



SOIL AND WATER CONSERVATION MEASURES FOR CEREAL-LEGUME CROPPING SYSTEMS



**A TRAINING MANUAL FOR FARMERS AND AGRICULTURE
EXTENSION OFFICERS**

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Foreword

The production guide on soil and water conservation measures for cereal-legume cropping systems is a collaborative work by a team of scientists from the CSIR-Crops Research Institute and the CSIR-Soil Research Institute in collaboration with the Alliance Bioversity & CIAT through the Sustainable Intensification of Mixed Farming Systems Initiative (SI-MFS) Initiative. This manual is intended to serve as a guide and a reference material for extension agents and other trainers to build capacities of farmers, students, and other trainees in sustainable measures for soil and water conservation. As a decision support material, this manual can help guide users, especially farmers and producers to improve the productivity and environmental sustainability of their production systems. All reference materials used here are duly acknowledged with special mention to the Climate Smart Training manual developed under AICCRA in Ghana.

We envisage that this guide would be used extensively for training and capacity building activities under the Sustainable Intensification of Mixed Farming Systems Initiative to improve knowledge of farmers and other beneficiaries whilst working towards achieving the objectives of the project towards a sustainable production systems and improved livelihoods.

Prof M.B. Mochiah

Director

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Executive Summary

This manual is meticulously crafted to serve as an indispensable resource for extension officers, training institutions, and farmers alike, offering comprehensive guidance on the implementation of sustainable soil and water conservation measures tailored specifically for cereal-legume cropping systems. Designed with the overarching goal of enhancing the livelihoods of farmers, particularly in climate-vulnerable environments where food security remains a pressing concern, this manual aims to empower stakeholders with practical knowledge and actionable strategies.

With a focus on improving crop productivity through soil and water conservation, this manual provides a thorough compendium of production guidelines for extension officers and educational materials for farmers. It furnishes invaluable insights into the intricate interplay of climatic factors that influence soil and water conservation efforts, equipping readers with the necessary understanding to navigate diverse environmental conditions effectively.

Central to this manual are the delineated steps for implementing soil and water conservation measures on farms. Ranging from fundamental practices such as contour farming and terracing to advanced techniques like cover cropping, mulching, composting, and crop diversification, each measure is meticulously elucidated to ensure clarity and efficacy in application. Through the integration of these measures, farmers can fortify their agricultural endeavors against the vagaries of climate, thereby safeguarding both their livelihoods and the sustainability of their farming practices.

This manual represents a concerted effort to distill decades of research and practical experience into a single, cohesive resource, poised to catalyze positive change in agricultural landscapes. By embracing the principles outlined herein, stakeholders can embark on a journey towards resilient, productive, and sustainable agriculture, laying the groundwork for a future where food security is no longer a distant aspiration but a tangible reality.

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1.0 Introduction

Soil and water conservation strategies are critical for improving soil resilience and ensuring sustainable food production. In Sub-Saharan Africa (SSA), notably Ghana, low crop yields are directly connected to low soil productivity and the continuous threat of drought (Kugbe and Zakaria, 2015). This shows that soil and water conservation in the region is deteriorating over time (Kugbe et al., 2012), necessitating the implementation of appropriate measures to protect these invaluable resources continuously. Soil is the loose, weathered, unconsolidated substance that promotes plant growth and development while also serving as a reservoir of important nutrients, a habitat for a branching network of creatures, and a conduit for plant nutrient intake (Huggett, 2023). At the same time, water serves as the cornerstone of the ecosystem, nourishing both plants and wildlife. With a growing global population and increasing climatic uncertainties, conserving these resources will necessitate combined efforts and prompt action.

Soil and water conservation in modern agriculture, particularly in cereal-legume cropping systems, holds numerous benefits. The cereal-legume cropping system combines the development of two diverse and necessary crop groups, grains and legumes, which are the fundamental sources of human nourishment (Daryanto et al. 2017). On a global scale, main cereals (maize, wheat, and rice) and minor cereals (barley, sorghum, oat, rye, and millet) account for 56% of total dietary energy and 50% of protein consumption (Oghbaei and Prakash, 2016). In terms of global food production, legumes come in second only to cereals, accounting for 27% of primary crop output and 33% of protein requirements (Graham and Vance, 2003; Samtiya et al., 2020). They process soybeans and groundnuts, accounting for more than 35% of global vegetable oil production (Graham and Vance, 2003). The symbiotic interaction between various crop groups in a unified agricultural system gives several advantages over typical monocultures.

Cereals are heavy feeders of soil nutrients, whilst legumes ensure recovery to the soil due to their nitrogen-fixing ability (Ismaila et al., 2010; Maitra et al., 2019). Additionally, cereals act as a natural shield for legumes against pest infestation, thereby reducing the need for chemical intervention and mitigating the environmental footprint of agriculture in terms of more sustainable and resilient food production (Pala et al., 2007). In essence, the cereal-legume cropping system represents a glimmer of hope for addressing the challenges of food security, environmental sustainability, and human health. Its perfect balance not only increases agricultural yields, but also meets the global demand for a diverse, resilient, and nutrient-dense diet. To deal with the complexity of our modern world, the incorporation of cereal-legume into the current agricultural system is critical to guaranteeing sustainable agricultural production in the face of climate change.

2.0 Climatic Conditions that Affect Soil and Water Conservation

Climatic conditions are pivotal factors that can significantly impact soil and water conservation efforts. These conditions can either facilitate or hinder the conservation of soil and water for the enhancement of crop productivity. Key conditions that affect soil and water conservation are outlined in this manual.

2.1 Rainfall Patterns

Rainfall patterns play a significant role in soil and water for cereal and legume crops. Cereals and legumes are very sensitive to the amount, timing, and distribution of rainfall (Woldearegay et al., 2018; Golla, 2021). The amount of precipitation during the growing season largely determines the availability of soil moisture (Fang et al., 2018). Insufficient rainfall can cause water stress to crops and negatively affect growth and yields, while excessive rainfall can saturate the soil and lead to waterlogging and nutrient leaching. Rainfall intensity and duration are critical factors affecting soil erosion. Heavy rainfall can lead to surface runoff, resulting in topsoil loss and erosion, ultimately undermining soil fertility and conservation efforts (Demelash and Stahr, 2010; Barthès and Roose, 2002).

Excessive rainfall can lead to runoff that removes important nutrients from the soil, further affecting plant health and crop yields. Prolonged or intense rainfall can lead to flooding, which causes physical damage to plants and disrupts soil structure. Flooded soils can become compacted, reducing their water infiltration capacity and affecting conservation efforts. In regions with erratic or irregular rainfall patterns, farmers may rely on irrigation to maintain adequate soil moisture. Effective irrigation practices can supplement rainfall and support soil and water conservation by ensuring a consistent supply of water to crops (Baig et al., 2013). Seasonal variations in rainfall patterns have significant implications for conservation practices. For example, heavy rainfall during the wet season can lead to surface runoff and soil erosion, while dry season periods may require careful water management to maintain soil moisture.

Climate change may create uncertainty in long-term precipitation patterns and make precipitation more variable and unpredictable. The increasing frequency of extreme weather events, such as droughts and severe storms, may pose challenges to soil and water conservation efforts (Altieri et al., 2015). In regions with erratic rainfall, rainwater harvesting techniques, such as building reservoirs or collecting rainwater in cisterns, can help conserve soil and water. Stored rainwater can supplement irrigation and support plant growth during dry periods.

2.2 Temperature

Temperature is considered one of the most central factors affecting the distribution and abundance patterns of plant species (Parmesan and Yohe, 2003). Optimal temperature ranges are critical because both cereals and legumes have specific temperature requirements for growth and development. Temperature affects critical stages such as germination, flowering, and fruit set (Prasad et al., 2001). Deviations from the optimal range can result in slower growth and lower yields (Skobelev et al., 2020; Wheeler et al., 2000). It regulates the rate of water evaporation from the soil surface and transpiration (water loss) from plant leaves (Crawford et al., 2012). Soil health and erosion dynamics are also affected by temperature fluctuations (Muchow and Sinclair, 1991; Carter et al., 1997).

Colder temperatures leading to freeze-thaw cycles can cause soil cracking and erosion, especially in regions with marginal soil health (Hazirbaba and Gullu, 2010; Liu et al., 2021). Microbial activities are also directly impacted by temperature (Blume et al., 2002; Hofmann et al., 2016). Microbial metabolic rates increase with higher temperatures and affect nutrient cycling and decomposition of soil organic matter (Fang et al., 2020). Legumes in cereal-legume systems have the unique ability to fix

atmospheric nitrogen through a symbiotic partnership with nitrogen-fixing bacteria (Lai et al., 2022). However, temperature directly influences the activity and efficiency of these bacteria.

High soil temperatures in tropical and subtropical areas are a major problem for the biological nitrogen fixation of legumes (Zahran, 1999; Hungria and Vargas, 2000). High root temperatures influence bacterial infection and N₂ fixation in several legume species, including soybeans, peanuts, cowpeas, and beans (Dwivedi et al., 2015). This can result in reduced nodule numbers, rhizobial growth, colonization rates and delay in nodule formation (Belel et al., 2014). Optimal temperatures favor improved nitrogen fixation and improve soil fertility for both cereals and legumes (Gopalakrishnan et al., 2015). Temperature fluctuations can have a significant impact on pest and disease pressure, as elevated temperatures can trigger increased pest activity, which can threaten crop health (Field et al., 2015).

2.3 Wind

Air in motion affect crops production in different ways. Strong winds can detach and carry away valuable topsoil, resulting in reduced soil fertility and water-holding capacity (Bashir et al., 2017). In addition, wind can carry dust and sediment from bare fields into water bodies, contributing to sedimentation and affecting water quality (Zobeck et al., 2006). Wind promotes the spread of weed seeds, potentially increasing competition for resources in fields (Thill et al., 1997; Benvenuti, 2007).

In addition, wind can accelerate soil surface desiccation by increasing evaporation rates, which can lead to soil desiccation and problems maintaining adequate soil moisture for crops (Davarzani et al., 2014). However, there are strategies to mitigate the negative effects of wind. Planting windbreaks, such as trees or shrubs, can reduce wind speeds near the ground, prevent soil erosion, and provide protection for crops (Nordstrom and Hotta, 2004). Windbreaks also help conserve soil moisture by reducing evaporation (Brandle et al., 2004). Strong winds can disrupt the flight and feeding habits of certain pests, reducing the need for chemical pest control, which indirectly contributes to soil and water conservation.

2.4 Humidity

Humidity has a significant impact on soil and water conservation and crop management. High humidity is beneficial for maintaining soil moisture due to its ability of reducing evaporation of water from the soil surface (Cuthbert et al., 2022). This phenomenon help maintains soil moisture and reduce the need for frequent irrigation, while promoting plant growth even at dry periods. Moderate humidity contributes to a lower transpiration rate and reduces water loss from plant leaves. Lower transpiration rates are critical to conserving water in plants, there helping plants to maintain adequate moisture levels and reducing water stress, especially in regions with limited water availability.

Humidity has a significant impact on soil microbial activity, with higher humidity serving as favorable conditions for soil microbes. The favorable conditions created promote nutrient cycling, organic matter decomposition, and overall soil health, which is critical for effective soil and water conservation (Chen et al., 2020). However, high humidity can also create conditions that favor fungal diseases in crops, so effective disease management is needed to protect crops (Milani, 2014). In addition, high humidity can promote the growth of weeds that compete with cereal-legume for resources (Yadav et al., 2018).

Effective weed control measures are essential for conserving soil nutrients and water for cereal and legume crops. Humidity can also affect postharvest activities of cereals and legumes, especially the periods of drying and storage.

3.0 Soil and Water Conservation Measures for Smallholder Farmers

Soil and water conservation measures are of paramount importance to smallholder farming, as limited resources and fragile ecosystems often require sustainable and efficient practices. There are two categories of measures for soil and water conservation: mechanical/engineering/structural measures and biological measures (Kumawat et al., 2020). Mechanical measures encompass permanent and semi-permanent structures, including terracing, bunding, trenching, check dams, gabion structures, the use of boulders, and crib walls, among others. In contrast, biological measures involve vegetative strategies such as forestry, agroforestry, horticulture, and various agricultural and agronomic practices. Implementing these measures can satisfactorily improve soil fertility, water availability, and crop yields while reducing erosion and environmental degradation. Below are some key soil and water conservation measures that can be tailored by smallholder farmers to ensure soil and water conservation:

3.1 Contour Farming

Contour farming stands as one of the most frequently employed agronomic practices for soil and water conservation in hilly agro-ecosystems and sloped terrain. This method involves conducting all agricultural operations, including plowing, sowing, inter-cultivation etc. along the contour lines. With contour farming, crops are planted in rows that follow the natural contour lines of the soil rather than planting on slopes or in a straight line (Malvar et al., 2013).

Contour cropping reduces soil erosion by minimizing downhill water runoff and protecting topsoil (Farhani et al., 2023). It also improves soil moisture retention, allows rainwater to infiltrate the soil, and reduces water runoff. This helps maintain soil moisture during periods of low rainfall and improves drought resistance.

Contour cropping also supports nutrient management by preventing nutrient runoff, maintaining soil fertility, and reducing the need for excessive fertilization (Liu et al., 2013). It facilitates weed and pest management by reducing the need for weed control and monitoring pests in an organized pattern of crops (Thapa and Yila, 2012). In addition, contour farming can promote biodiversity by creating microhabitats for beneficial insects and organisms (Stevens et al., 2009).

Contour farming can help stabilize slopes in hilly or sloping terrain, reducing the risk of landslides and soil shifts (Chalise et al., 2019). While contour farming offers numerous benefits, it may require initial investments in labor and materials for construction. It should be adapted to local conditions and regularly maintained to ensure its continued effectiveness in preventing erosion.



Figure 1: Contour farming across the slope.

Source <https://www.agrifarming.in/contour-farming-guide-what-is-contour-farming-how-to-start-from-scratch-for-beginners>

3.1.1 Steps to implement contour farming as soil and water conservation measures

Implementing contour farming measures on the field involves a series of steps to ensure proper planning and execution. Contour farming is a soil conservation technique that helps reduce soil erosion on sloping terrain. Here is a step-by-step guide to implementing contour farming measures:

3.1.1.1 Site Assessment and Planning

To effectively implement contour farming, these steps are essential for tailoring contour farming practices to your specific land and environmental conditions.:

- i. Start by conducting a field survey to identify slopes and assess water runoff patterns.
- ii. Understanding the soil type and its susceptibility to erosion is crucial, as different soils may require specific contour farming techniques.
- iii. Additionally, analyze local rainfall patterns, considering factors such as intensity and frequency, to gauge the risk of soil erosion.
- iv. To establish precise contours, begin by determining contour lines based on the slope data acquired in your assessment. These contour lines should run perpendicular to the slope.
- v. For accuracy, employ an A-frame level or utilize GPS technology to mark these contour lines at consistent intervals throughout the field.

3.1.1.2 Implement Contour Farming Techniques

- i. Establish contour strips or ridges along the marked contour lines. Various techniques, including plowing, terracing, or specialized machinery for contour farming, can be employed to create these strips.

- ii. Following this, plant vegetation on the contour strips, with grasses or cover crops being common choices due to their erosion-preventing qualities and soil structure enhancement.
- iii. The roots of these plants play a crucial role in stabilizing the soil and preventing erosion.

3.1.1.3 Maintenance and Management

- i. Contour strips should be designed to direct water flow along the contours, slowing it down and allowing it to infiltrate into the soil.
- ii. Install check dams or silt basins at regular intervals along the contours to further slow down water runoff and trap sediment.
- iii. Periodically inspect the contour strips and make necessary adjustments to maintain their effectiveness.
- iv. Repair any erosion or damage promptly. Maintain the vegetation cover on the contour strips by controlling weeds and replanting as needed.
- v. Continuously assess the effectiveness of your contour farming measures by observing soil erosion patterns, especially after heavy rainfall events.
- vi. If erosion still occurs, consider modifying your contour layout or adding additional measures, such as grassed waterways or sediment basins.
- vii. Keep records of contour layouts, maintenance activities, and any changes made over time. This information can help improve the effectiveness of contour farming on your field.
- viii. Ensure that field workers are trained in contour farming techniques and understand the importance of proper implementation.

3.2 Terracing

Terraces are earth embankments constructed on sloping terrain to create level planting areas that prevent soil erosion and facilitate water infiltration (Blanco and Lal, 2008). Terraces are designed to slow and control water runoff, allowing water to infiltrate into the soil instead of carrying away valuable topsoil and nutrients (Wen et al., 2021). It is typically recommended for lands with slopes of up to 33%, but its adoption may extend to lands with slopes ranging from 50% to 60%, contingent upon the socioeconomic conditions prevailing in a given region (Kumawat et al., 2020).

This approach offers several benefits such as reducing soil erosion through the capture of runoff water. It also aids in preserving soil fertility and safeguarding valuable topsoil. It also helps conserve moisture by allowing rainwater to infiltrate the soil, reducing runoff, retaining soil moisture, and increasing drought resistance. Terracing also supports nutrient management by minimizing nutrient runoff and preserving soil fertility, which benefits plant growth while reducing the need for excessive fertilization (Arunrat et al., 2022). The structured arrangement of terraced fields also facilitates weed and pest management by simplifying weed control and making it easier to monitor and control pests (Chhetry and Belbahri, 2009). Terraced landscapes can help promote biodiversity by creating microhabitats for beneficial insects and organisms that help with pest control and pollination. In addition, terracing plays an important role in stabilizing slopes on hilly or sloping terrain and reduces the risk of landslides and soil erosion.



Figure 2: Bench terraces for soil and water conservation.

Source: <https://www.greener.land/index.php/product/terracing/>

3.2.1 Steps to implement terracing as soil and water conservation measures

Implementing terracing measures on the field involves a series of steps to effectively create small embankments on sloping terrain. Terracing is a soil conservation technique that helps reduce soil erosion and conserve water on hilly or sloping land. Here is a step-by-step guide to implement terracing measures:

3.2.1.1 Site Assessment and Planning

- i. Survey your field to identify the slopes and determine the direction of water runoff. Terracing is most effective on sloping land.
- ii. Understand the soil type and its erodibility. Different soils may require different terracing techniques.
- iii. Analyze the local rainfall patterns, including intensity and frequency, to determine the potential for soil erosion and water runoff.
- iv. Plan the layout of your terraces, including the spacing and dimensions of each terrace. The design should ensure proper water flow and soil conservation.

3.2.1.2 Constructing terraces

- i. Choose the most suitable terracing technique for your field. Common methods include bench terraces, contour bunds, or stone terraces. The choice depends on the slope, soil type, and available resources.
- ii. Clear the area where the terraces will be constructed. Remove any trees, shrubs, or existing vegetation that may obstruct the terracing process.
- iii. Build the terraces according to your planned layout. This may involve excavating soil to create level planting areas and constructing walls or bunds to retain water and prevent soil erosion.

- iv. Terraces should run horizontally across the slope.

3.2.1.3 Maintenance and Management

- i. Plant grass, cover crops, or other suitable vegetation on the terraces to stabilize the soil and prevent erosion. The roots of these plants help bind the soil together.
- ii. Ensure proper drainage by adding outlets or spillways at the lower end of each terrace to allow excess water to flow without causing damage.
- iii. Periodically inspect the terraces to check for signs of erosion, wall stability, and proper drainage. Repair any erosion or damage promptly. Maintain the vegetation cover on the terraces by controlling weeds and replanting as needed.
- iv. Terraces should be designed to direct water flow horizontally along the contour, reducing its velocity and allowing it to infiltrate the soil. Install check dams or silt basins at regular intervals along the terraces to further slow down water runoff and trap sediment.
- v. Continuously assess the effectiveness of your terracing measures by observing soil erosion patterns, especially after heavy rainfall events. If erosion still occurs, consider modifying your terrace layout or adding additional measures, such as grassed waterways or sediment basins.
- vi. Ensure that field workers are trained in terracing techniques and understand the importance of proper implementation.

3.3 Cover Cropping

Cover cropping stands as a pivotal and sustainable soil and water conservation measure within cereal-legume production systems. Offering multifaceted benefits, cover crops play a crucial role in erosion control, nutrient management, weed suppression, and soil enhancement (Hartwig and Ammon, 2002; Blanco-Canqui et al., 2015). Among the array of cover crops utilized, common varieties encompass legumes such as clover and vetch, grasses like rye and oats, and cabbage species such as radish (Chapagain et al., 2020). These cover crops are strategically integrated into agricultural systems through intercropping with main crops or inclusion in crop rotation schemes, with a particular focus on cereals (Fageria et al., 2005).

Erosion control stands as one of the primary benefits of cover cropping, as these plants form a protective layer on the soil surface, mitigating soil erosion by attenuating the impact of raindrops and impeding soil runoff (Bodner et al., 2010). Furthermore, cover crops contribute to moisture conservation by functioning as a living mulch layer, shading the soil and curtailing evaporation rates, all while enhancing soil structure and facilitating water infiltration to minimize surface runoff (Balkcom et al., 2007).

The role of cover crops extends to nutrient management, notably through atmospheric nitrogen fixation (Koudahe et al., 2022). Upon incorporation into the soil, cover crops release stored nutrients, augmenting their availability for subsequent crops. Moreover, cover crops exhibit efficacy in weed suppression by outcompeting weeds for sunlight, water, and nutrients, thereby reducing weed pressure

on the primary crop. Certain cover crops even demonstrate the capacity to suppress nematode populations, fostering overall plant health.

An additional advantage of cover cropping lies in soil improvement facilitated by their root systems, which aid in soil aggregation and structure enhancement, fortifying the soil against erosion (Fageria et al., 2005). As cover crops decompose, they contribute organic matter to the soil, heightening fertility and augmenting water-holding capacity (McGourty and Reganold, 2005). Furthermore, cover crops foster biodiversity by attracting beneficial insects, including pollinators and pest controllers, thereby enriching overall biodiversity.

Among cover crop options, legumes exhibit notable ground cover and offer heightened protection against runoff and soil erosion compared to cultivated fallow. With legumes boasting superior biomass for soil protection in contrast to non-leguminous crops, the efficacy of cover crops hinges on their crop geometry and the development of a canopy, which aids in raindrop interception, subsequently mitigating soil surface exposure to erosion.



Figure 3: Leguminous plants (Crimson clover) as cover crops used in the cultivation of cotton. Source: <https://www.sare.org/publications/cover-cropping-for-pollinators-and-beneficial-insects/cover-crops-on-your-farm/>

3.3.1 Steps to implement cover cropping as soil and water conservation measures

3.3.1.1 Implementing cover cropping

- i. Determine your specific goals for cover cropping. These goals may include improving soil health, reducing erosion, enhancing nutrient management, or weed control.
- ii. Choose appropriate cover crops based on your goals, local climate, and soil conditions. Consider factors such as the crop's growth habit, root depth, and nutrient contribution.
- iii. Plant cover crops at the right time of the year, either in between cash crops (intercropping) or during fallow periods (cover cropping during off-seasons). This timing depends on your region's growing seasons.
- iv. Broadcast or drill-seed cover crop seeds at the recommended planting density. Ensure good seed-to-soil contact for optimal germination.

- v. Consider using a mix of cover crop species for diverse benefits. Mixtures can improve soil health, increase biodiversity, and provide various ecosystem services.
- vi. Determine the right time to terminate cover crops based on your goals. Termination can occur when cover crops reach specific growth stages, such as flowering or early grain formation.
- vii. Use appropriate termination methods such as mowing, roller-crimping, or herbicides, depending on the cover crop species and your objectives.
- viii. Incorporate cover crop residues into the soil using tillage or a no-till approach, depending on your farming practices.
- ix. Leave cover crop residues on the surface to act as mulch. This conserves moisture, suppresses weeds, and protects the soil from erosion.

3.3.1.2 Maintenance and Management

- i. Monitor and manage weeds among your cover crops. Some cover crops may suppress weeds, but additional measures may be required.
- ii. Provide adequate irrigation or rely on natural rainfall to ensure cover crop establishment.
- iii. Adequate moisture is essential for germination and growth.
- iv. Keep an eye out for potential pest issues, and use appropriate integrated pest management practices to address them.
- v. Maintain records of cover crop species, planting and termination dates, and outcomes. This information can guide future cover cropping decisions.
- vi. Assess the impact of cover cropping on your soil health, crop yields, and other objectives. Measure improvements in soil organic matter, nutrient levels, and erosion control.
- vii. Incorporate cover cropping into your crop rotation plans.
- viii. Rotate cover crop species and cash crops to maximize benefits and minimize pest pressures.

3.4 Mulching

Mulching encompasses the application of any material, whether organic or non-organic, onto the soil surface to shield it from erosion and evaporation, while concurrently enhancing water infiltration, regulating soil temperature, improving soil structure, and preserving soil moisture (Kumawat et al., 2020; Jabran, 2019). A diverse array of materials, including straw, leaves, plastics, and compost, are commonly employed for mulching purposes (Bhardwaj, 2013).

Central to the role of mulching is moisture retention, achieved through the reduction of water evaporation from the soil surface and the maintenance of consistent soil moisture levels (Ramakrishna et al., 2006). Moreover, mulching serves as an effective strategy for weed suppression by establishing a physical barrier that impedes weed growth and diminishes competition for water and nutrients (Arentoft et al., 2013).

In addition to moisture conservation and weed control, mulching contributes to temperature regulation by furnishing thermal insulation, thereby safeguarding against extreme temperature fluctuations. This protective function aids in maintaining optimal soil conditions for plant growth and development (Gill and McSorley, 2010; Tang et al., 2023). Furthermore, mulching plays a pivotal role in soil

improvement by introducing valuable organic matter, stimulating microbial activity, and mitigating erosion by mitigating the impact of raindrops.

The benefits of mulching extend to smallholders and farmers, offering a pathway to ensure the long-term sustainability and resilience of their cereal-legume crops while conserving soil and water resources. While both organic and inorganic mulches confer advantages, inorganic mulches typically exhibit a longer lifespan, albeit without the capacity to directly enhance soil health.



Figure 4: Plant residues as mulch over the surface of the land.

Source:<https://ifdc.org/2023/04/21/mulching-a-win-win-for-the-earth-the-farmer-and-the-food-consumer/>

3.4.1 Steps to implement mulching as soil and water conservation measures

3.4.1.1 Planning and site preparation

- i. Choose the appropriate mulch material based on your specific goals and local availability. Common options include organic materials (straw, hay, leaves, compost), plastic mulch, or inorganic materials (gravel, rocks).
- ii. Remove any existing vegetation or weeds from the area where mulching will be applied. This helps prevent weed growth underneath the mulch.

3.4.1.2 Planting or Crop Establishment

- i. If you are using mulch in a garden or agricultural setting, plant your desired crops or seeds in the prepared soil. Ensure proper spacing and planting depth.
- ii. Apply a layer of mulch material over the soil around your plants or crops.
- iii. The mulch layer should be thick enough to provide effective coverage but not so thick that it impedes water infiltration.

- iv. Leave a small gap around the base of plants or crop stems to prevent moisture-related issues or plant diseases.

3.4.1.3 Maintenance and Management

- i. Regularly inspect the mulched area for weed growth.
- ii. Remove any weeds that penetrate the mulch to prevent competition for water and nutrients.
- iii. Over time, organic mulch materials may break down and become less effective.
- iv. Replace or top up the mulch as needed to maintain its protective properties.
- v. Ensure that you water the area adequately before applying mulch. This helps the mulch settle and hold in moisture more effectively.
- vi. Maintain records of the type of mulch used, the date of mulching, and any observations regarding its impact on soil moisture, weed suppression, and crop performance.
- vii. Assess the effectiveness of mulching in conserving soil and water.
- viii. Measure improvements in soil moisture retention, reduced erosion, and weed suppression.
- ix. Based on your observations and goals, make adjustments to your mulching practices as necessary. This might include changing the type of mulch, adjusting mulch thickness, or altering your irrigation schedule.
- x. Integrate mulching into your crop rotation plans, ensuring that it complements your overall agricultural practices.

3.5 Rainwater Harvesting

Rainwater harvesting is an effective and sustainable measure for conserving soil and water in cereal-legume production systems. It involves the collection and storage of rainwater for agricultural use through systems ranging from rain barrels to rooftop catchment structures (Kinkade-Levario, 2007; Abdulla et al., 2021).

This approach enhances soil moisture management by providing supplemental irrigation during dry periods (Amankwaa-Yeboah et al., 2023a), enhancing drought resilience, supporting sustainable and cost-effective crop irrigation with reduced salinity impact, minimizing erosion through reduced surface runoff, providing high-quality water for various agricultural purposes, ensuring resource efficiency and cost savings (Li et al., 2002; Ding et al., 2021).



Figure 5: Rainwater harvesting technique for farming activities.

Source: <https://www.fao.org/platforms/water-scarcity/Knowledge/knowledge-products/detail/rainwater-harvesting-and-agroecological-irrigation-make-farmers-more-resilient-in-senegal/en>.

3.5.1 Steps to implement rainwater harvesting as soil and water conservation measures

3.5.1.1 Planning and installing rainwater harvesting systems

- i. Identify the rainfall pattern and average annual rainfall in your area.
- ii. Assess the water flow and volume during rainfall events to determine the feasibility of runoff water harvesting. Determine the water requirements for your farm, including irrigation, livestock, and other uses.
- iii. Identify areas on the farm with high runoff potential, such as slopes, hills, or compacted soil.
- iv. Choose a suitable catchment area, such as a natural depression, a slope, or a constructed runoff collection channel.
- v. Ensure the catchment area is free from contaminants and pollutants.
- vi. Design and construct a runoff collection system, such as a channel, ditch, or pipe, to direct water to the storage tank.
- vii. Choose a suitable storage tank material, such as concrete, steel, or plastic, considering factors like durability, cost, and water quality.
- viii. Install the tank in a location that allows easy access and minimizes contamination risks.

3.5.1.2 Management and maintenance of rainwater harvesting systems

- i. Use geotextiles, riprap, lawn grass or other erosion control measures to prevent soil erosion and damage to the collection system.
- ii. Regularly inspect and clean the collection system, storage tank, and distribution system to prevent contamination and damage.

- iii. Ensure the system is designed and installed to prevent waterlogging and erosion.
- iv. Consider the potential for flooding and take measures to mitigate risks.
- v. Regularly test the water quality to ensure it is suitable for the intended uses.
- vi. Consider integrating the runoff water harvesting system with other water management practices, such as conservation agriculture and precision irrigation.

3.6 Conservation Tillage

The imperative to address food security concerns through enhanced soil and water management techniques underscores the necessity of adopting conservation tillage practices within cereal-legume production systems. Conservation tillage entails the reduction or elimination of conventional tillage operations, opting instead for alternative approaches that retain crop residues on the field surface (Peigné et al., 2007; Hussain et al., 2021).

A spectrum of techniques falls under the umbrella of conservation tillage practices, encompassing zero tillage (No-till), reduced (minimum) tillage, mulch tillage, ridge tillage, and contour tillage (Amankwaa-Yeboah et al., 2023b; Busari et al., 2015). No-till represents the minimal disruption of the soil surface, with soil disturbance limited to planting activities (Busari et al., 2015). Conversely, minimum tillage involves a restrained approach to soil management by incorporating plant residues into the top layer of the soil, while mulch tillage maximizes the coverage of plant residues or other organic materials to protect the soil surface (Davies and Finney, 2002; Alskaf et al., 2020; Ito et al., 2007).

Ridge tillage entails planting crops in rows, either alongside or on top of ridges formed at the beginning of the growing season (Alagbo et al., 2022; Amankwaa-Yeboah et al., 2022). Contour tillage, conducted perpendicular to the slope's direction, aids in minimizing soil erosion (Zhang et al., 2004).

Conservation tillage practices offer a myriad of benefits, including mitigating soil erosion by creating a protective mulch layer and enhancing soil structure (Dumanski et al., 2006). Moreover, conservation tillage enhances moisture retention, thus preserving soil moisture levels and promoting consistent moisture distribution. Increased organic matter and enhanced microbial activity foster improved soil health, while energy and cost savings are realized through reduced fuel consumption and enhanced time efficiency (Li et al., 2020).

Additionally, conservation tillage practices contribute to biodiversity conservation by creating habitats for beneficial insects and other organisms. Furthermore, the adoption of conservation tillage leads to

reduced carbon emissions, thereby contributing to lower carbon footprints and aligning with broader sustainability goals.



Figure 6: Conservation tillage practice.

Source: <https://www.journey2050.com/conservation-tillage/>

3.6.1 Steps to implement conservation tillage as soil and water conservation measures

3.6.1.1 Planning and residue generation

- i. Determine your specific goals for conservation tillage. These goals may include reducing erosion, conserving moisture, improving soil health, or enhancing crop productivity.
- ii. Choose the most suitable conservation tillage practices based on your goals, crop type, and local conditions. Common options include no-till, reduced tillage, and strip-till.
- iii. After harvesting your previous crop, leave the crop residues (stalks, leaves, etc.) on the field. These residues act as mulch, protecting the soil.
- iv. If you are using no-till or strip-till practices, plant your desired crops or seeds directly into the untilled soil.
- v. If you are using reduced tillage, minimize soil disturbance during planting.

3.6.1.2 Maintenance and Management

- i. Implement effective weed control strategies, such as herbicides or cover crops, to manage weeds in conservation tillage systems.
- ii. Monitor and manage pests according to integrated pest management (IPM) principles.
- iii. Adjust your nutrient management practices to account for the reduced tillage impact on nutrient availability.

- iv. Regularly monitor soil health indicators such as organic matter content, soil structure, and nutrient levels. Observe the impact of conservation tillage on soil erosion rates and sediment loss from the field.
- v. Maintain records of your conservation tillage practices, including the type of tillage used, crop residues left on the field, and any changes made over time. These records will help you optimize your approach.
- vi. Based on your observations and goals, make adjustments to your conservation tillage practices as necessary. Modify your approach to improve soil health, moisture conservation, and crop performance.
- vii. Integrate conservation tillage into your crop rotation plans, ensuring that it aligns with your overall agricultural practices and crop sequence.

3.7 Farm Diversification

Farm diversification involves expanding crop varieties and agricultural activities beyond monoculture, promoting ecological balance through reduced soil erosion, enhanced soil fertility, improved water use efficiency, and diversified pest and disease management. Farm diversification is a strategic approach of producing diversity of crops through systems such as crop rotation, multiple cropping or intercropping to improve crop productivity, stability and delivery of ecosystem services (Kremen and Miles, 2012; Garbach et al., 2017). Smallholder farm diversification may involve animal integration, usually small ruminants and poultry into the cropping system.

Crop diversification practices encompass a range of strategies, such as increasing crop diversity, implementing diverse crop rotation schemes, mixed cropping, introducing grain legumes in predominantly cereal-based systems, establishing perennial leys or grasslands, and utilizing regionally adapted varieties or blends of varieties (Hufnagel et al., 2020). Crop diversification measures, such as altering seeding times or adjusting cropping patterns, hold the promise of achieving elevated and consistent yields, enhancing profitability, and bolstering the long-term resilience of agro-ecosystems (Rosa-Schleich et al., 2019).

This phenomenon provides habitats for beneficial organisms, spreads risks associated with weather and market fluctuations, and addresses challenges related to crop selection, management complexity, market access, and knowledge-sharing among farmers. Farm diversification significantly contributes to sustainable and productive agriculture, benefiting smallholders and farmers by ensuring the long-term sustainability and resilience of their cereal-legume crops while conserving vital soil and water resources (Heumesser and Kray, 2019).



Figure 7: Intercropping maize with climbing beans as a diversified crop rotation system (Fischer et al., 2020)

3.7.1 Steps to implement farm diversification as soil and water conservation measures

3.7.1.1 Planning and Selecting Farm Diversification Practices

- i. Determine your specific goals for farm diversification, which may include reducing soil erosion, conserving water, improving soil health, enhancing biodiversity, or increasing farm income.
- ii. Evaluate your farm's topography, soil type, climate, and available resources. These factors will influence the diversification measures you can implement.
- iii. Select the appropriate diversification practices for your farm. Common options include mixed cropping, intercropping, agroforestry, integrating livestock, or crop rotation.
- iv. If practicing mixed cropping or intercropping, carefully plan and plant a mix of crops that complement each other in terms of growth, nutrient requirements, and water use.
- v. If implementing agroforestry, strategically plant trees or shrubs alongside crops to provide shade, reduce wind erosion, and improve soil health.
- vi. If integrating livestock, manage grazing areas and ensure that livestock do not overgraze, which can lead to soil erosion and degradation.

3.7.1.2 Maintenance and Management

- i. Implement effective weed and pest control strategies to protect crops and ensure they thrive.
- ii. Adapt your nutrient management practices to suit the diversified crop and soil needs.
- iii. Implement efficient irrigation practices, such as drip irrigation or rainwater harvesting, to conserve water resources in diverse cropping systems.

- iv. Regularly monitor soil health indicators, such as organic matter content, nutrient levels, and soil structure, to evaluate the impact of diversification.
- v. Observe how diversification practices impact water use and conservation on your farm.
- vi. Integrate farm diversification into your overall farming system, including crop rotation plans and livestock management.

3.8 Composting

Composting is a biological technique that transforms biodegradable organic materials into stable products, facilitated by the activity of microorganisms (Ghanney et al., 2021). Composting is a highly effective and environmentally sustainable measure for conserving soil and water in cereal-legume production systems. This practice involves the controlled decomposition of organic matter, such as crop residues, kitchen scraps, and manure, into nutrient-rich compost, which is then applied to the soil (Ayilara et al., 2020).

The utilization of compost offers a multifaceted range of benefits for soil and agriculture. It enhances soil fertility by enriching it with essential nutrients and promoting beneficial microbial activity (Singh et al., 2020). Compost use also improves soil structure, reducing moisture evaporation, and lowering the risk of erosion through enhanced soil aggregation and a protective layer against rainfall impact (Adugna, 2016).

Compost application increases organic matter content and facilitates carbon sequestration, contributing to sustained soil fertility and mitigating greenhouse gas emissions (Fortuna et al., 2003). This, in turn, reduces the reliance on synthetic fertilizers, thereby minimizing environmental impact. Compost also plays a vital role in supporting biodiversity by creating an environment conducive to beneficial soil microorganisms and attracting beneficial soil fauna (Ghanney et al., 20).



Figure 8: Composting process by farmers to ensure soil water conservation.

3.8.1 Steps to implement composting as soil and water conservation measures

3.8.1.1 Planning and selecting Composting Methods

- i. Define your specific goals for composting, which may include enhancing soil fertility, reducing erosion, conserving moisture, and improving overall soil health.
- ii. Evaluate your farm's soil type, climate, and crop types to determine the composting methods that are most suitable for your specific context.
- iii. Choose the composting method that best fits your needs.
- iv. Common options include traditional heap composting, vermicomposting (using earthworms), or in-vessel composting.
- v. Collect organic materials like kitchen scraps, crop residues, animal manure, yard waste, and other suitable materials for composting.

3.8.1.2 Composting Process

- i. Start the compost pile by layering the organic materials.
- ii. Alternate between green materials (high in nitrogen) and brown materials (high in carbon) to achieve the right balance.
- iii. Keep the compost pile moist, similar to a wrung-out sponge. Adequate moisture is essential for microbial activity and decomposition.
- iv. Turn or aerate the compost pile regularly to provide oxygen to the microbes and promote decomposition.
- v. Monitor the compost pile's temperature, which should rise as microbial activity occurs. A hot compost pile indicates that decomposition is happening effectively.
- vi. Assess the compost's texture and smell. Well-composted materials will have a crumbly texture and an earthy, pleasant smell.
- vii. Allow the compost pile to mature for several months to a year, depending on the method used. This allows any remaining organic matter to decompose fully.
- viii. If desired, sieve the compost to remove any larger, uncomposed materials.
- ix. Apply the mature compost to your soil. Ensure it is well-mixed to distribute nutrients and improve soil structure.
- x. Based on your observations and goals, make adjustments to your composting practices as necessary.
- xi. Modify your approach to improve soil health, conserve moisture, and enhance crop performance

3.9 Stover Retention

Stover or residue retention is an agronomic practice of leaving crop residues, including stems, leaves, and other plant materials, on the field surface after harvesting, rather than removing them. Stover retention is an endorsed conservation strategy aimed at mitigating soil erosion risk and enhancing soil

fertility through the reintroduction of organic matter and nutrients into the soil (Karlen et al., 2014; Jin et al., 2017).

Retaining enough stover on the fields does not only reduce erosion but increase soil aggregation and structure, infiltration and water retention, thereby mitigating temperature fluctuations in soils (Ojekanmi and Johnson, 2021).



Figure 9: Corn residue retained on the field as a means to ensuring water retention etc.

Source:<https://lgseeds.com/agronomy/taking-stock-of-your-stover-how-to-utilize-and-manage-corn-residue#>.

3.9.1 Steps to implement stover and residue retention as soil and water conservation measures

3.9.1.1 Planning and selecting residue retention methods

- i. Determine your specific goals for stover and residue retention. These may include reducing soil erosion, conserving soil moisture, improving soil health, and enhancing crop productivity.
- ii. Evaluate your farm's topography, soil type, climate, and crop types to determine the best residue retention methods for your specific context.
- iii. Choose the residue retention methods that best fit your needs. Common options include leaving crop residues on the field, using cover crops, or incorporating no-till or reduced-till farming practices.

3.9.1.2 Crop and Residue Management

- i. After harvesting your previous crop, leave the crop residues (stems, leaves, and other organic matter) on the field's surface. This acts as a natural mulch, protecting the soil.
- ii. If using cover crops, plant suitable cover crop species that help protect the soil and improve its health during fallow periods.
- iii. If you choose to use no-till or reduced-till practices, adapt your planting methods accordingly to minimize soil disturbance.
- iv. Implement effective weed control strategies to manage weeds in residue-retained fields. Monitor and manage pests according to integrated pest management (IPM) principles.

- v. Implement efficient irrigation practices, such as drip irrigation or rainwater harvesting, to conserve water resources in residue-retained fields.
- vi. Regularly monitor soil health indicators, such as organic matter content, nutrient levels, and soil structure, to evaluate the impact of residue retention.
- vii. Observe how residue retention practices impact soil erosion rates and sediment loss from the field.
- viii. Based on your observations and goals, make adjustments to your residue retention practices as necessary.
- ix. Modify your approach to improve soil health, conserve water, and enhance crop performance.
- x. Introduce residue retention into your crop rotation activities, making sure that it is consistent with your overall agricultural practices.

4. Conclusion

In conclusion, implementing soil and water conservation measures such as contour farming, composting, conservational tillage, terracing and cover cropping is vital for sustainable agriculture. Terracing effectively reduces soil erosion and conserves water on sloping terrain, with steps including site assessment, terrace design and construction, vegetation planting, and ongoing maintenance.

Cover cropping further enhances soil and water conservation by providing erosion control, moisture retention, nutrient management, weed suppression, and soil improvement. By integrating these techniques into agricultural practices, farmers can safeguard soil health, enhance crop productivity, and promote environmental sustainability for future generations. Each of these conservational practices plays a pivotal role in maintaining that soils are in good conditions that can easily support plant growth and other processes.

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