Chapter

Soil and Water Conservation Measures for Agricultural Sustainability

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Abstract

Limited natural resources are available on the planet under immense pressure due to the ever-increasing population and changing climate. Soil and water are fundamental natural resources for the agricultural production system. Anthropogenic and adverse natural activities are the major factors for the deterioration of natural resources. Among the various degradation processes, soil erosion is one of the serious threats for the deterioration of soil and water resources. In India, about 68.4% of the total land area has been degraded by the water erosion process. Intensive agricultural practices accelerate the soil erosion process. Similarly, increased exploitation of groundwater resulted in depletion of groundwater level. Hence, the holistic management of soil and water resources is indispensable for agricultural sustainability as well as for the protection of the natural ecosystem. Development and adoption of improved technologies, judicious use of natural resources, and effective management practices are the need of the hour for protection of soil and water from degradation. This chapter highlights the status of natural resource degradation, erosion processes and, soil and water conservation strategies for agricultural sustainability and soil health in the long run.

Keywords: agricultural sustainability, conservation measures, erosion, natural resources, soil, water

1. Introduction

Soil and water are indispensable for the existence and survival of all terrestrial life. These are the basic resources to the requirement for food, feed, fuel, and fiber of human beings. Soil supports plant life by providing a medium for their growth and development [1, 2]. It is a non-renewable natural resource and susceptible to rapid degradation through various forms of erosion processes. Worldwide, around 52% of total productive land has been degraded by various kinds of degradation processes and almost 80% of the terrestrial land is affected by water erosion [3, 4]. Further, annually ~10 million hectares (mha) of cropland becomes an unproductive at the global level due to soil erosion with an average rate of 30 t ha^{-1} $year^{-1}$ soil erosion [5]. It has been estimated that water erosion results in a global flux of sediments of 28 Pg $year^{-1}$ [6]. This, extensive degradation of finite soil resources can severely jeopardize global food security while deteriorating environmental quality. On the other hand, the future of living beings and agricultural production systems is at stake due to continuously depleting aquifers and increasing pressure on underground water under projected climate change scenarios [7]. Moreover, climate change will increase water demand globally by about 40% of the water needed for irrigation [8]. Hence, under the emerging scenario of acute water shortages and land degradation, we must focus our effort on the development and adoption of efficient approaches for soil and water conservation as well as for agricultural sustainability. Even the theme for "World soil day," 2019 was "stop soil erosion, save our future" to raise awareness on the importance of sustaining healthy ecosystems and human well-being. Judicious use and management soil and water resources are more vital now than ever before to satisfy the needs of the ever-growing world population [9]. Conservation of soil and water has several agronomic, environmental, and economical benefits. Worldwide, around US$ 400 billion annual cost of on- and -off-site erosion has been estimated for replenishing lost nutrients, cleaning of water reservoirs and conveyances, and preventing erosion [10, 11].

2. The extent of land degradation

Globally, changes in land use and management practices accelerated soil erosion and have led to irrevocable land degradation, which is affecting 23.5% of the earth's land area [12, 13]. Soil erosion is one of the serious problems which not only impair the quality of land and water resources but also harm agricultural production and the socio-economic condition of farmers. Soil erosion has degraded about 32% of total land area in the USA, 30.7% in China, 16% in Africa, 17% in Europe, and 45% in India through a wide range of degradation processes [14]. Among various land degradation processes, water erosion is a major problem affecting 68.4% of the total land area in India [15, 16]. In India, various organizations have estimated the extent of land degradation (**Table 1**). NBSS and LUP has been reported about 146.8 mha degraded land area in India [17].

A harmonization exercise was done involving various organizations, to work out the water erosion, wind erosion, physical, and chemical degradation in India [18].

Agency	Estimation year	Degraded area (mha)
National Commission on Agriculture	1976	148
Ministry of Agriculture-Soil and Water Conservation Division	1978	175
Department of Environment	1980	95
National Wasteland Development Board	1985	123
Society for Promotion of Wastelands Development	1984	130
National Remote Sensing Agency	1985	53
Ministry of Agriculture	1985	174
Ministry of Agriculture	1994	107
National Bureau of Soil Survey and Land Use Planning (NBSS&LUP)	1994	188
NBSS&LUP (Revised)	2004	147

Table 1.
Extent of land degradation estimated by different agencies in India.

Degradation type	Arable land (mha)	Open forest* (mha)	Data source
Water erosion (>10 t/ha/year)	73.27	9.30	ICAR-IISWC
Wind erosion (Eolian)	12.40	—	ICAR-CAZRI
Sub-total	85.67	9.30	
Chemical degradation			
Exclusively salt-affected soils	5.44	—	ICAR-CSSRI, NBSS&LUP and NRSA, 2004
Salt-affected and water eroded soils	1.20	0.10	
Exclusively acidic soils#	5.09	—	NBSS&LUP, 2005
Acidic and water eroded soils#	5.72	7.13	
Sub-total	17.45	7.23	
Physical degradation			
Mining and industrial waste	0.19		Visual interpretation of satellite data, NRSA, 2003
Permanent Water logging$	0.88		
Subtotal	1.07		
Total	104.19	16.53	
Grand total (Arable + open land)	120.72		

**Area with <40% tree canopy cover.*
#pH < 5.5 and areas under paddy and plantation crops were also included in the total acid soils.
$Sub-surface water logging is not considered.

Table 2.
Harmonized data of degraded and wastelands in India.

The harmonized data on degraded and wastelands with all possible combination classes is given in **Table 2**.

3. Soil Erosion and erosion causing agents

Soil erosion is the removal of topsoil by the physical forces of erosion causing agents at a greater rate than the rate of its formation. Initially, erosion removes the nutrient-rich fertile top layer of soil which leads to the reduced production potential of soil. Soil erosion is classified into two categories, i.e., accelerated and geological erosion. Geological erosion is the natural phenomenon, occurs through the constant process of weathering and disintegration of rocks in which the rate of erosion remains lower than the soil formation rate. In contrast, in accelerated erosion, the rate of soil erosion exceeds a certain threshold level and becomes rapid. Anthropogenic activities such as slash-and-burn agriculture, overgrazing, deforestation, mining, and intensive and faulty agriculture practices are accountable for accelerated soil erosion [9]. This higher rate of soil erosion leads to the removal of organic matter and plant nutrients from the fertile topsoil and eventually lowering crop productivity. Hence, the conservation and management of natural resources are essential. Although the soil erosion cannot be eliminated, however it must be reduced to the level that can minimize its adverse impact on productivity and agricultural sustainability.

Water and wind are two key agents that degrade soils through various kinds of erosion processes. Globally, around 1100 mha is affected by water erosion (56% of the total degraded land) and around 28% of the total degraded land area is affected by wind erosion [19]. Runoff removes the soil particles from sloping and bare lands while the wind blows away loose and detached soil particles from unprotected lands. Other processes of land degradation are soil compaction, waterlogging, acidification, alkalinization, and salinization depends on parent material, climatic conditions, and crop management practices. In this chapter, we will discuss about the soil erosion by water, different types, processes, factors, and management.

4. Water erosion

Worldwide, water erosion is the most severe type of soil erosion. In this form of erosion, detachment, and transportation of soil particles from their parental source take place by water through the action of rainfall, runoff, hailstorm, and irrigation. Water erosion is a prevailing form of erosion in humid and sub-humid agro-ecosystems. It also creates the problem in arid and semiarid regions, characterized by an intensive rainstorm and scanty vegetation cover. Water erosion comprises three basic phases, i.e., detachment, transportation, and deposition. Rainfall is one of the major factors which causes the movement and detachment of soil particles. The detached soil particles seal the open-ended and water-conducting soil pores, reduce water infiltration, and cause runoff. The first two phases determine the quantity of soil to be eroded and the third phase determines the distribution of the eroded material along the landscape. If there is no dispersion and transport of soil particles, there will be no deposition. Hence, detachment and transport of soil particles are the primary processes of soil erosion. Understanding the mechanisms and extent of water erosion is crucial to manage and develop erosion control practices. Splash, sheet, rill and gully erosion are main forms of soil erosion by water (**Figure 1**). The other forms of water erosion are ravine formation, slip, tunnel, stream bank, and coastal erosion [20, 21]. The different forms of water erosion are described below:

4.1 Splash erosion

Splash erosion is the first form of soil erosion by water. Falling raindrops on the soil surface break the soil aggregates and disperse and splash soil particles from their source, known as splash erosion. The process of splash erosion involves raindrop impact on soil particles, a splash of soil particles, and the formation of craters [22]. The raindrops falling on soil surface act like a small bomb which disintegrates soil particles and forms cavities of contrasting shapes and sizes. The depth of craters is equal to the depth of raindrop penetration which is a function of raindrop velocity, size, and shape. In this form, soil particles can move only a few centimeters away from their source.

4.2 Sheet erosion

This is the next phase to splash erosion, which promptly initiates sheet erosion. The fertile topsoil surface is removed uniformly as a thin layer from the entire sloping surface area of the field by runoff water. Sheet erosion is a function of particle detachment, rainfall intensity, and land slope. The shallow flow of runoff water causes this type of soil erosion in which small rills are formed. This is the most common and severe form of soil erosion from an agricultural point of view as it removes the nutrient-rich top layer of soil. Out of total soil erosion, nearly 70% is caused by splash and sheet erosion only.

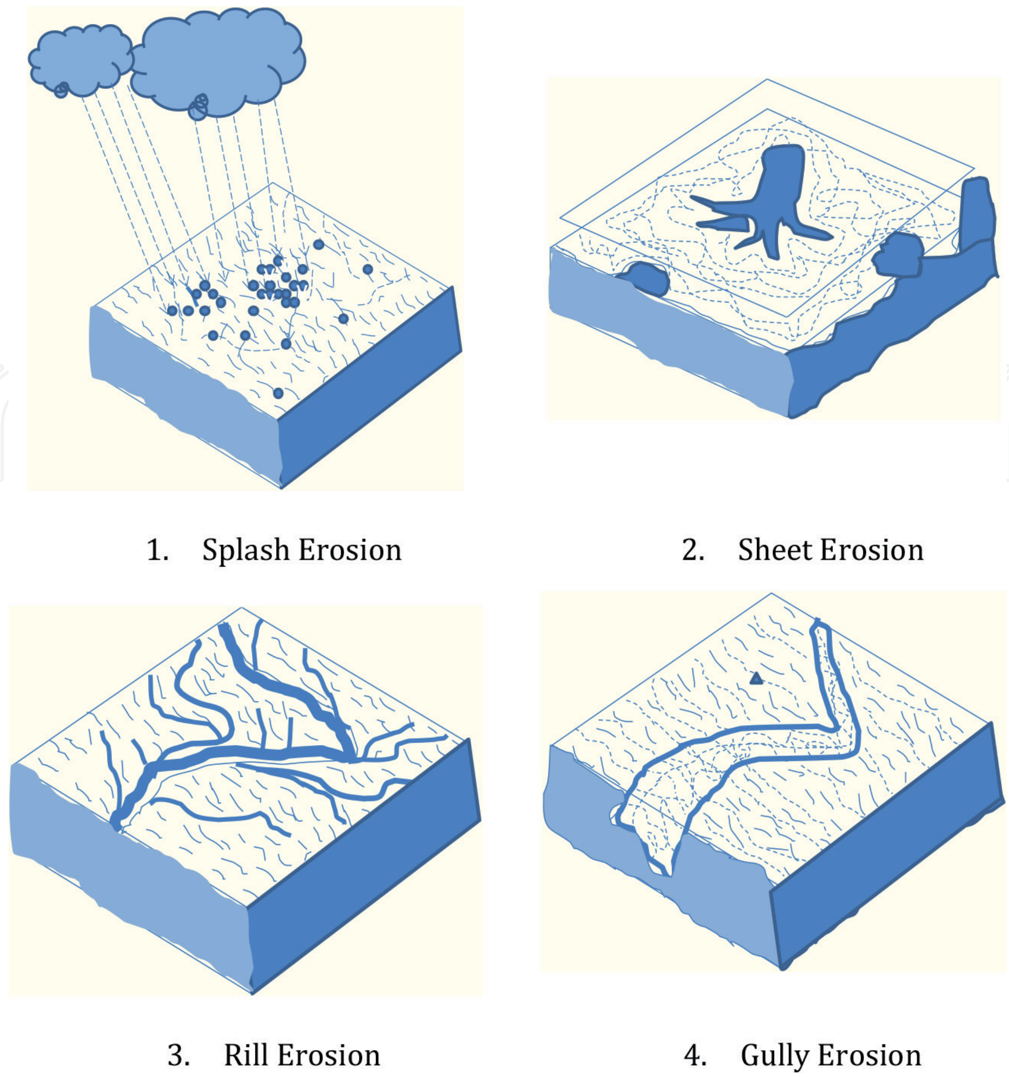

Figure 1.
Four basic forms of soil erosion by water.

4.3 Rill erosion

It describes the flow of runoff water loaded with soil particles and organic matter in finger-like small channels, known as rill erosion. This is the advanced form of sheet erosion for soil loss. Water flow in small channels erodes soil at a faster rate than sheet erosion. Rill erosion is the second most common form of water erosion. These rills can be easily managed by tillage operations but can cause higher soil loss during intensive rainfall. The key factors that cause rill erosion are soil erodibility, land slope, runoff transport capacity, and hydraulic shear of water flow.

4.4 Gully erosion

Gully erosion is the advanced form of rill erosion. When the volume and velocity of concentrated runoff water increase, the rills become deep and broad and forms gullies. The gullies are linear incision channels with 0.3 m width and 0.3 m depth. Concentrated runoff flow is a primary factor for gully formation. Continuous gully erosion results in the removal of the entire soil profile. The extreme form of gully erosion may results in failure of crops, expose plant roots, reduce the groundwater level, and adversely affects landscape stability. It can cut apart the fields and aggravate the non-point source pollution (e.g., sediment, chemicals) to nearby water bodies. Gullies cannot be corrected by usual tillage operations. The dominant factors affecting gully erosion are shear stress of flowing water and critical shear stress of the soil. The further erosion of gullies results in ravines formation. Based on the size, depth, and drainage area, gullies can be classified as:

a. **U-shaped gullies:** These types of gullies are usually formed in alluvial soils where the characteristics of both the surface and subsurface soils are similar.

b. **V-shaped gullies:** This is the most common shape of gully erosion which occurs in the areas where the subsurface of soil is more resistant than the topsoil surface.

4.5 Ravine formation

It is referred to as a network of deep and narrow gullies that flows parallel to each other while linking with the river system. Mismanagement and non-judicious use of land result in enlargement of rills and gullies and eventually lead to ravine formation. Abrupt changes in elevation of the river bed and the adjoining land surface, deep and permeable soil with high erodibility, sparse vegetation, and backflow of river water during the recession period causes severe bank erosion which consequently results in ravine formation.

4.6 Tunnel erosion

It is the sub-soil erosion through runoff flow in channels while surface soil remains intact. Tunnel erosion is also known as pipe erosion and commonly occurs in arid and semiarid regions where the soil permeability for water varied with the soil profile. The further widening and deepening of tunnels form large gullies which degrade the productive agricultural lands. Soil with erodible characteristics, having sodic B horizon and stable A horizon are highly prone to tunnel erosion. Runoff flow through natural cracks and animal burrows initiates tunnel formation by infiltrating thorough dispersible subsoil layers. Seepage, lateral flow, and interflow are key indicators of tunnel erosion. It alters the geomorphic and hydrologic characteristics of the affected areas. Management practices for tunnel erosion are ripping, contour farming, vegetation including trees and deep-rooted grasses with proper fertilization and liming, consolidation of surface soil, and diversion of concentrated runoff.

4.7 Slip erosion or landslip erosion

It is the downward and outward movement of slope forming materials composed of natural rocks and debris from sloppy lands. It is also known as mudslide or mass erosion. This type of erosion mostly occurs in hilly regions having water-saturated soils slips down the hillside or mountain slope. Banks along highways, streams, and ocean fronts are often subject to landslides. The large masses of land slip down which destroy the vegetation and degrade the productivity of lands. The slope can be stabilized through developments of diversion drains, contour trenches, crib structures, geotextiles, kutta—crate structures, and retaining walls.

4.8 Stream bank erosion

The scouring of soil material from the stream bed and cutting of stream bank by the action of flowing water is known as stream bank erosion. Streams and rivers change their direction of flow by cutting the bed from one side and depositing the sediment to the other side of the stream. Flash floods enhanced the stream bank erosion which is more destructive. Stream and gully erosion are relatively comparable. Primarily, stream bank erosion predominantly occurs at the lower end water tributaries which have a relatively flat slope and continuous flow of water.

4.9 Coastal erosion

Sea level is incessantly rising due which can increase the frequency of occurrence of natural disasters like the tsunami in the coastal areas in the future. Such natural hazards produce strong water waves which can severely erode the seaside areas. It is projected that the erosion rate will be higher in coastal regions in the coming years. The anthropogenic activities leading to coastal erosion are port construction, destruction of mangroves, and beach and river bed mining [23].

4.10 Universal soil loss equation for water erosion

The universal soil loss equation (USLE) was given by Wischmeier and Smith (1978) based on the soil erosion causing factors [24].

$$A = RKL\ SCP \tag{1}$$

where A, mean annual soil loss (metric tons hectare^{-1} year^{-1});
R, rainfall erosivity factor;
K, soil erodibility factor
L, slope-length factor
S, slope-steepness factor;
C, cover and management factor;
P, support practice factor.

Among the above-listed factors, vegetation and to some extent soil can be managed to reduce the rate of the soil erosion but the climatic and topographic factors, except slope length, are not manageable. Primarily, soil loss through erosion is a function of erosivity of raindrops and erodibility of the soil which can be mathematically expressed as follows:

$$\text{Erosion} = f\ (\text{Erosivity, Erodibility}) \tag{2}$$

where Erosivity is the potential of rainfall to cause erosion under given soil type and climatic condition; Erodibility is the vulnerability or susceptibility of the soil to erosion which depends on soil bio-physico-chemical properties, and land use and crop management practice. Sandy soils can be easily detached while well aggregated clayey soils are more resistant to erosion than sandy soils. When clay particles detached they can be easily removed by runoff due to their smaller size. Silt soils are the most erodible type of soil [9].

5. Impact of soil erosion on agriculture

The accelerated soil erosion significantly influences the soil quality, agricultural production and nutritional quality [25]. Higher soil erosion results in the removal of fertile topsoil along with nutrients which leads to reduced agronomic yield, land degradation, and terrain deformation [25–27]. The main causal factors affecting the rate of soil erosion are parent material, soil texture, slope steepness, plant cover, tillage, and climate [13]. According to an estimate of existing soil loss data, the mean annual rate of soil erosion in our country is approximately 16.4 ton ha^{-1} which results in annual total soil loss of 5334 million tons (m t) and nutrient loss of 8.4 m t throughout the country [17]. However, the mean annual permissible limit of soil loss is 12.0 tons ha^{-1}. Out of total eroded soil around 29% is permanently lost to the sea, while 61% is transported by runoff from one place to another and the remaining 10% is directly deposited in reservoirs [21]. Higher nutrient concentration has been recorded in soil samples collected from runoff loads over the soil of agricultural fields [28]. Further, around 45.9 kg C ha^{-1} and 4.3 kg N ha^{-1} were recorded in eroded soil during the month of July [29].

The soil organic matter (SOM) is vital for improving soil bio-physico-chemical properties and contains nearly 95% of N and 25–50% of phosphorus [30]. Higher rate of erosion results in loss of soil and fine organic particles. The soil removed by erosion has 1.5–5 times higher SOM than the soil left behind [31]. The availability of SOM also affects the biological activities and soil biodiversity in a particular agro-ecosystem. Moreover, the intensive and erratic rainfall results in higher soil erosion which leads to reduced infiltration and eventually less water availability to the vegetation. Sharda et al. studied the impact of the harshness of water erosion on agricultural productivity and advocated that water erosion reduced the annual crop production by 13.4 Mt in 2008–2009 at the national level [32]. Thus, the soil loss by water and wind severely affects the productive efficiency of all ecosystems [17, 33, 34]. The comprehensive impacts of erosion on soil and water resources which are liable to reduce agricultural productivity are given in **Figure 2** [21].

The vegetation cover is imperative for moderating surface runoff and water erosion from agricultural lands [35]. The rate of runoff, soil, and nutrient loss is predominantly determined by the type of vegetation, canopy cover, slope gradient, and rainfall characteristics [36]. The higher canopy cover and crop residues mulching on soil surface results in the reduced rate of surface runoff and also reduces the impact of rainfall erosivity and soil erodibility [13, 35, 37]. Vegetation cover reduces the detachment of soil particles along with the protection of soil surface from intensive rainfall. Moreover, it also conserves soil moisture and retains sediment and organic materials [38]. To sustain agricultural productivity, it is imperative to reduce runoff, soil loss, and nutrient loss through water erosion [13].

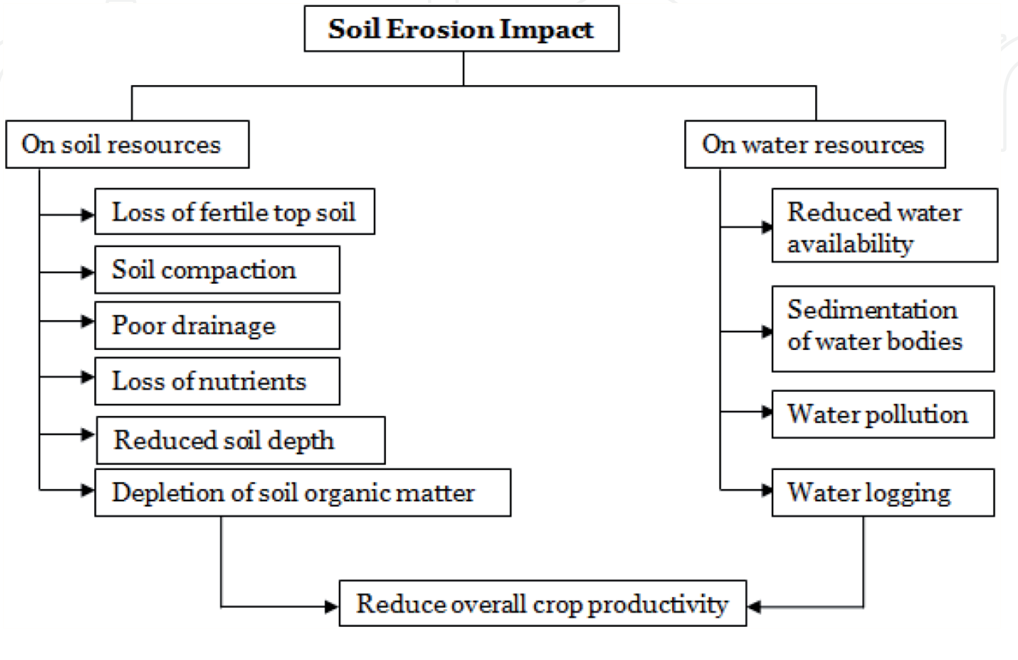

Figure 2.
Impact of erosion on soil and water resources.

6. Soil and water conservation measures

There are two types of measures for soil and water conservation, that is, mechanical/engineering/structural measures and biological measures. Mechanical measures are permanent and semi-permanent structures that involve terracing, bunding, trenching, check dams, gabion structures, loose/stone boulders, crib wall, etc., while biological measures are vegetative measures which involve forestry, agroforestry, horticulture and agricultural/agronomic practices [21].

6.1 Biological measures (agronomic/agricultural and agroforestry)

Agronomic measures are applicable in the landscape of ≤2% slope. Agronomic measures reduce the impact of raindrops through the covering of soil surface and increasing infiltration rate and water absorption capacity of the soil which results in reduced runoff and soil loss through erosion [39]. These measures are cheaper, sustainable, and may be more effective than structural measures, sometimes [4]. Important agronomic measures are described below.

6.1.1 Contour farming

Contour farming is one of the most commonly used agronomic measures for soil and water conservation in hilly agro-ecosystems and sloppy lands. All the agricultural operations viz. plowing, sowing, inter-culture, etc., are practiced along the contour line. The ridges and furrows formed across the slope build a continual series of small barriers to the flowing water which reduces the velocity of runoff and thus reduces soil erosion and nutrient loss [40, 41]. It conserves soil moisture in low rainfall areas due to increased infiltration rate and time of concentration, while in high rainfall areas, it reduces the soil loss. In both situations, it reduces soil erosion, conserves soil fertility and moisture, and thus improves overall crop productivity. However, the effectiveness of this practice depends upon rainfall intensity, soil type, and topography of a particular locality.

6.1.2 Choice of crops

The selection of the right crop is crucial for soil and water conservation. The crop should be selected according to the intensity and critical period of rainfall, market demand, climate, and resources of the farmer. The crop with good biomass, canopy cover, and extensive root system protects the soil from the erosive impact of rainfall and create an obstruction to runoff, and thereby reduce soil and nutrient loss. Row or tall-growing crops such as sorghum, maize, pearl millet, etc. are erosion permitting crops which expose the soil and induce the erosion process. Whereas close growing or erosion resisting crops with dense canopy cover and vigorous root system viz. cowpea, green gram, black gram, groundnut, etc. are the most suitable crops for reducing soil erosion [42]. To increase the crop canopy density, the seed rate should be always on the higher side.

6.1.3 Crop rotation

Crop rotation is the practice of growing different types of crops in succession on the same field to get maximum profit from the least investment without impairing the soil fertility. Monocropping results in exhaustion of soil nutrients and deplete soil fertility. The inclusion of legume crops in crop rotation reduces soil erosion, restores soil fertility, and conserves soil and water [43]. Further, the incorporation of crop residue improves organic matter content, soil health, and reduces water pollution. A suitable rotation with high canopy cover crops helps in sustaining soil fertility; suppresses weed growth, decreases pests and disease infestation, increases input use efficiency, and system productivity while reducing the soil erosion [42].

6.1.4 Cover crops

The close-growing crops having high canopy density are grown for protection of soil against erosion, known as cover crops. Legume crops have good biomass to protect soil than the row crops. The effectiveness of cover crops depends on crop geometry and development of canopy for interception of raindrops which helps in reducing the exposure of soil surface for erosion. It has been reported that legumes provide better cover and better protection to land against runoff and soil loss as compared to cultivated fallow and sorghum. The most effective cover crops are cowpea, green gram, black gram, groundnut, etc.

Advantages

- Protection of soil from the erosive impact of raindrops, runoff, and wind.
- Act as an obstacle in water flow, reduce flow velocity, and thereby reduce runoff and soil loss.
- Increase soil organic matter by residue incorporation and deep root system.
- Improve nutrients availability to the component crop and succeeding crops through biological nitrogen fixation.
- Improve water quality and water holding capacity of the soil.
- Improve soil properties, suppress weed growth, and increase crop productivity.

6.1.5 Intercropping

Cultivation of two or more crops simultaneously in the same field with definite or alternate row pattern is known as intercropping. It may be classified as row, strip, and relay intercropping as per the crops, soil type, topography, and climatic conditions. Intercropping involves both time-based and spatial dimensions. Erosion permitting and resisting crops should be intercropped with each other. The crops should have different rooting patterns. Intercropping provides better coverage on the soil surface, reduces the direct impact of raindrops, and protects soil from erosion [36, 43].

Advantages

- High total biomass production.
- Efficient utilization of soil and water resources.
- Reduction of marketing risks due to the production of a variety of products at different periods.
- Drought conditions can be mitigated through intercropping.

- Reduce the weed population and epidemic attack of insect pests or diseases.
- It improves soil fertility.

6.1.6 Strip cropping

Growing alternate strips of erosion permitting and erosion resistant crops with a deep root system and high canopy density in the same field is known as strip cropping. This practice reduces the runoff velocity and checks erosion processes and nutrients loss from the field [36, 44]. The erosion resisting crops protects soil from beating action of raindrops, reduces runoff velocity, and thereby increased time of concentration which results in a higher volume of soil moisture and increased crop production [4]. Strip cropping is practiced for controlling the run-off and erosion and thereby maintaining soil fertility.

Types of strip cropping

i. **Contour strip cropping:** The growing of alternate strips of erosion permitting and erosion resisting crops across the slopes on the contour is known as contour strip cropping. It reduces the direct beating action of raindrops on the soil surface, length of the slope, runoff flow and increases rainwater absorption into the soil profile.

ii. **Field strip cropping:** In this practice the field crops are grown in more or less parallel strips across fairly uniform slopes, but not on exact contours. It is useful on regular slopes and with soils of high infiltration rates, where contour strip cropping may not be practical.

iii. **Wind strip cropping:** It consists of the planting of tall-growing row crops (such as maize, pearl millet, and sorghum) and close or short growing crops in alternately arranged straight and long, but relatively narrow, parallel strips laid out right across the direction of the prevailing wind, regardless of the contour.

iv. **Permanent or temporary buffer strip cropping:** It is the growing of permanent strips of grasses or legume or a mixture of grass and legume in highly eroded areas or in areas that do not fit into regular rotation, i.e. steep or highly eroded, slopes in fields under contour strip cropping. These strips are not practiced in normal strip cropping and generally planted permanent or temporary basis.

6.1.7 Mulching

Mulch is any organic or non-organic material that is used to cover the soil surface to protect the soil from being eroded away, reduce evaporation, increase infiltration, regulate soil temperature, improve soil structure, and thereby conserve soil moisture [45–47]. Mulching prevents the formation of hard crust after each rain. The use of blade harrows between rows or inter-culture operations creates "dust mulch" on the soil surface by breaking the continuity of capillary tubes of soil moisture and reduces evaporation losses. Mulching also reduces the weed infestation along with the benefits of moisture conservation and soil fertility improvement. Hence, it can be used in high rainfall regions for decreasing soil and water loss, and in low rainfall regions for soil moisture conservation. Organic mulches improve organic matter and consecutively improving the water holding capacity, macro and micro fauna biodiversity, their activity, and fertility of the soil [48, 49].

Inorganic mulches have a longer life span than organic mulches and can reduce soil erosion, water evaporation losses, suppress weeds but cannot improve soil health. This practice is costly and labor intensive therefore, suitable for cash crops such as fruits and vegetables. Polyethylene mulch is commonly used for the conservation of soil and water resources to increase crop productivity [21].

6.1.8 Conservation tillage

In this practice at least 30% of soil surface should remain covered with crop residue before and after planting the next crop to reduce soil erosion and runoff, as well as other benefits such as C sequestration. This term includes reduced tillage, minimum tillage, no-till, direct drill, mulch tillage, stubble-mulch farming, trash farming, strip tillage, etc. The concept of conservation tillage is widely accepted in large scale mechanized crop production systems to reduce the erosive impact of raindrops and to conserve the soil moisture with the maintenance of soil organic carbon. Conservation tillage improves the infiltration rate and reduces runoff and evaporation losses [4]. It also improves soil health, organic matter, soil structure, productivity, soil fertility, and nutrient cycling and reduces soil compaction [50].

6.1.9 Organic farming

Organic farming is an agricultural production system that devoid the use of synthetic fertilizers or pesticides and includes organic sources for plant nutrient supply viz. FYM, compost, vermicompost, green manure, residue mulching, crop rotation, etc. to maintain a healthy and diverse ecosystem for improving soil properties and ensuring a sustained crop production. It is an environmentally friendly agricultural crop production system.

The maintenance of high organic matter content and continuous soil surface cover with cover crops, green manure, and residue mulch reduce the soil erosion in organic farming. It leads to the addition of a large quantity of organic manures which enhances water infiltration through improved bio-physico-chemical properties of soil, and eventually reduces soil erodibility [51]. Organic materials improve soil structure through the development of soil binding agents (e.g., polysaccharides) and stabilizing and strengthening aggregates which reduce the disintegration of soil particles and thus reduced soil erosion. Soil erosion rates from soils under organic farming can be 30–140% lower than those from conventional farming [9].

6.1.10 Land configuration techniques

Adoption of appropriate land configuration and planting techniques according to crops, cropping systems, soil type, topography, rainfall, etc. help in better crop establishment, intercultural operations, reduce runoff, soil and nutrient loss, conserve water, efficient utilization of resources and result in higher productivity and profitability. Ridge and furrow, raised bed and furrow, broad bed and furrow, and ridging the land between the rows are important land configuration techniques.

i. **Ridge and furrow system:** Raising rainy season crops on ridges and *rabi* season crops in furrows reduces the soil crusting and ensures good crop stand over sowing on flat beds. Moreover, inter-row rainwater can be drain out properly during the monsoon period and collected in farm ponds, for life-saving irrigations and profile recharging for the establishment of *rabi* crops. It leads to the increased moisture content in soil profile which reduces moisture stress on plants during the drought period. This method is most suitable for wide-spaced crops viz. cotton, maize, vegetables, etc.

ii. **Broad bed and furrow system:** This system has been developed by the ICRISAT in India. It is primarily advocated for high rainfall areas (>750 mm) having black cotton soils (Vertisols). Beds of 90–120 cm width are formed, separated by sunken furrows of about 50–60 cm wide and 15 cm depth. The preferred slope along the furrow is between 0.4 and 0.8% on Vertisols. Two to four rows of the crop can be grown on the bed, and the width and crop geometry can be adjusted to suit the cultivation and planting equipment.

Advantages

- Increase *in-situ* soil moisture conservation
- Safely dispose of excess runoff without causing erosion
- Improved soil aeration for plant growth and development
- Easier for weeding and mechanical harvesting
- It can accommodate a wide range of crop geometry.

6.1.11 Agroforestry measures

Agroforestry is a sustainable land management system which includes the cultivation of trees or shrubs with agricultural crops and livestock production simultaneously on the same piece of land [52, 53]. It is an emerging technology for effective soil and water conservation and comprises a wide range of practices for controlling soil erosion, developing sustainable agricultural production systems, mitigating environmental pollution, and increasing farm economy. The leaf litter addition act as a protective layer against soil erosion improves soil health and moisture retention capacity of the soil and increases crop productivity [54–56]. It has been reported that different agroforestry practices can reduce up to 10% of soil erosion [57]. Agroforestry not only controls soil erosion but also produce tree-based several marketable products.

Types of agroforestry systems

Agri-Silviculture: It is the growing of agricultural crops as a primary component with the secondary component of multipurpose trees (MPTs) on the same managed land unit. The tree species bind soil particles in the root zone and increase water infiltration, and reduce runoff.

Agri-Horticulture: Growing of agricultural crops and fruit trees on the same managed land unit is known as agri-horticulture. Fruit tree species like lemon (*Citrus limon*), mango (*Mangifera indica*), ber (*Ziziphus mauritiana*), and aonla (*Phyllanthus emblica*) can be successfully planted in agricultural fields and on degraded and low fertile lands with some restoration measures.

Alley Cropping: Growing of agricultural crops in the alley formed between the hedge rows of leguminous nitrogen-fixing tree species. This system is one of the effective measures for soil and water conservation in hilly areas.

Silvi-pasture System: Raising grasses or livestock with MPTs on the same managed land unit is known as silvi-pasture system. This system has the potential to reclaim eroded and degraded lands. Mechanical measures combined with grass species cultivation are more effective for controlling soil erosion processes [58]. The grass species such as *Cenchrus ciliaris* (buffel grass), *Cenchrus setigerus* (bird-wood grass), *Dichanthium annulatum* (marvel grass), *Panicum antidotale* (blue panicgrass), *Panicum maximum* (Guinea grass), *Brachiaria mutica* (para grass) and *Pennisetum purpureum* (elephant grass) are important in ravine restoration [59].

6.2 Mechanical measures

Mechanical measures or engineering structures are designed to modify the land slope, to convey runoff water safely to the waterways, to reduce sedimentation and runoff velocity, and to improve water quality. These measures are either used alone or integrated with biological measures to improve the performance and sustainability of the control measures. In highly eroded and sloppy landscape biological measures should be supplemented by mechanical structures. A number of permanent and temporary mechanical measures are available such as terraces, contour bunding, check dams, gabions, diversion drains, geo-textiles, etc. [43]. The mechanical measures are preferred based on the severity of erosion, soil type, topography, and climate [4].

6.2.1 Bunding

i. **Contour bunding:** Contour bunding is used to conserve soil moisture and reduce erosion in the areas having 2–6% slope and mean annual precipitation of <600 mm with permeable soils [60]. The vertical interval between two bunds is known as the spacing of bunds. The spacing of bund is dependent on the erosive velocity of runoff, length of the slope, slope steepness, rainfall intensity, type of crops, and conservation practices.

ii. **Graded bunding:** Graded bunds are made to draining out of excess runoff water safely in areas having 6–10% land slope and receiving rainfall of >750 mm with the soils having infiltration rate < 8 mm/h.

iii. **Peripheral bunds:** Peripheral bunds are constructed around the gully head to check the entry of runoff into the gully. It protects the gully head from being eroded away through erosion processes. It creates a favorable condition for the execution of vegetative measures on gully heads, slopes, and beds.

6.2.2 Contour trenching

Trenches are constructed at the contour line to reduce the runoff velocity for soil moisture conservation in the areas having <30% slope. Bunds are formed on the downstream side of trenches for the conservation of rainwater. Trenches are of two types:

i. **Continuous contour trenches:** Continuous contour trenches are constructed based on the size of the field in the low rainfall areas with the 10–20 cm trench length and 20–25 cm equalizer width without any discontinuity in trench length (10–20 m).

ii. **Staggered contour trenches (STCs)** Generally, these trenches are constructed in alternate rows directly beneath one another in a staggered manner in the high rainfall areas, where the risk of overflow is prominent. SCTs are 2–3 m long with 3–5 m spacing between the rows. Planting of tree species is done based on the land slope. It is highly effective in forestalling extension of gully head, soil loss, and arrest the overflow.

6.2.3 Terracing

Terraces are earthen embankments built across the dominant slope partitioning the field in uniform and parallel segments [9]. Generally, these structures are combined with channels to convey runoff into the main outlet at reduced velocities. It reduces the degree and length of slope and thus reduced runoff velocity, soil erosion and improves water infiltration [5]. It is recommended for the lands having a slope of up to 33%, but can be adopted for lands having up to 50–60% slope, based on socio-economic conditions of a particular region. Where plenty of good-quality stones are available, stone bench terracing is recommended. Sometimes, semi-circular type terraces are built at the downstream side of the plants, known as half-moon terraces. Based on the slope of benches, the bench terraces are classified into the following categories:

i. **Bench terraces sloping outward:** These types of terraces are used in low rainfall areas having permeable soils. A shoulder bund is provided for stability of the edge of the terrace and thus has more time for rainwater soaking into the soil.

ii. **Bench terraces sloping inward (hill-type terraces):** These types of bench terraces are suitable for heavy rainfall areas where a higher portion of rainfall is to be drained as runoff. For this, a suitable drain should be provided at the inward end of each terrace to drain the runoff. These are also known as hill-type terraces.

iii. **Bench terraces with level top:** These types of terraces are suitable for uniformly distributed medium rainfall areas having deep and highly permeable soils. These are also known as irrigated bench terraces because of their use in irrigated areas.

6.2.4 Contour wattling

Wattling is a technique of dividing the length of the slope into shorter sections and in these sections, the wattles are constructed at a vertical interval of 5–7 m up to 33% slope and 3 m up to 66% slope. It is not effective on slopes steeper than 66% and on very loose or powdery rocks [61].

6.2.5 Crib structures

Crib structures are used to stabilize the steep slopes of >40% by constructing log wood structures filled with stone/brushwood. Eucalyptus poles with 2–3 m length and 8–12 cm diameter can be used for the construction of crib structures. These poles are joined together with the help of 20–25 cm long nails. The height of the structure is kept 1.5–2 m above the ground depending upon the land slope [62].

6.2.6 Geo-textiles

Geo-textiles are made up of natural fibers of jute or coir, which are used for stabilization of degraded slopes in mine spoil and landslides areas along roadsides. It facilitates the initial establishment of vegetation on highly degraded sloping lands by holding the vegetation in place and conserving moisture. The open mesh size of geo-textiles varies from 3 to 25 mm. The biodegradability of geo-textiles was reported for 2–3 years. It can absorb 12–25% water under 65 and 95% humidity, respectively and when fully soaked in water it can absorb 40% moisture [63].

6.2.7 Loose boulder/stone/masonry check dams

Check dams are effective for preventing runoff rate and severe erosion in steep and broad gullies, and most suitable for high elevation areas of the catchment [62]. These structures are cheap, having a long life, and fewer maintenance requirements. The depth of gully bed is kept about o.3 m and flat stones of 20–30 cm size are used for the construction of dams. A spillway is provided in the middle of the dam to allow the safe discharge of runoff water [21, 60]. Similarly, gabion check dams are also used for drainage line treatment in sharp slanted gullied areas to check sedimentation, erosion, and to conserve soil moisture [62].

6.2.8 Brushwood check dams

Branches of tree and shrub species are staked in two rows parallel to each other filled with brushwood and laid across the gully or way of the flow. These are usually built to regulate the overflow in small and medium gullies which are supplemented with vegetative barriers for long term effectiveness. There is enough soil volume to establish the vegetation. The tree species are planted in 0.3 m × 0.2 m trenches across the way of gullies. It reduces the runoff velocity, soil loss, and improves soil moisture which helps in the successful establishment of vegetative barriers.

6.2.9 Diversion drains

The channels are constructed to protect the downstream area and for safe draining and diverting of runoff water. It is applicable in high rainfall areas to control runoff losses during the initial stage. The gradient of diversion drain should preferably be kept within 0.5%. Generally, a narrow and deep drain does not get silted up as rapidly as a broad and shallow drain of the same cross-sectional area. Soil dug from the drain should be dumped on the lower side of the drain. Outlet end should be opened at natural drainage lines.

6.2.10 Conservation bench terrace

In the conservation bench terrace (CBT) system, the land is divided into 2:1 ratio along the slope in which the upper 2/3 area (Donor area) contributes runoff to the lower 1/3 runoff collecting area (recipient area). The donor area is left in its natural slope condition. It is also known as the zingg terrace and developed by Zingg and Hauser in 1959. The runoff contributing area is used for cultivation of *kharif* while the lower 1/3 area with conserved soil moisture is used to cultivate *rabi* crops. This mechanical measure can be successfully applied in a semi-arid climate on mild sloppy lands (2–5%) for erosion control, water conservation, and improvement of crop productivity. This system can be used in silty loam to silty clay loam soils. CBT system resulted in the reduction of runoff from 36.3 to 7.4% and soil loss from 10.1 to 1.19 Mg ha^{-1} as compared to the conventional system of sloping border [64]. An average reduction of 78.9 and 88.0% in runoff and soil loss, respectively reported in the CBT system over the conventional system [65].

7. Conclusion

The land is finite and diminishing gradually due to the increasing rate of varied kinds of degradation and thus there is no alternative to expend cultivable land area.

The only way is either increasing agricultural productivity per unit resource available or restoring the degraded lands. Healthy soil and availability of water are vital for productivity in all kinds of terrestrial ecosystems because plants require fertile soil with improved bio-physico-chemical properties and good quality of water for their growth and development. Use of soil and water conservation measures including biological (agroforestry and agricultural) and mechanical measures (terracing, bunding, trenching, check dams, etc.) is imperative to reduce runoff, soil erosion and to improve soil quality, water quality, moisture conservation, and overall crop productivity in a sustainable way. Biological measures are economically feasible and environmental friendly; also improve soil properties along with the conservation of soil and water resources. Further, the combined use of biological and mechanical measures will help in improving and sustaining agricultural productivity.

8. Future perspectives for soil and water conservation

The burgeoning world population, food insecurity and natural resource degradation are the major issues in the present era of climate change. It has been projected that the world population will be ~10 billion in 2050 [66]. Further, the rapid industrial growth and intensive farming practices are expected to increase the pressure on land and water resources in near future. Therefore, a paradigm shift in soil and water conservation, and its management is needed for agricultural sustainability. The some of the future concern for soil and water conservation and sustainable agriculture are the following:

- Formulation of new policies and development of new technologies based on social, economical and cultural aspect of a particular regional.
- Implementation and adoption of effective conservation measures for sustaining agricultural productivity.
- Existing soil and water conservation practices should be improved and developed based on the level of natural resources degradation.
- Greater emphasis should be given on participatory approach for effective soil and water conservation.
- Post impact assessment and monitoring of soil and water conservation measures should be done to evaluate their efficacy in increasing productivity, monetary returns, and livelihood of the stakeholders.
- Development of cost effective conservation practices to restore the degraded lands and to sustain agricultural productivity.
- The efficient technologies for soil and water conservation should be demonstrated on farmers' fields with their active participation.
- Emphasis on research, education and extension of soil and water conservation effective technologies to the stakeholders.
- Adoption of efficient management practices and judicious use of soil and water resources.

Abbreviations

C	carbon
CAZRI	Central Arid Zone Research Institute
CSSRI	Central Soil Salinity Research Institute
ICAR	Indian Council of Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-arid Tropics
IISWC	Indian Institute of Soil and Water Conservation
N	nitrogen
NBSS&LUP	National Bureau of Soil Survey and Land Use Planning
NRSA	National Remote Sensing Agency

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