**In-situ soil and water conservation for sustainable agriculture**

**Abstract**

Conserving soil and water in agriculture is becoming more and more important for the sustainability of agriculture and the environment. By employing innovative and sustainable techniques such as contour farming, no-till or reduced tillage, mulching, cover crops, crop rotation, residue burning alternatives, crop residue management, water harvesting, organic soil amendments, etc., this chapter seeks to highlight in-situ soil and water conservation practices in agriculture and ensure a bright future for food production and the environment. In particular, the chapter will conclude that using these in-situ conservation techniques enhances water availability, fosters agricultural resilience, and maintains soil health.

To improve retention of soil moisture essential for production, support long-term agricultural sustainability and the fight against land degradation, field-based moisture conservation techniques are vital. The chapter also looks at the growing use of geospatial approaches in monitoring soil conditions, which are vital for enhancing in-situ conservation efforts since they provide information on nutrient content and moisture levels. The best places for water harvesting techniques, including check dams and percolation tanks, which collect and hold precipitation to increase water availability and diminish soil erosion, may also be found using geospatial tools. Farmers may support sustainable agriculture and save their land for future generations by concentrating on resource management and the local ecology. In order to ensure long-term agricultural productivity and environmental health, the chapter will also conclude by synthesizing these in-situ soil and water conservation strategies. These strategies not only support sustainable agricultural practices, but also build resilience against climate variability.

#### Keywords: Conservation, Implementing, Practices, Resilience, Strategies.

#### 1. Introduction

Land degradation typically signifies a temporary or permanent reduction in the productive capacity of the land. Misuse of land resources can lead to degradation. Factors such as floods, salinization, prolonged droughts, waterlogging, excessive runoff, acidity, deforestation, intensive farming, and other developmental activities can hasten soil degradation. Additional contributors to land degradation include loss of vegetation due to deforestation, unsustainable extraction of fuel, wood and fodder, shifting cultivation, reduction of forest lands, forest fires, overgrazing, and the non-adoption of adequate soil conservation measures. The primary cause of soil erosion is deforestation (Balboni *et al.* 2023). The roots of grasses, trees, and bushes keep the soil in its proper location and stop soil erosion. In some regions with light to medium-textured soils, soil erosion has become an imminent risk as a result of widespread deforestation. Around 5.3 billion tonnes of soil lose their value yearly nationwide due to soil loss, which occurs at a rate of roughly 16.4 tons per hectare per year (Bhattacharyya *et al*. 2015). Although 5334 million tonnes of soil are displaced each year by river and reservoir, 29% of the soil disappears to the sea, 10% accumulates in water bodies, and 61% is separated from one location and transferred somewhere else. High siltation rates negatively impact agricultural output, leading to a 1% to 2% annual reduction in the storage capacity of large reservoirs. Soil erosion involves the weakening and detachment of soil particles, their transport from one place to another, and their eventual deposition by various agents such as wind and water.

Soil and water are both essential for sustainable agricultural development in arid and semi-arid regions. Therefore, it is crucial for sustained agricultural growth that these two resources be conserved. Sustainable food production depends on the preservation of soil quality via the application of agroecosystem techniques. Numerous soil and water conservation strategies are available to preserve or enhance soil aggregation and structure in-situ, maintain an ideal soil moisture content and shield soils from wind and water erosion. This chapter provides a brief description of many kinds of in-situ soil and water conservation methods, along with the challenges associated with their evaluation. In dry and semi-arid areas, water must be preserved since it is also vital to the production of animals. Sustainable agricultural development results from the development of arid and semi-arid regions' soil and water resources in conjunction with national development plans and strategies. The article outlines steps to safeguard soil and water resources at the agroecosystem level, including the management and use of natural resources in an integrated manner that considers the different relationships between the agro-ecosystem and the outside world. Additionally, the best way to assess various soil and water conservation techniques is through quantitative evaluations, and the approaches currently employed for this purpose are discussed. Also covered are a few methods that require moving a lot of soil.

# 2. Principles and Strategies for Soil and Water Conservation

Sustainable agriculture requires the conservation of soil and water, which may be achieved through a number of practical methods. According to the mechanical methods of in-situ soil moisture conservation, the land surface should be shaped by hand or with tools to lower runoff velocity, give rainfall more time to stand on the soil surface, and allow more rainfall to infiltrate soil layers. Terracing and cover crops are two methods used to preserve soil health and lower the risk of erosion. Furthermore, water harvesting is essential because it collects and stores rainfall, which helps to save water and reduce flow that can cause soil erosion.

Another useful technique is mulching, which covers the soil with organic materials to help control temperature, inhibit weeds and conserve moisture all of these benefits further lessen erosion. Various in situ soil and water conservation techniques are employed depending on the site conditions and objectives, broadly categorized into agronomical, engineering, and biological methods (Fig. 1)

**Fig.1: Classification of In-situ soil water conservation methods based on Agronomical, Mechanical, and Biological Approaches**

Similar to this, cover crops improve soil structure and increase soil organic matter, which can reduce erosion by up to 50% during fallow times (Kaspar and Singer, 2011). By improving moisture conservation and soil stability and health, practices like agroforestry and the use of cover crops greatly reduce soil erosion in agricultural settings. By incorporating trees into agricultural systems, agroforestry can increase soil organic matter and minimize erosion by as much as 70% (Lal, 2014). Last but not least, conservation tillage reduces soil disturbance while maintaining soil organic matter and structure, both of which are critical for lowering erosion and enhancing water penetration. Together, these strategies offer a comprehensive approach to soil and water conservation. Furthermore, it is crucial to maintain a healthy soil biota since these organisms improve nutrient cycling and soil aggregation, which lowers the danger of erosion (Lal, 2015). By reducing soil disturbance and maintaining organic matter, conservation tillage also aids in these initiatives and can reduce erosion by as much as 40% (Peigné *et al* 2015). When combined, these methods create a robust agricultural environment that efficiently prevents soil erosion and maintains biodiversity (Bajoriene *et al.* 2013).

**3. Techniques and Practices**

In order to enhance soil health and raise soil moisture, in-situ soil and water conservation measures are applied in agricultural areas or young forest plantings. These methods can be used as preventative measures or in real time during dry spells to assist minimize soil and water losses. The following are some in-situ methods for conserving water and soil:

**3.1. Agronomical/cultural methods:**

**3.1.1.** [**Conservation Tillage**](https://www.slideshare.net/slideshow/soil-and-moisture-conservation-techniques-248539304/248539304#4)

By improving soil structure and moisture retention, conservation tillage is essential to in-situ soil and water conservation. The Conservation Technology Information Center in West Lafayette, Indiana, USA, gives the definition of conservation tillage as "any tillage or planting system in which at least 30% of the soil surface is covered by plant residue after planting to reduce erosion by water; or wind is the primary concern." This technique entails lowering the frequency and severity of tillage while leaving crop remains on the soil's surface. Reduced use of equipment conservation tillage enhances water infiltration, which lowers surface runoff and raises the soil's ability to store water, thus improving crop water usage efficiency. By maintaining soil structure and encouraging aggregation, which shields streams from sedimentation, this technique also lessens soil erosion. By preserving soil cover, lowering erosion, and encouraging beneficial soil biota activity, crop residue management also improves soil health. Additionally, conservation tillage improves aeration and root development, which are essential for efficient water absorption, by reducing soil compaction. Finally, it contributes to the preservation of soil organic matter, which is necessary to preserve soil fertility and lessen the effects of climate change. (Jat *et al.* 2023). By protecting important soil and water resources for future generations, this strategy not only improves agricultural production but also has a favorable impact on the overall health of the ecosystem.

**3.1.2. Contour ploughing**

Especially on hilly or sloping terrain, contour ploughing is an essential technique for conserving water and soil in-situ. By rerouting the water flow following the land's contours, contour plowing slows down runoff and enhances infiltration into the soil, increasing its ability to store water and reducing runoff (Huang and Liu, 2023).

By creating barriers that slow down water movement, techniques like contour furrows help retain moisture, lessen soil erosion, and maintain the fertility and structure of the soil. For example, compared to conventional techniques, contour tillage has demonstrated a 49.02% drop in sediment output and a 35.86% reduction in runoff (Jia *et al.* 2020). Additionally, by establishing a microclimate that lowers evaporation and hence lessens the need for irrigation, contour plowing preserves soil moisture. Healthy crops and increased soil biota are the results of contour ploughing improved soil structure, which also makes it easier for roots to develop and for aeration to occur. All things considered, contour plowing successfully combines a number of conservation advantages, making it an essential tactic for sustainable land management.

**3.1.3. Cover cropping**

If the ground surface is completely covered by vegetation, erosion can be minimized. such as groundnuts, blackgram, greengram and fodder grasses including Diannath, Marvel and Cenchrus ciliaris and glaucus. When the slope is less than 2 percent, cover crops can be used. An efficient farming method that greatly aids in the preservation of in-situ soil and water is cover cropping. In order to promote soil health, increase water retention, and lessen erosion, this strategy entails planting particular crops in between cash crop cycles. The following are the main advantages of cover crops for conserving water and soil:

1. Erosion Control:

Cover crops help prevent soil erosion by creating a protective layer that stabilizes the soil's surface. Their roots intertwine with the soil, diminishing the force of raindrops and decelerating water flow over the land. This process aids in preserving precious topsoil (Baets *et al.* 2011).

1. Nutrient retention:

Cover crops are effective at capturing and retaining nutrients, especially nitrogen, which prevents them from being washed away during heavy rains. For example, cereal rye and oats can reduce nitrate-nitrogen loss by approximately 31% and 28%, respectively (Nowatzke & Arbuckle, 2018). This retention not only boosts soil fertility but also reduces nutrient runoff into waterways.

1. Soil Structure Improvement:

Cover crops improve soil structure by adding organic matter and encouraging the formation of stable aggregates. This results in better aeration and water infiltration, both of which are vital for healthy plant growth. Deep-rooted cover crops, such as tillage radish, can break up compacted soils, further enhancing water movement through the soil profile (Snapp *et al.* 2022).

1. Moisture retention:

Cover crops help retain soil moisture by intercepting rainfall and reducing evaporation rates (Quintarelli *et al.* 2022). When terminated, their biomass acts as mulch, protecting the soil surface and minimizing evaporation. This is especially beneficial in drought-prone areas where moisture conservation is essential for crop survival. Integrating cover crops with no-till practices has been shown to increase soil water storage and reduce surface runoff, thus enhancing water availability for subsequent crops (Dhakal *et al.* 2024).

1. Increased infiltration

The presence of living roots in the soil increases its permeability, allowing more water to infiltrate rather than run off. This is crucial during periods of heavy rainfall, as it reduces surface runoff (Koudahe *et al.* 2022).

1. **Enhanced Crop Resilience**:

Fields with cover crops have shown higher yields during drought conditions compared to those without. For instance, farmers reported an average increase of 9.6% in corn yields and 11.6% in soybean yields during drought years when cover crops were utilized (Nowatzke & Arbuckle, 2018). This resilience is attributed to improved moisture retention and nutrient availability.

**3.1.4. Mulching**

Mulching is the process of covering the soil surface with materials like groundnut shells, husks, straw, coir pith, and agricultural stubble in order to reduce erosion and preserve 40-60% of the moisture. By decreasing the soil temperature surrounding plant roots and inhibiting the growth of weeds, it also aids in moisture conservation. This technique supports soil and water conservation by helping crops under circumstances of moisture stress at both the surface and vertical layers of the soil.

[**Types of mulches:**](https://www.slideshare.net/slideshow/soil-and-moisture-conservation-techniques-248539304/248539304#12)

* **Plastic films:** These films help maintain higher water content in the soil by reducing evaporation, enhancing infiltration, and decreasing transpiration from weeds. Examples include polythene and polyvinyl.
* **Crop residues or stubble mulch:** Crop residues and plant waste products such as corn and sawdust are commonly used as mulch. These materials are cheap and often readily available. They allow water to enter the soil easily while maintaining an adequate level, increasing water content and reducing evaporation. Examples include straw, cloves, and leaves.
* **Sawdust mulch:** Sawdust is often used as mulch, particularly for acid-loving plants due to its acidity. It has a high-water absorption capacity, making it an effective mulch choice.
* **Soil or dust mulch:** Loosening the surface of the soil creates a soil mulch or dust mulch that reduces evaporation. Inter-culturing in growing crops creates this soil mulch and helps close deep cracks in Vertisols.
* **Vertical mulch:** This technique involves digging trenches across slopes, increasing the surface area available for water absorption.

**3.1.5.** [**Strip cropping**](https://www.slideshare.net/slideshow/soil-and-moisture-conservation-techniques-248539304/248539304#7)

Strip cropping involves growing alternating strips of erosion-permitting crops (such as maize, jowar, bajra, and cotton) and erosion-resisting crops (such as green gram, black gram, moth, and groundnut) in the same field. This practice reduces the velocity of runoff and prevents the eroded soil from being washed away. Strip cropping is crucial for controlling runoff erosion and maintaining soil fertility. It incorporates various good farming practices, such as crop rotation, contour cultivation, proper tillage, stubble mulching, and cover cropping. The different forms of strip cropping are given below:

* **Permanent or temporary buffer strip cropping**
* **Wind strip cropping**
* **Field strip cropping**
* **Contour strip cropping**

**3.2.** [**Engineering/Mechanical measures**](https://www.slideshare.net/slideshow/soil-and-moisture-conservation-techniques-248539304/248539304#17)

Mechanical measures involve constructing barriers across the direction of water flow to retain runoff and reduce soil and water loss. These measures are generally used on land with a slope greater than 2 percent and to supplement agronomical practices when those alone are not sufficiently effective. These measures include: ***Bunding, Terracing, Trenching, Basin-listing and Subsoiling.*** By implementing these techniques, farmers can better manage water flow, reduce erosion, and maintain soil health on sloped lands.

**3.2.1. Bunding**

Building embankments or barriers, generally constructed of stone or earth, along the land's contours is known as bunding, and it is a vital technique in agriculture and land management to improve soil and water conservation, particularly in areas that are prone to erosion and water runoff. Effectively maintained bunds would hold water to decrease soil erosion and conserve moisture; by reducing runoff, improving infiltration, controlling erosion, and increasing crop production, bunds elevate the integrity of the soil and provide more applicants erosion control while encouraging biodiversity.

(i) *Contour bunding*

In arid and semi-arid regions with high infiltration and permeability, contour bunding is the most widely used mechanical technique to prevent soil erosion and preserve moisture. It consists of building relatively narrow-based embankments at regular intervals across the land's slope on a level that is along the contour (Itabari and Wamuongo, 2003). It is typically used on cropland up to a slope of about 6 percent and in regions where the mean annual precipitation is less than 600 mm. A formula is used for estimating the bund spacing.

*V.I= S/a + b*

where,

*V.I*.= vertical interval (m) between consecutive builds,

*S* = % slope of land

*a*' and ‘*b*' = constants depend on soil and rainfall characteristics.

The elevation of the contour bunds relies on slope of terrain, spacing of bunds and utmost intensity predicted in deep black soils. Contoured bunds have been a failing due to buckling of bunds during arid months and pooling of water above the them for extensive intervals, during rainy season.

*(ii)* [*Graded Bunding/Channel*](https://www.slideshare.net/slideshow/soil-and-moisture-conservation-techniques-248539304/248539304#20)*Terraces*

In graded bunding, water flows through graded channels built on the upstream side of bunds. This setup leads to a safe outlet on grassy waterways. Graded bunding can be narrow-based or broad-based. A broad-based graded terrace features a wide, low embankment at the lower edge of the channel, from which soil is dug out. The channel is dug at specific intervals along a downward slope, with an appropriate longitudinal grade. This method is used on land with a slope of about 2-10 percent and in regions where the average annual rainfall exceeds 600 mm.

*(iii) Compartmental bunding*

The area can be divided into little basins or divisions that range in size from 6 x 6 m to 10 x 10 m by using a bund maker to create micro bunds that are 15 cm wide and 15 cm high in each direction. They are useful for short-term rainwater storage, which encourages high infiltration and raises soil moisture levels. For dark soils, slopes of 0.5 to 1% have been recommended. In compartmental bunding, sorghum, sunflower, and maize all perform well.

*(iv) Grass waterways*

Grass waterways, which are artificial or natural streams with vegetation to stop erosion, are used to dispose of surface water from crops. They are constructed in accordance with the slope of the terrain. Channel terraces are connected to grassed streams to protect the soil from gullies and rills and to safely dispose of concentrated runoff. A grass's appropriateness was determined by the amount of shelter it provided, its ability to grow, and how much feed its produce. The best-suited grass was *Panicum repens*, which was followed by *Paspalum notatum, Brachiara mutica, Cynodon plectostachyus* and *Cynodon dactylon*.

**3.2.2.**  [**Terracing:**](https://www.slideshare.net/slideshow/soil-and-moisture-conservation-techniques-248539304/248539304#24)

Because terracing improves soil moisture retention and inhibits soil erosion on steep hill slopes, it is a useful technique for in-situ soil and water conservation. Terracing, which consists of an order of sloping or level plots, decreases water flow, minimizing soil loss and maintaining soil fertility, hence enabling improved water penetration. According to Bhattacharyya *et al*. (2008), this structure also makes it easier to harvest rainwater by allowing precipitation to gather and seep into the soil, replenishing groundwater and lowering runoff. In regions with limited water resources, the enhanced moisture retention is especially advantageous since it results in better soils, higher yields of crops and less water stress. In general, terracing promotes sustainable farming methods and lessens land degradation, improving the availability of food and farmer economies.

**Bench terracing:** Converting slope land into terraced fields may often extend the amount of arable land by 20% to 40%, which is important for increasing grain output by around 20% to 40% (Hu *et al.* 2005). The ground surface must be transformed into step-like fields in order to build a bench terrace. The inclines is susceptible to erosion; however, it is sheltered by vegetation and occasionally has concrete or stones high up it.

**3.2.3. Trenching**

1. The soil contour is used to create trenches, and the water that remains in the trenches helps to preserve moisture and offers advantages for planting and sowing.
2. Excavated materials fill half of the trenches, while the other half of the earth creates the spoil bank.
3. Spacing between trenches - 10-30 meters
4. The size of trenches - 60 cm x 48 cm moisture conservation and afforestation purposes.

**3.2.5.** [**Subsoiling**](https://www.slideshare.net/slideshow/soil-and-moisture-conservation-techniques-248539304/248539304#27)

Using a subsoiler to break up the hard and impermeable subsoil layers can significantly enhance the efficiency of work, allowing a large area to be covered at minimal cost and in a short amount of time. The subsoiler operates at a depth of 30-60 cm and at intervals of 90-180 cm. Employing a tractor-drawn chisel plough for subsoiling at a 2-meter horizontal interval is an effective in-situ soil and water conservation technique that aids in the early establishment and improvement of pastures. This method, which avoids soil inversion, facilitates deeper moisture penetration into the soil, thereby reducing both runoff and soil erosion, and ultimately conserves more rainwater by improving the soil's physical conditions.

**[3.2.6. Check dam](https://www.slideshare.net/slideshow/soil-and-moisture-conservation-techniques-248539304/248539304" \l "28)**

Its length can vary from less than three meters to ten meters, and its height can vary from one to three meters. The water that has been stored raises the nearby soil's moisture content and permits percolation to replenish the aquifers. One check dam's water spread area ought to be larger than another's. It decreases velocity and erosive activity. Over long valleys and tiny streams created by the erosive action of floodwater, check dams are built. Low weirs frequently cross these valleys.

**3.3 Biological measures**

**3.3.1. Forestry measures**

1. **Afforestation and Reforestation**

Reforestation involves artificially or naturally restoring forests and woodlands after they have been harvested or cut down, while afforestation refers to the artificial establishment of forest tree species or stands in areas that previously lacked tree cover Wolosin (2017) focused on India's objectives for forest ecosystem restoration and afforestation. Soil and water conservation (SWC) may be implemented with species such as palms, bamboo, shrubs, and perennial trees (Yadav *et al.* 2018). In India's Western Ghats, Bonell *et al.* (2011) studied how soil hydraulic conductivity affects tree growth and forest utilization. They discovered that hydraulic conductivity near the soil surface was restored under *Acacia auriculiformis* (Ear-leaf acacia) plantations on red and lateritic soils at a relatively low rate compared to less disturbed forests.

1. **Natural Forest**

The conservation of natural resources and the restoration of both cultivable and uncultivable wastelands benefit from the enhanced microclimatic conditions created by forest coverage (Ong and Swallow 2003). The arrangement of perennial trees in the upper layer, shrubs in the middle, and grasses in the lower layer can form a net-like structure that slows the fall of raindrops, thereby reducing splash erosion and other types of soil erosion.

1. **Agroforestry Measures**

Agroforestry involves the simultaneous or sequential cultivation of crops, trees, bamboo, shrubs, palms, and livestock within the same management area. It is a sustainable land-use system that enhances total yield by integrating forest plants and animals with agricultural crops, employing management practices that align with the traditions of the local community (Fahad *et al.* 2022).

1. **Agri-silviculture**

In a particular, transient order, multipurpose trees (MPTs) are grown as an extra crop on the same land management unit as agricultural crops. Perennial tree species' deep taproot system improves infiltration, lowers runoff losses, and stabilizes the soil at the root zone. The addition of leaf litter and its eventual breakdown, which releases vital plant nutrients, are two ways that growing nitrogen-fixing tree (NFT) species improves soil fertility, particularly nitrogen content. Reclamation of degraded areas is a common use for this technique.

1. **Sequential agroforestry**

In sequential agroforestry, agricultural crops and multifunctional tree species are cultivated one after the other, rather than at the same time. This method is utilized by many to enhance soil fertility, which often diminishes due to continuous monocropping. Plants like subabool, arhar (*Cajanus cajan*) and Sesbania sesban (Egyptian river hemp), which are short-rotation, fast-growing and nitrogen-fixing, are grown on fallow lands for four to five years. Afterward, they are harvested for various uses before the land is employed for agriculture again.

1. **Shelterbelts and windbreaks**

In order to reduce soil erosion, water evaporation, and wind velocity, the vegetative barriers are positioned perpendicular to the direction of the predominant wind. They play a crucial role in protecting crops and controlling the drift of sand particles. Trees, shrubs and other vegetation are used to form these barriers around agricultural lands and farm structures to shield them from wind damage. Shelterbelts, akin to windbreaks, are extensive plantings designed to protect multiple fields.

1. **Alley cropping**

This method is frequently used in mountainous areas where crops are cultivated on slopes, and nitrogen-fixing plants and shrubs are arranged as hedges along the contours. Typically, there is a 4-5 meters distance between two rows of hedges and a 25-40 centimetres space between plants within a row. Crop residues and cut plant materials are employed in this practice as mulch and fertilizer and they can also serve as feed for livestock.

1. **Fencing**

Versatile trees like Poplar, Willow, Ficus, Boswellia, Erythrina, Linnea and Bombax were propagated using vegetative cuttings, usually 18 to 36 inches in length and 0.5 to 1.5 inches in diameter. The side branches of the cuttings were meticulously removed. This technique ensures that young shoots, aged 1-2 years, are effective for resource conservation. Fencing is crucial for protecting treated ravine lands from biotic agents. It can result in a 70–120% increase in the biomass of grasses, which helps reduce erosion. The gully area of the Chambal River was successfully covered with grass in 2-5 years. Common plant species used for live fencing in home gardens include *Acacia caesia* (aila), *Acacia concinna* (shikakai), sisal, *Agave americana* (century plant), *Duranta repens* (golden dewdrop), *Erythrina variegata* (Indian coral tree), *Mexican lilac, Euphorbia spp.*, *Jatropha spp.*, *Pithecellobium dulce* (Manila tamarind) and *Vitex negundo* (chaste tree), typically planted at a close spacing of 0.2-0.5 meters.

1. **Conclusion**

The problem under dryland agriculture is that of low yield and unstable production. Despite the realization that it is much difficult to increase the production from drylands, it cannot be neglected, as a large number of farmers and more than two-thirds of the cultivated area. Generally, there are many technologies for in-situ rainwater harvesting and their impact is enhanced by combining these technologies with integrated soil fertility improvement. The In-situ rainwater harvesting technologies have potential to increase crops and fodder productivity and are viable for farmer adoption.

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