD: Person-day, the work of 1 person in 1 day (2 PDs for 3 trenches; Desta et al., 2005).

Note: The information provided in this table can be used for general planning. In certain circumstances, however, calculating the spacing by using empirical formulas may result in either an under- or overestimation of the number of trenches in an area. For instance, the use of closer spacing may result in higher labor costs, whereas wider spacing can cause lower effectiveness in reducing runoff and soil loss. A rule of thumb combined with expert or farmer judgment could be used for reasonable spacing and design of trenches, while at the same time generally following technical standards.

Annex 6. Comprehensive evaluation matrix used for documenting SLM technologies

The necessary inputs (technical details and scientific evidence contained in this guideline) were acquired from researchers who investigated SLM technologies under the SATREPS-Ethiopia Project using this matrix Table.

I. Topics to describe the technology	Details
1. Name of technology	
1.1. Short description (definition)	
1.2. Detailed description (purpose, establishment, and environment)	
1.3. Photos (illustrative photo/s of the technology)	
1.4. Location (country, region, and specific location)	
1.5. Date of implementation	
1.6. Method of introduction of technology	☐ Project ☐ Land users ☐ Research ☐ Others
2. Classification of the technology: Check box/es suitable for the technology	
2.1. Suitable land-use type/s	☐ Cropland ☐ Forest/woodland ☐ Grassland ☐ Degraded land ☐ Wetlands ☐ Mixed
2.2.Water supply	☐ Irrigation ☐ Rainfed
2.3. SLM group to which the SLM technology belongs (choose all that apply)	☐ Agroforestry ☐ Cross-slope measures ☐ Exclosure ☐ Water harvesting ☐ Surface water management ☐ Ground water management ☐ Irrigation management ☐ Integrated soil fertility management ☐ Minimum soil disturbance ☐ Improved plant variety ☐ Improved animal breeds ☐ Improved feeding ☐ Rotational systems ☐ Grassland management ☐ Livestock management ☐ Crop–livestock management ☐ Improved vegetation cover ☐ Plantation management ☐ Forest management ☐ Home gardens ☐ Economic efficiency ☐ Energy efficiency ☐ Other (mention)
2.4. SLM measures comprising the technology	☐ Agronomic ☐ Structural ☐ Vegetative ☐ Management
2.5. Types of land degradation addressed by the technology	☐ Soil erosion by water ☐ Soil erosion by wind ☐ Chemical soil degradation

Annex 6 (2.5. continued)	☐ Biological soil degradation ☐ Physical soil degradation ☐ Water degradation ☐ Other (mention)
2.6. Specific goal/s of the technology	☐ Prevent land degradation ☐ Reduce land degradation ☐ Restore land degradation ☐ Improve production ☐ Ecosystem conservation ☐ Adaptation to climate change ☐ Create beneficial social impact ☐ Improve economic benefits ☐ Improve biodiversity ☐ Mitigate climate change impacts ☐ Protect downstream areas ☐ Other (…)
3. Technical specifications	
3.1. Technical drawing and details of the technology (if applicable, provide a drawing with information about the function, materials, and application of the technology)	
3.2. Establishment activities (list activities and timing (season))	
3.3. Inputs and costs needed for establishment (estimated cost of labor and inputs per unit of measurement, such as area, length, etc.)	
3.4. Maintenance and recurring activities (list activities and timing/frequency)	
3.5. Inputs and costs for maintenance and recurring activities (provide estimated costs of labor and input per year)	
3.6. Main factors affecting the costs (list factors determining costs of implementing and maintaining)	
4. Natural and human environments: Check box/es suitable for the technology	
4.1. Climate	Average annual rainfall (mm): ☐ < 250 ☐ 1501–2000 ☐ 251–500 ☐ 2001–3000 ☐ 501–750 ☐ 3001– 4000 ☐ 751–1000 ☐ > 4000 ☐ 1001–1500 Agro-climatic zone: ☐ Hyper-arid ☐ Sub-humid ☐ Arid ☐ Humid ☐ Semi-arid
4.2.Topographic features	Slope range (%): ☐ Flat (0–3) ☐ Gentle (3–8) ☐ Moderate (8–15) ☐ Steep (15–30) ☐ Very steep (30–50) ☐ Extremely steep (> 50)

Annex 6 (4.2 continued)	Landforms: ☐ Plains ☐ Hillslopes ☐ Ridges ☐ Foot slopes ☐ Mountain slopes ☐ Valley floors
Topographic features	Altitudinal zone (elevation, m a.s.l): ☐ 0–100 ☐ 2001–2500 ☐ 101–500 ☐ 2501–3000 ☐ 501–1000 ☐ 3001– 4000 ☐ 1001–1500 ☐ > 4000 ☐ 1501–2000
4.3. Soil characteristics	Depth class (average depth in cm): ☐ Very shallow (0–20) ☐ Shallow (21–50) ☐ Moderately deep (51–80) ☐ Deep (81– 120) ☐ Very deep (> 120) Textural class of topsoil: ☐ Clay ☐ Clay loam ☐ Silt ☐ Silt loam ☐ Loam ☐ Silt clay loam ☐ Sandy loam ☐ Sand clay loam ☐ Sand ☐ Sandy clay ☐ Loamy sand ☐ Silt clay Topsoil organic matter level (%): ☐ Very low (<1) ☐ Medium (2.1– 4.2) ☐ Low (1–2) ☐ High (> 4.2)
4.4.Characteristics of land users	Farming/production system: ☐ Subsistence ☐ Commercial ☐ Mixed Wealth class: ☐ Poor ☐ Medium ☐ Rich Level of mechanization: ☐ Manual work ☐ Animal traction ☐ Machinery Farm category/landholding in ha: ☐ Landless / < 0.20 ☐ Marginal /0.21– 0.50 ☐ Small /0.51–1.00 ☐ Medium /1.01–2.00 ☐ Large />2.00
4.5. Land ownership and use rights	Ownership: ☐ State ☐ Private Use right: ☐ Open access ☐ Private

II. Impacts on key indicators (Annex 6 continued**):** Provide an appropriate impact scale by using signs (– –, negative; –, slightly negative; –/+, neutral; +, slightly positive; ++, positive; +++, very positive; na, not applicable) and quantitative relative impact levels (%) observed at different agroecological sites (LL, lowland; ML, midland; HL, highland).

Key indicators		Impact scale			Impact level (%)			Remarks
		LL	ML	HL	LL	ML	HL	
Economic indicators	Crop production							
	Fodder production							
	Fodder quality							
	Milk yield							
	Meat yield							
	Wood production							
	Non-wood forest products							
	Employment creation							
	Farm income							
	Labor reduction							
	Cost–benefit ratio (short-term returns)							
	Benefit-cost ratio (long-term returns)							
	Food security							
Sociocultural indicators	Community institutions							
	National institutions							
	Awareness of land degradation and SLM							
	Sense of ownership							
	Gender empowerment							
Ecological indicators	Runoff reduction							
	Sheet and rill erosion reduction							
	Wind erosion reduction							
	Gully erosion reduction							
	Flooding control							
	Siltation reduction							
	Base flow increase							
	Soil moisture increase							
	Soil protective cover increase							
	Soil bulk density reduction							

Annex 6 (continued)

Key indicator		Impact scale			Impact level (%)			Remarks
		LL	ML	HL	LL	ML	HL	
Ecological indicators	Soil fertility improvement							
	Biodiversity improvement							
	Microclimate change							
	Climate change mitigation							
	Climate change adaptation							

III. Main advantages, drawbacks, and factors in adoption of the technology (Annex 6 continued):	
Advantages (opportunities and strengths): check box/es or write in the parentheses for others	**Drawbacks of the technology (weaknesses and risks):** check box/es or write in the parentheses for others
☐ Decreased runoff ☐ Decreased soil erosion ☐ Increased soil moisture ☐ Improved soil organic matter ☐ Improved soil fertility ☐ Enhanced vegetation growth ☐ Increased fodder availability ☐ Increased land productivity ☐ Improved farm income ☐ Reduced downstream impacts ☐ Mitigated climate change ☐ Other mention)	☐ Loss of cultivated land ☐ Loss of grassland ☐ Low productivity ☐ Labor intensive ☐ Lack of multiple benefits ☐ Sensitivity to damage ☐ Causing damage downstream ☐ Hindrance to farm operations ☐ High cost of establishment ☐ High cost of maintenance ☐ Short-term effect/benefit ☐ Other (mention)
Main factors affecting adoption of the technology: check box/es or write in the parentheses for others	
Factors (constraints)	**Ways to overcome them (solutions)**
☐ High cost of inputs and materials ☐ Lack of awareness ☐ Insecure land tenure system ☐ Technical difficulties ☐ Lack of accesses to market ☐ Social insecurity ☐ Lack of integration among stakeholders ☐ Less attention for evaluating impacts compared to conventional practices ☐ Lack of participation ☐ Diversity of interest on communal lands ☐ Other (mention)	☐ Provide alternatives ☐ Training and education ☐ Amend policy and land-use rights ☐ Demonstrate through research ☐ Provide market access for inputs and products ☐ Improve community institutions ☐ Engage relevant stakeholders and institutions ☐ Monitor and evaluate for outcomes ☐ Improve participation of users ☐ Harmonize community interests ☐ Other (mention)

Annex 7. Recommended rates of urea–NPS fertilizer application in areas with sufficient moisture in the Abay basin of Ethiopia (BoA, 2022)

Testing site (*district*)	Recommended rate of urea–NPS (kg ha^{-1})	Soil type
Adet	75–150	Red soil (Nitisol)
Bichena	75–150	
Debre Tabor	75–150	
Finote Selam	75–150	
Estie	36–130	
Achefer	50–100	
Dembecha	10–87	
Bure	10–87	
Gozamen	79–130	
Dangila	10–87	
Dejen	100–160	Black soil (Vertisol)
Adet	125–150	
Bichena	125–150	
Debre Tabor	125–150	
Finote Selam	125–150	
Hulet Ej Enesie	123–130	
Awabel	87–140	
Denbia	87–96	
Gonder Zuria	100–100	
Jama	100–110	
Delgi	100–110	

NPS: Nitrogen, Phosphorus, Sulfur.

Annex 8: Reviewers and resource persons

Ten reviewers listed below carefully reviewed the document and suggested corrections and improvements. They also incorporated additional texts during the review. Taking in to account the multidisciplinary nature of the document, the reviewers were diverse in profession/expertise.

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As resource persons, the flowing six experts were consulted at different stages of developing this guideline and provided their valuable comments that helped improve the document.

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