Chapter 6

Soil Erosion and Conservation Strategies

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Abstract

Soil erosion, a natural phenomenon exacerbated by human intervention, entails the stripping away of topsoil due to both natural forces and anthropogenic activities. Human-induced factors, including deforestation, improper land-use practices, and unregulated construction, have notably accelerated this process. The depletion of vegetation, especially trees, weakens the soil's integrity, making it susceptible to erosion caused by wind and water. In India, regions characterized by steep gradients and high precipitation, as well as areas experiencing robust and persistent winds, are more vulnerable to soil erosion. These conditions significantly elevate the risk of rapid and substantial soil loss. The consequences of soil erosion extend beyond agricultural concerns;

it is not merely a challenge for farmers due to the loss of organic matter and fertility, but also a pressing environmental issue. Soil conservation practices serve as essential tools for farmers in mitigating soil degradation and enhancing organic content. The primary objective of these efforts is to counteract soil deterioration, encompassing issues like fertility loss and erosion. Soil conservation comprises a variety of techniques employed to shield soil from degradation. Central to this approach is the recognition of soil as a dynamic living ecosystem. Crucially, addressing soil conservation demands the advancement and integration of enhanced technologies, prudent utilization of natural resources, and the implementation of efficient management strategies. These measures are imperative for safeguarding both soil and water resources from degradation.

Keywords: soil erosion, soil conservation, soil loss, ecosystem, soil fertility

I. INTRODUCTION

Since the start of the 20th century, the escalating demand for food production in India has led to the widespread adoption of intensive farming techniques, often at the expense of soil health and conservation priorities. Intensive agriculture, while optimizing yields, minimizing costs, and maximizing profits, fails to be sustainable in the long term. A number of factors, such as rainfall erosivity, soil erodibility, slope, land use, and conservation inteventions, all have an impact on soil erosion, an intricate phenomenon. Notably, areas characterized by dense forest cover (> 40% canopy), arid regions, and cold desert regions of India exhibit an annual water erosion rate of less than 5 Mg/ha/yr. Wind erosion is prevalent in the northwestern Indian desert. Moderate erosion rates (5-10 Mg/ha/yr) are observed in the region of Indo-Gangetic plains, encompassing salt-affected lands in Haryana, Punjab, Uttar Pradesh, West Bengal, and Bihar. Regions with severe erosion rate (>20 Mg/ha/yr) include the northwestern Himalayan regions, Shiwalik Hills, ravines, Western Coastal Ghats, shifting cultivation zones, and the black cotton soil areas of Peninsular India. The remaining parts of the country experience erosion rates ranging between 10-20 Mg/ha/yr. This diverse erosion pattern underscores the need for targeted soil conservation strategies across India's varied landscapes. Globally, efforts to prevent or alleviate water-induced soil erosion have employed various strategies. These include augmenting vegetation cover, adopting sustainable cultivation techniques, and constructing cross-slope barriers to impede runoff and sediment movement (Critchley *et al.*, 1994; Hudson, 1983). The fundamental principles of erosion management revolve around reducing the erosive potential of rainfall. This is achieved through manipulation of the soil surface, meticulous crop management, and effective runoff disposal methods. Certain practices, such as crop and soil management, are focused on preventing or minimizing erosion. In contrast, others, like slope and runoff management, are geared towards controlling erosion once it has occurred (Lal, 1990). These strategies constitute the cornerstone of erosion mitigation techniques and play a pivotal role in sustainable soil conservation efforts worldwide.

II. TYPES OF SOIL EROSION

There are different types of soil erosion depending on the natural process that causes it. They are explained as follows:

1. Water Erosion

Water erosion stands as a significant threat to agricultural productivity, posing the risk of rendering farmland unsuitable for cultivation. This erosive process manifests in various types based on its origins and developmental stages. Water erosion, a consequence of factors like rainfall, snowmelt, irrigation, runoff, and inadequate irrigation management practices, involves the removal of the top soil layer. Primarily, rainfall emerges as the predominant contributor to this phenomenon. Streaming water transports both organic and inorganic soil particles across the land surface, subsequently depositing them in lower-lying areas. Over time, this can lead to flooding. The eroded soil material may either establish new soil formations or be carried into nearby water reservoirs such as lakes and streams. This intricate process of erosion underscores the intricate dynamics between water movements and soil composition, necessitating careful management strategies to preserve agricultural land quality.

A. Splash Erosion

Splash erosion occurs when raindrops strike the ground, transforming barren soil into flowing mud. Raindrops fall at an average speed of about 20 mph. The process involves the impact of raindrops on soil particles, resulting in the splashing of these particles and the formation of craters (Ghadiri *et al.*, 2004). Raindrops hitting the soil surface act as miniature explosives, disintegrating soil particles and creating cavities of varied shapes and sizes. The depth of these craters corresponds to the depth of raindrop penetration, which is impacted by raindrop size, shape, and velocity. Consequently, soil particles can travel only a few centimetres away from their original location in this manner. This process elucidates the intricate dynamics of raindrop impact on soil erosion and underscores the importance of understanding the factors governing this phenomenon for effective erosion control strategies.

B. Sheet Erosion

The loss of the smallest soil particles, rich in nutrients and organic content, occurs when rainfall intensity surpasses the soil's water absorption capacity. This phenomenon commonly follows soil crusting, a consequence of prior water damage. Shallow runoff water initiates this type of erosion, leading to the formation of small rills. This form of soil erosion, termed splash and sheet erosion, is widely recognized as the most prevalent and severe in agricultural contexts due to its removal of the nutrient-enriched topsoil layer. Remarkably, nearly 70% of total soil erosion can be attributed solely to the processes of splash and sheet erosion. This highlights the critical significance of these erosion mechanisms in agricultural landscapes and underscores the need for comprehensive erosion control strategies to safeguard soil fertility.

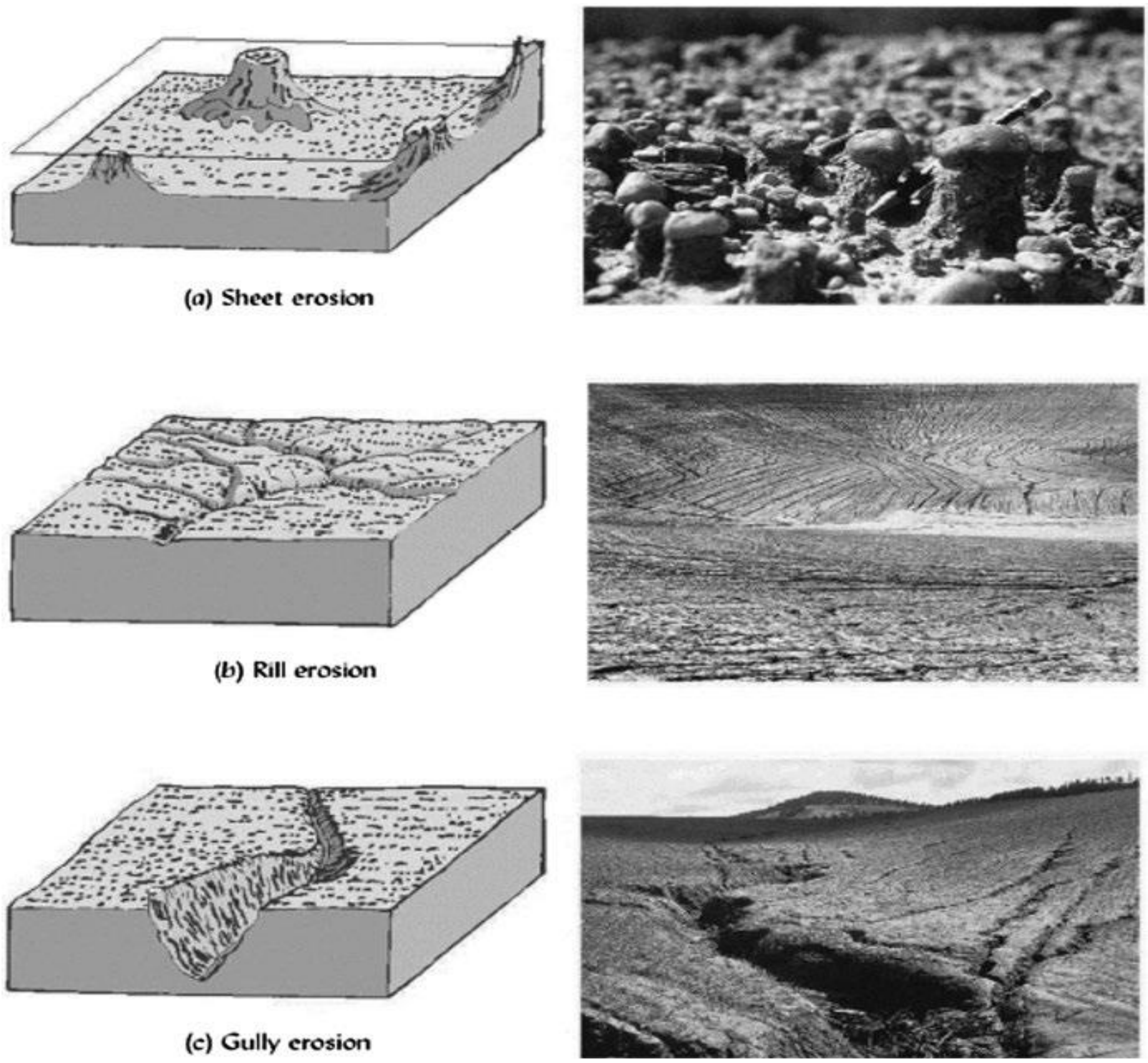


Figure 1: Basic forms of soil erosion by water (Ahmed *et al.*, 2019)

C. Rill Erosion

Rill erosion occurs when runoff water laden with soil ascends slopes, shaping small finger-like channels. Positioned between sheet erosion and gully erosion, rill erosion represents an escalated stage of soil loss. In comparison to sheet erosion, water flowing in these miniature channels accelerates soil erosion. Rill erosion stands as the second most prevalent type of water-induced erosion. Although tillage operations can effectively manage these rills, they pose a substantial risk for intensified soil loss during periods of heavy rainfall. Understanding and addressing rill erosion dynamics are crucial in devising erosion control strategies to preserve soil integrity.

D. Gully Erosion

The rill grows into gullies as concentrated runoff increases in volume and gains speed on slopes. Common starting points for gullies include bullock cart tracks and animal burrows. These gullies progressively transform into ravines, reaching depths ranging from 50 to 10 feet. Moreover, this process degrades water quality, augmenting sediment load in streams. When concentrated runoff's volume and speed surge, rills deepen and broaden, evolving into gullies with dimensions typically measuring 0.3 meters in width and depth. Gully formation is primarily steered by the flow of concentrated runoff. Sustained gully erosion results in the complete removal of the soil profile. In severe cases, it leads to crop failure, exposure of plant roots, lowering of groundwater levels, and destabilization of the landscape, thereby underscoring the far-reaching consequences of this erosive process. Understanding the dynamics of gully erosion is vital for devising effective erosion control strategies, especially in regions susceptible to these destructive formations.

2. Wind Erosion

Wind erosion is instigated by forceful turbulent winds sweeping across an exposed soil surface characterized by smoothness, bareness, looseness, dryness, and fine granulation. Soil particles commence movement when wind force surpasses gravity. The threshold wind speed for initiating particle movement hinges on the size and weight of the soil particles. For loose sand, soil displacement commences at approximately 13 miles per hour, a measurement taken at a height of 1 foot above the ground surface. This precise speed requirement illustrates the delicate balance between wind energy and gravitational force governing the onset of wind erosion, crucial information for comprehending and managing this erosive phenomenon.

A. Surface Creep

During a wind erosion episode, substantial particles spanning 0.5 mm to 2 mm in diameter are propelled along the soil surface until wind velocity decreases. The particles either collide with other elements, become immobilized by existing particles, or find refuge in sheltered spots like furrows or vegetated regions. This interaction leads to the displacement and detachment of adjacent particles. Surface creep wind erosion confines the movement of these larger particles within a few meters, contributing to localized loss and deposition within specific areas. Understanding the dynamics of particle movement in wind erosion events is pivotal for assessing erosion patterns and devising effective mitigation strategies.

B. Saltation

Saltation occurs among intermediate-sized soil particles, ranging from 0.05 mm to 0.5 mm in diameter. These particles possess a weight that allows them to be lifted from the surface but prevents them from becoming suspended in the air. Saltation involves a series of low bounces over the soil surface, inducing abrasion on the terrain. The energy gained by the grains during higher jumps enables them to initiate movement in larger grains and smaller dust particles, which can be suspended in the air and transported over significant distances due to wind-driven forces. Additionally, saltating grains collide with clods, leading to their fragmentation and diminishing surface roughness. Understanding these intricacies of saltation dynamics is fundamental for grasping the complexities of soil erosion processes and devising effective erosion control strategies.

C. Suspension

Particles measuring less than 0.1 mm in diameter can be lifted into the air through saltation, potentially forming dust storms as they ascend further due to atmospheric turbulence. This category encompasses exceedingly fine sand grains, clay particles, and organic matter. Suspension of these particles can lead to visibility issues, while a minor portion of suspended particles may pose health risks if inhaled. Understanding the composition and behaviour of these airborne particles is crucial for assessing environmental impact and public health concerns associated with dust storms.

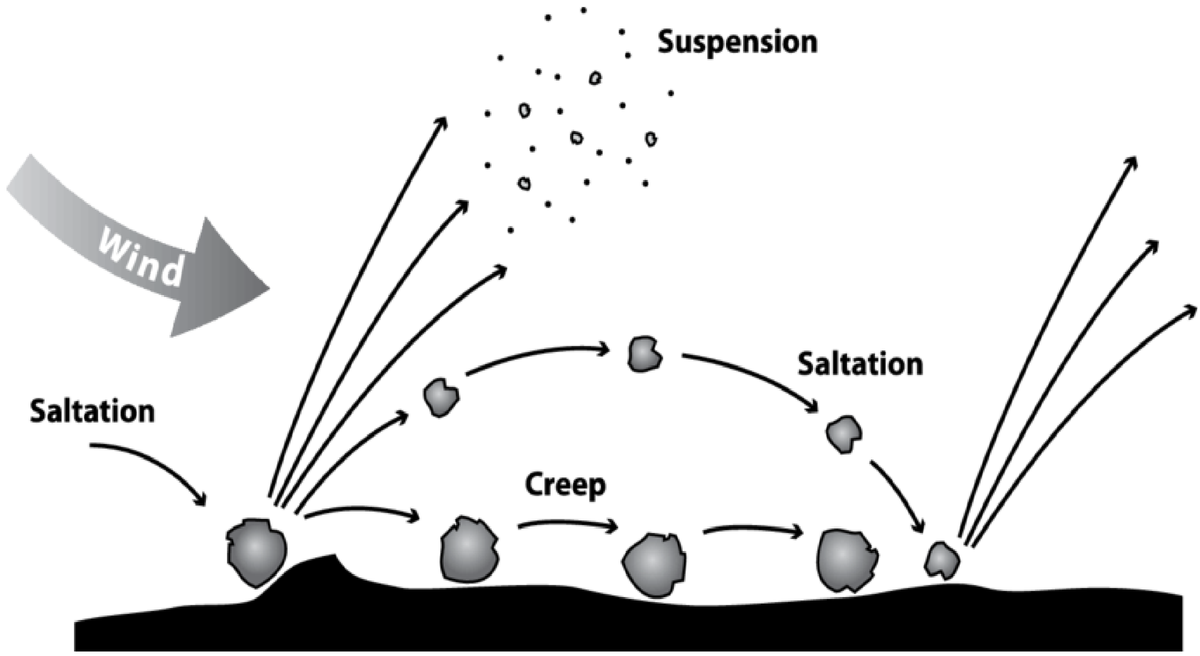
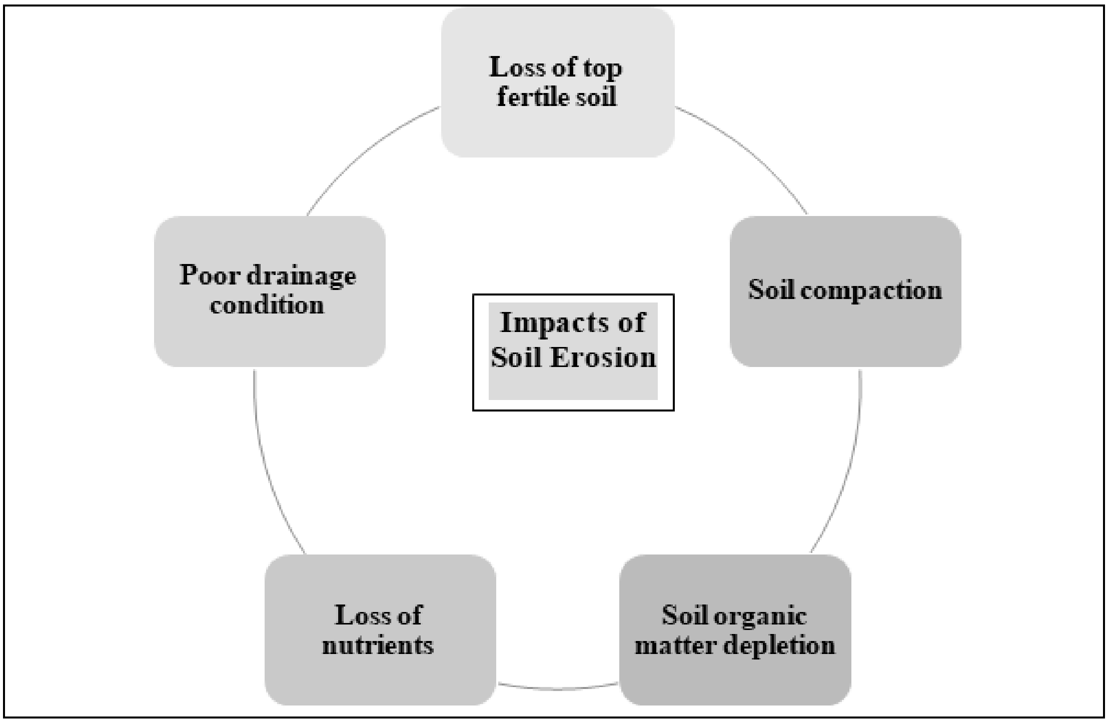


Figure 2: Soil particles can move through saltation, creep, and suspension (Tatarko *et al.*, 2009)

III. IMPACT OF SOIL EROSION ON AGRICULTURE

Soil organic matter (SOM) plays a pivotal role in nutrient storage, release, and ecosystem carbon cycling. It significantly influences soil physical and hydrological properties, providing essential substrates for soil biota. SOM contains near about 95% of nitrogen (N), 25-50% of phosphorus (P) (Allison *et al.*, 1973), making it crucial for soil bio-physico-chemical attributes. However, erosion rates lead to the loss of soil and its fine organic particles. Remarkably, the removal of soil by erosion contains 1.5-5 times higher SOM than the retained soil (Lal *et al.*, 1990). Accelerated soil erosion profoundly impacts soil quality, nutritional content, and agricultural production (Lal *et al.*, 2009). Increased erosion removes fertile topsoil along with nutrients, resulting in land degradation, diminished agronomic yield, and terrain deformities (Wang *et al.*, 2016).

Globally, soil compaction stands as a significant form of land degradation, substantially reducing agricultural productivity. This compaction leads to soil desiccation, manifesting in diminished crop production and adverse environmental conditions. Soil compaction disrupts structure of soil, reducing porosity, air exchange, and water infiltration, hindering root penetration, thereby diminishing crop yields (Raghavan *et al.*, 1992; Dexter, 2004; Botta *et al.*, 2007; Wolkowski and Lowery, 2008). Research by Sharda *et al.* (2010) indicated that water erosion reduced national annual crop production by 13.4 Mt in 2008-2009, underscoring the significant impact of erosion on agricultural productivity. Both water and wind erosion severely compromise the productive ecosystems efficiency (Meena *et al.*, 2017; Lal *et al.*, 2015), emphasizing the critical need for erosion management strategies to sustain agricultural and environmental integrity.



IV. SOIL CONSERVATION MEASURES

1. Agronomic Measures

Agronomic measures find applicability in landscapes with slopes ≤2%. These measures operate by mitigating the impact of raindrops. They achieve this through enhancing soil infiltration rate, and bolstering the soil's water absorption capacity. Consequently, these actions lead to decreased runoff and mitigate soil loss caused by erosion.

A. Contour Farming

Contour farming stands as a widely employed agronomic measure for soil and water conservation in hilly agro-ecosystems and sloping terrains. This method involves aligning all agricultural operations, including plowing, sowing, and inter-cultivation, along contour lines. The resultant formation of ridges and furrows across the slope establishes a consistent sequence of minor barriers in the path of flowing water. These barriers effectively diminish runoff velocity, subsequently reducing soil erosion and nutrient loss (Dimelu *et al.*, 2013; Liu *et al.*, 2014).

B. Cover Crops

Cover crops, characterized by their close-growing nature and high canopy density, are cultivated specifically for shielding soil against erosion. Among these, legume crops exhibit superior biomass compared to row crops, enhancing their ability to protect the soil. The efficacy of cover crops is contingent upon crop geometry and the development of a canopy, crucial for intercepting raindrops and thereby reducing soil surface exposure to erosion. Research indicates that legumes, in particular, offer enhanced cover and protection against runoff and soil loss when compared to cultivated fallow lands and sorghum cultivation. Plants and crop residues play a pivotal role in safeguarding soil particles on the surface. They achieve this by absorbing a portion of the direct force of the wind, trapping mobile soil particles, and enhancing soil particle cohesion, thus contributing significantly to erosion control mechanisms.

C. Strip Cropping

The cultivation practice of planting alternating strips of erosion-permissive and erosion-resistant crops, characterized by deep root systems and dense canopies within the same field, is termed strip cropping. This approach significantly diminishes runoff velocity, curbing erosion processes, and minimizing nutrient loss from the field (Singh *et al.*, 1997; Morgan *et al.*, 2005). Strips prone to wind erosion are interspersed with strips featuring wind-resistant cover. This strategic alternation curtails the downwind avalanche effect, restricting the distance particles can travel before being trapped, thus mitigating wind erosion.

D. Windbreaks and Shelterbelts

Linear plantations, comprising a single or multiple rows of trees or shrubs, are strategically established for the dual purpose of wind erosion control and snow management. These plantations serve to safeguard crops, offer shelter to livestock, and create habitats for wildlife. A distinctive advantage of windbreaks over various other wind erosion control methods is their relative permanence. Particularly during drought periods, windbreaks often emerge as the sole effective and enduring control measure on cropland, underscoring their significance in sustainable agricultural practices.

2. Mechanical Measures

Mechanical measures, also referred to as engineering structures, are meticulously designed interventions aimed at altering land slopes, facilitating the safe conveyance of runoff water to waterways, curtailing sedimentation and runoff velocity, and enhancing water quality. These interventions can function independently or be integrated with biological methods to optimize the effectiveness and sustainability of erosion control measures. In landscapes characterized by severe erosion and steep slopes, it is imperative to complement biological interventions with mechanical structures to comprehensively address erosion challenges and ensure landscape stability.

A. Contour Bunding

This approach entails constructing bunds or embankments aligned along the natural contour lines of the land, conforming to the inherent slope of the terrain. These bunds function as impediments, decelerating the water flow and facilitating its infiltration into the soil. Contour bunding finds particular applicability in regions marked by hilly or sloping topography, where water runoff poses a substantial risk of soil erosion. This technique is employed to preserve soil moisture and mitigate erosion, especially in areas featuring slopes ranging from 2% to 6%, and mean annual precipitation of less than 600 mm, coupled with permeable soils (Shinde *et al*., 2019).

B. Graded Bunding

Graded bunding, or graded contour bunding, represents an agricultural soil conservation methodology, akin to contour bunding, with a distinct emphasis on adeptly managing water runoff in sloping terrains. This technique is meticulously engineered to curb erosion and preserve soil moisture, specifically in regions vulnerable to soil degradation triggered by water runoff. Graded bunds are structured to facilitate the secure drainage of surplus runoff water, a crucial intervention for areas featuring land slopes ranging from 6% to 10%, coupled with rainfall exceeding 750 mm and soil types possessing an infiltration rate of less than 8 mm/h.

C. Contour Trenching

In the context of soil conservation, trenches are strategically excavated along contour lines to mitigate runoff velocity and conserve soil moisture in regions featuring slopes below 30%. Adjacent to these trenches, bunds are constructed to retain rainwater effectively. Trenches come in two primary types:

- **Continuous Contour Trenches:** These trenches are designed based on field dimensions, particularly in regions with low rainfall. They possess a trench length of 10-20 cm and an equalizer width of 20-25 cm. The trench length is maintained consistently without any interruptions, typically spanning 10-20 meters.

- **Staggered Contour Trenches:** Typically implemented in high rainfall areas where overflow risks are significant, staggered contour trenches are constructed in alternating rows, placed directly beneath one another in a staggered configuration. These trenches have a length of 2-3 meters, with a spacing of 3-5 meters between rows. This arrangement effectively manages water flow and minimizes the potential for overflow in areas prone to high precipitation.

D. Terracing

Terraces constitute earthen embankments constructed across the prevailing slope, segmenting the field into uniform and parallel divisions (Blanco *et al.*, 2008). Typically, these structures have channels that collect runoff into the main exit at slower speeds. Terracing effectively mitigates slope degree and length, thereby minimizing the runoff velocity, soil erosion, and enhancing infiltration of water (Gachene *et al.*, 2019). This technique is recommended for lands with slopes up to 33%, although its applicability can extend to regions with slopes ranging from 50% to 60%, contingent on the specific socio-economic conditions of the area.

- **Outward-Sloping Bench Terraces:** Deployed in low rainfall areas with permeable soils, these terraces incorporate a shoulder bund for edge stability, allowing ample time for rainwater to permeate the soil due to the sloping nature.

- **Inward-Sloping Bench Terraces (Hill-Type Terraces):** Ideal for high rainfall areas necessitating rapid runoff drainage, these terraces are designed to channel a significant portion of rainfall as runoff. Adequate drainage systems, typically in the form of drains at the inner ends of each terrace, are incorporated to manage runoff effectively. Commonly referred to as hill-type terraces, they cater to regions with intense precipitation patterns.

- **Level-Top Bench Terraces:** Suited for areas experiencing uniform and moderate rainfall distribution coupled with deep, highly permeable soils often utilized in irrigated regions, these terraces facilitate efficient water management in areas where medium rainfall prevails uniformly.

V. CONCLUSION

Productivity within terrestrial ecosystems hinges upon the interplay of robust soil health and the availability of water. These fundamental elements are essential because plants, which form the foundation of terrestrial ecosystems, demand fertile soil endowed with enhanced bio-physico-chemical attributes, alongside access to high-quality water to foster their growth and development. Consequently, the implementation of soil and water conservation practices, encompassing both biological (such as agricultural and agroforestry practices) and mechanical interventions (including bunding, terracing, trenching, check dams, etc.), becomes imperative. These measures are instrumental in curbing runoff, mitigating soil erosion, and enhancing water quality, soil quality, moisture retention capacity, and overall crop productivity, all while adhering to principles of sustainability. In recent years, the adoption of conservation tillage practices, coupled with the judicious utilization of cover crops, has demonstrated its efficacy in revitalizing soil health and augmenting the physico-chemical attributes of soil. The deployment of innovative and advanced management techniques is typically tailored to the specific requirements of each region and the prevailing climatic conditions, making it a site-specific endeavor designed to optimize the sustainable utilization of natural resources.

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