Sustainable Agricultural Livelihood Restoration, Rehabilitation and Resilience in Kenya

Training Manual

2.2.3 SUB-MODULE 3: SOIL AND WATER MANAGEMENT

Conservation of soil and water resources is important for the sustainability of agriculture and the environment. The concept of soil conservation cannot be materialized without conserving and efficient use of water resources. Soil and water conservation can be carried out through tillage management or in-situ water harvesting.

This section consists of:

- Tillage management
- In-situ water harvesting
- Rainwater harvesting for Storage **(**Ex-situ water harvesting)
- Soil and water conservation measures
- Future perspectives for soil and water conservation

Tillage Management

This section presents an overview of the benefits of tillage and residue management and techniques for implementing it. Tillage is defined as the mechanical manipulation of the soil for the purpose of crop production significantly affecting the soil characteristics such as soil water conservation, soil temperature, infiltration and evapotranspiration processes. Tillage systems are sequences of operations that manipulate the soil in order to produce a crop. The ways in which these operations are implemented affect the physical and chemical properties of the soil, which in turn affect plant growth.
Tillage management is any form of conservation tillage where residue, mulch, or sod is left on the soil surface to reduce soil disturbance and decrease emissions release. Recent studies on tillage show that conservation tillage increases soil carbon in the upper layers. This is of crucial importance for the productivity of most tropical soils.

Tillage Systems

Conservation Tillage

This is the tillage and planting system that covers 30 percent or more of the soil surface with crop residue, after planting, to reduce soil erosion by water. Where soil erosion by wind is the primary concern, conservation tillage is defined as any system that maintains at least 1,120 kilograms per hectare of flat, small grain residue equivalent on the surface throughout the critical wind erosion period. The tillage systems classified as conservation tillage are no-till, ridge-till, and mulch-till.

No-till - The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disk openers, in-row chisels, or rototillers. Weed control is accomplished primarily with herbicides. Cultivation may be used for emergency weed control.

Ridge-till - The soil is also left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with herbicides and/or cultivation. Ridges are rebuilt during cultivation.

Mulch-till - The soil is disturbed before planting and includes all conservation tillage practices other than no-till and ridge-till. Tillage tools such as chisels, field cultivators, disks, sweeps or blades are used. Weed control is accomplished with herbicides and/or cultivation. Two tillage practices that fall into this category are zone-till and strip-till. Both of these tillage practices involve tilling a strip into which seed, and fertiliser are placed. Although these are popular terms in some areas, they are not official survey categories because they are considered modifications of no-till, mulch-till or "other tillage types." Less than 25% row width disturbance is considered no-till. More than 25% row width disturbance would be considered mulch-till or "other tillage type," depending on the amount of residue left after planting.

Reduced-till - Reduced-till systems leave 15-30 percent residue cover after planting or 560 to 1,120 kilograms per hectare of small grain residue equivalent throughout the critical wind erosion period.

Conventional-till - Conventional-till systems leave less than 15 percent residue cover after planting, or less than 560 kilograms per hectare of small grain residue equivalent throughout the critical wind erosion period. These systems generally involve ploughing or some other form of intensive tillage.

There are other tillage systems that leave less than 30 percent crop residues but meet erosion control goals with or without other supporting conservation practices, such as strip cropping, contouring, terracing.

In-situ Water Harvesting

Rainwater harvesting for infiltration, also known as in-situ water harvesting, is a practice in which rainwater uptake in soils is increased through the soil surface, rooting system and groundwater. Soil effectively acts as the storage agent, which improves water holding capacity and fertility and reduce risks of soil loss and erosion. Examples of water harvesting practices include bench terraces, 'Fanya juu' terraces, check dams, contour bunds and hedgerows, planting pits / Zai pits, Katumani pits, stone lines, trash lines, grassed waterway, retention ditches as indicated below:

Cut-off drains

Cut-off drains are made across a slope for intercepting the surface runoff and carrying it safely to an outlet such as a canal or stream. Their main purpose is the protection of cultivated land, compounds, and roads from uncontrolled runoff, and to divert water from gully heads. It serves as both soil and water conservation method.

Retention Ditches

These are made along the contours to capture and retain incoming runoff water and hold it until it seeps into the ground. They are alternate to cut-off drains when there is no channel to discharge the water nearby. Sometimes these are for water harvesting in semiarid areas.

Terracing

Terraces are constructed across the field slope for soil and water conservation purposes. They reduce soil and water through erosion from hilly or sloppy lands by collecting and storing surface runoff. Terraces also increase water retention and infiltration in the soil. They consist of channels and embankments of soil constructed along the contour. They can be constructed using stone bunds or strips of vegetation (live or dead).

Infiltration Ditches

The structure used to harvest water from roads or other sources of runoff is infiltration ditches. They comprise dug along the contour, upslope from a crop field and a ditch of 0.7-1.5m deep. Water is blocked at the other end when it is diverted from the roadside into a ditch and seeps into soil after being trapped.

Water-Retaining Pits

Water-retaining pits allow runoff water to seep into soil after trapping the water. The runoff normally occurs into a series of pits which are dug into ground. Banks around the pits are made by the soil from the pit. Excessive water carries from one pit to the next by furrows. The amount of runoff determines the size of the pit and its typical size is 2 m square and 1 m deep.

Broad Beds and Furrows

The runoff water is diverted into field furrows (30 cm wide and 30 cm deep) in a broad bed and furrow system. The lower end of field furrows is blocked. The water backs up into the head furrow after the filling of one furrow and flows into the next field furrow. Crops are grown on the broad bed furrows of about 170 cm wide between the fields.

Rainwater Harvesting for Storage (Ex-Situ Rainwater Harvesting)

Rainwater harvesting for storage, also known as ex situ water harvesting, is a practice in which rainwater is collected and stored for productive use, for example drinking water, agriculture, sanitation and more. The rainwater can be directly captured in open storage systems, but can also be collected from roofs, soil surfaces or roads. The practice is important in arid and semi-arid areas that may experience extended periods without rain mixed with periods of intense precipitation.

Rooftop Water Harvesting with Above Ground Tank

A roof becomes a catchment when it is used for harvesting rainwater. Then it can be called a Roof catchment. Roofs are the most common types of catchments used for harvesting rainfall. In most cases, roof catchment systems provide water that can be used for domestic purposes. However, roof runoff harvesting is also used for agricultural purposes including micro irrigation of kitchen gardens, watering livestock, and for beekeeping projects. The tank size is dependent on the rainfall regime, the water demand and roof area available.

Water Pans

Water pans are shallow depressions (1 m to 3 m deep) constructed to collect and hold runoff water from various surfaces including from hillsides, roads, rocky areas and open rangelands. When properly designed and with good sedimentation basins, the water collected can be used for livestock watering or to supplement the irrigation of crops.

Small Earthen Dams

When larger quantities of water are desired, earthen dams are preferred. An earthen dam is constructed either on- stream or off-stream, where there is a source of large quantities of channel flow. The dam wall is 2 - 5 m high and has a clay core and stone aprons and spillways to discharge excess runoff. Volume of water ranges from hundreds to tens of thousands of cubic metres. Earth dams can provide adequate water for irrigation projects as well as for livestock watering. Sediment traps and delivery wells may help to improve water quality but, as with water from earthen dams, it is usually not suitable for drinking without being subject to treatment. The cost implication is the limiting factor.

Sand Dams

Many seasonal rivers in the semi-arid areas of Kenya have sand. Though dry for most part of the year, these rivers flood during the rainy season. A sand dam is a wall constructed across the stream to restrict surface flow. The height of the dam wall is increased by 0.3 m after 30 floods have deposited sand to the level of the spillway. The water in the sand dam can be reserved for a long time due to low evaporative losses. The most convenient way to harvest water in a sand river is by sand.

Wells and Boreholes

In regions without notable and reliable surface water resources it is necessary to obtain water from underground sources such as wells and boreholes.

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.

Biological Measures (agronomic/agricultural and agroforestry)

Contour Farming

Contour farming is one of the most used agronomic measures for soil and water conservation in hilly agro-ecosystems and sloppy lands. All the agricultural operations viz. ploughing, 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. 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.

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 creates an obstruction to runoff, and thereby reduces 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 resistant 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. To increase the crop canopy density, the seed rate should always be on the higher side.

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. Further, the Soil 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.

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 better biomass to protect soil than 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.

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.

Advantages

- High total biomass production.
- Efficient utilisation 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.

Intercropping maize and beans

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. The erosion resistant crops protect 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. Strip cropping is practised for controlling the run-off and erosion and thereby maintaining soil fertility.

Types of Strip Cropping

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.

- ***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.
- ***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.
- ***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 practised in normal strip cropping and generally planted on a permanent or temporary basis.

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. Mulching prevents the formation of hard crust after each rain. The use of blade harrows between rows or intercultural 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 consequently improve the water holding capacity, macro and micro fauna biodiversity, their activity, and fertility of the soil.

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 mechanised 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. It also improves soil health, organic matter, soil structure, productivity, soil fertility, and nutrient cycling and reduces soil compaction.

Organic Farming

Organic farming is an agricultural production system that is devoid of the use of synthetic fertilisers 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 organicmanures which enhances water infiltration through improved bio-physico-chemical properties of soil, and eventually reduces soil erodibility. Organic materials improve soil structure through the development of soil binding agents (e.g. polysaccharides) and stabilising 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.

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 utilisation of resources and result in higher productivity and profitability. Ridge and furrow raised bed and furrow, broad bed and furrow, and ridding 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 drained 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.

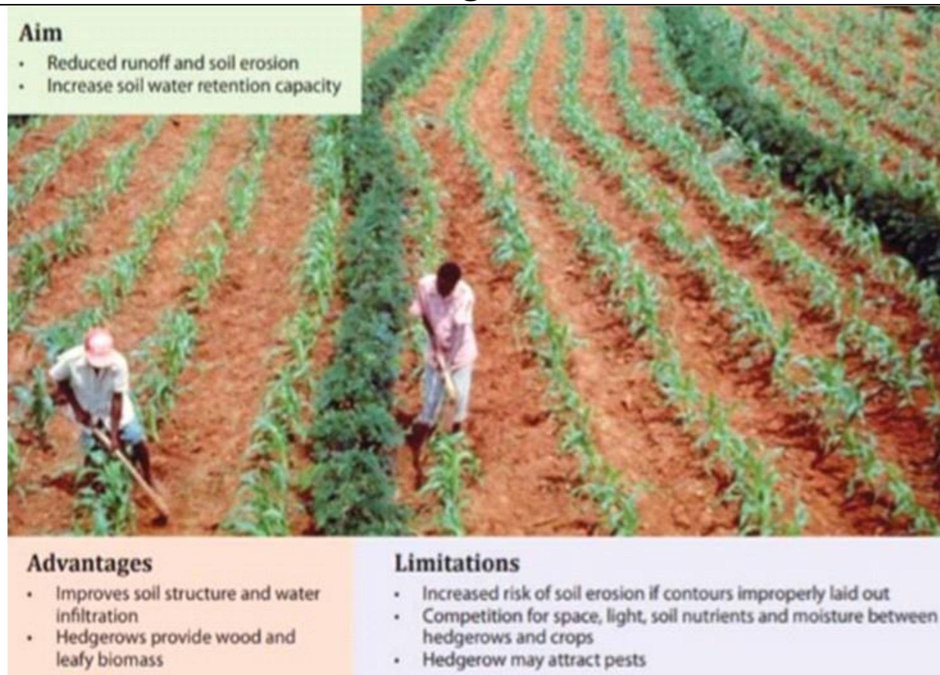
Mechanical Measures

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.

The mechanical measures are preferred based on the severity of erosion, soil type, topography, and climate.

Bunding

- ***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 . 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.
- ***Graded bunding:*** Graded bunds are made to drain 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.
- ***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 favourable condition for the execution of vegetative measures on gully heads, slopes, and beds.



Contour bunds

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:

- ***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 equaliser width without any discontinuity in trench length (10–20 m).
- ***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.

Terracing

Terraces are earthen embankments built across the dominant slope partitioning the field in uniform and parallel segments. 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 reduces runoff velocity, soil erosion and improves water infiltration. 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:

- 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.
- 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.
- 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.

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.

These structures are cheap, have a long life, and fewer maintenance requirements. The depth of the gully bed is kept about 0.3 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. 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.

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.

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.

Conservation Bench Terrace

Some of the future concern for soil and water conservation and sustainable agriculture are:

- Formulation of new policies and development of new technologies based on social, economic and cultural aspects of a particular region.
- 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.