CHAPTER 1. INTRODUCTION

1.1. Concepts and Facts of Soil and Water Conservation (SWC)

Soil and water conservation is multi-disciplinary subject which requires the knowledge of soil science, plant science, economics, engineering, geology, environmental sciences, hydrology, etc. Therefore, it can be defined as the application of soil sciences, engineering, agronomic and other fields' principles for the solution of soil and water management problems.

1.2. The Need for Conservation

The destiny of any country depends on the quantity and quality of the exhaustible natural resources present in it. Of course how wisely these available resources are being used is also equally important. A country can be said prosperous if the natural resources are properly used and their quality maintained.

Ethiopia is one of the most well endowed countries in Sub-Saharan Africa in terms of natural resources. However, natural resource degradation in Ethiopia has been going on for centuries. The major causes of land degradation in Ethiopia are rapid population growth, severe soil loss, deforestation, low vegetative cover and unbalanced crop and livestock production. Topography, soil types and agro-ecological parameters are also additional factors playing significant role in the degradation processes influenced by man. To combat land degradation, the Ethiopian government launched a massive soil and water conservation programme in the middle of 1970's.

Important points that emphasis the need for conservation in Ethiopia include

- ✓ Farmers are entirely dependent on agriculture & forestry production creating tremendous pressure on land resources, which cannot be much expanded
- ✓ Population growth is about 2.9% and much more of food should be produced to meet the increasing food demand.
- ✓ Arable land is shrinking
- ✓ 96% of our domestic energy source is fuel wood that should come from the forest
- ✓ In the northern Ethiopia cultivation is mostly in steep slopes (Ethiopian Highlands)
- ✓ Rainfall is erratic & intense.

What is soil conservation?

- It is the prevention and reduction of the amount of soil lost through erosion.
- It seeks to increase the amount of water seeping into the soil, reducing the speed and amount of water running off.
- Erosion is prevented by keeping enough vegetation to protect the soil surface and binds the soil together and maintains soil structure.

What is water conservation?

- This is a way of tapping as much water as possible and storing it in tanks or reservoirs.

- It allows water to sink into the soil increasing soil moisture levels.
- It ensures a protective cover of vegetation on the soil surface, slowing down the flow of running water and spreads the water over a large area.

Management and conservation of soil and water resources are critical to human well-being. Their prudent use and management are more important now than ever before to meet the high demands for food production and satisfy the needs of an increasing world population. Despite the extensive research and abundant literature on soil and water conservation strategies, concerns of worldwide soil degradation and environmental pollution remain high.

Soil and water conservation is necessary for sustained productivity of land. Soil erosion is prevented or reduced to a tolerable level, and water is conserved for judicious utilization. Sustainable production implies that agricultural practices would lead to economic gains without impairing environmental quality and the usefulness of the soil for future generation.

Therefore, the objectives for soil and water conservation are:

- Promotion of proper land use
- Prevention of soil erosion
- Restoration of the productivity of eroded land
- Maintenance of soil productivity
- Control of runoff, and regulation of water resource through irrigation and drainage
- Maintenance of environmental quality by preventing land and water pollution

1.3. Fundamentals of Soil Erosion

The word erosion is of Latin origin being derived from the verb ***erodere*** - to eat away/ excavate. The term erosion was first used in geology to describe the forming of hollows by water, the wearing a way of solid material by the action of river water.

Soil Erosion defined as the detachment, transportation and deposition of soil particles from one place to another under the influence of wind, water or gravity forces.

- ***Detachment*** is process of splitting soil particles in to smaller part and lifting up by the agent of erosion.
- ***Transportation*** it is the process, under which soil particles which dissolved in the running water are carried away from one place to another.
- ***Deposition*** is the process of settling detached and transported sediment

Soil erosion is a process of reduce the soil productivity through physical loss of top soil, reduction in rooting depth, removal of plant nutrient & loss of water. The soil erosion can be expressed quantitatively by the depth, volume or weight of soil removed per unit area & time.

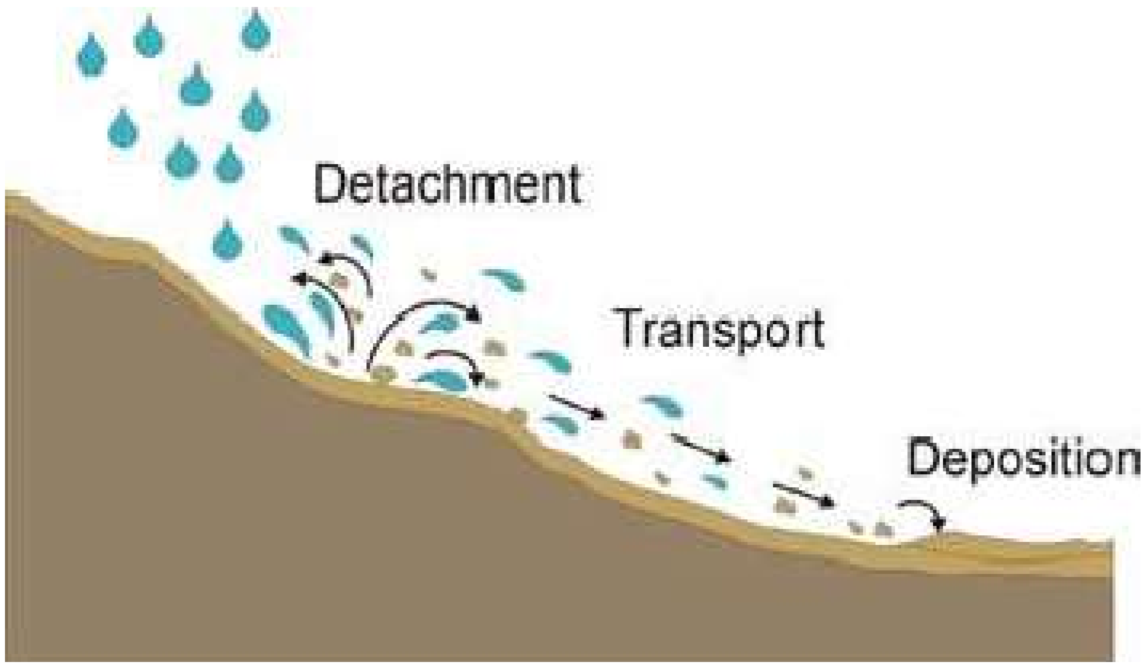


Figure 1.Phases of Soil Erosion

1.3.1. Agents of Erosion

Water starts with the splash effect. I.e. impact of raindrops, particular on the bare soil surface that destroys soil aggregates, transport soil particles through the air & prepares them for further transportation.

Wind:- high speed winds take up soil particles, particularly from a dry surface & also mechanically loosen other particles.

Gravity: - causes the mass movement such as soil creep, rock creep, rock slide & subsidence of the soil surface.

Glaciers: - Common on polar areas. It is the movement of mass of ice with soil particles slowly to lower (position) land.

1.3.2. Types of Erosion Processes

Depending on the disturbance of natural processes, there are two types of erosions namely ***Geologic Erosion*** and ***Accelerated Erosion***.

i. Geological or natural or normal erosion

Erosion can occur naturally, transforming soil into sediment. This naturally occurring erosion devoid of man's influence is called ***geological or natural or normal erosion***. It is a soil forming process that maintains the soil favorable balance or a normal process of weathering that generally occurs at low rates in all soils as part of the natural soil-forming processes. It occurs over long geologic time horizons and is not influenced by human activity. These types of erosion are assisting by the complex process of rock weathering. The process may take place as the result of the action of wind, water or gravity the erosion can take the form of splash, sheet, runoff, concentrated surface flow, stream flow, wave action & subsurface water flow.

Gravity causes mass movements, such as rock falls, landslides, soil creeps and mud flows, in which water plays a role as a lubricant or as carrying agent. However, under natural environment, there is always equilibrium between removal & formation of soil so that unless the equilibrium is disturbed by some outside agents, the soil preserves a more or less constant depth and character. It contributes to the formation of soil and their distribution on the surface of the earth, which resulted the present to geographic features. The various topographical features such as existing of stream channels, valleys, gulley's etc… are the result of geologic erosion.

ii. Accelerated erosion

When the process of soil erosion is influenced by human activities, it is **accelerated**. It is caused primarily by water and wind which remove and transport soil particles. This type of erosion is triggered by anthropogenic (human activity) causes such as deforestation, slash-and burn agriculture, intensive plowing, uncontrolled grazing and biomass burning. Man's interference with the natural vegetation & upset of nature's balance by removing the protective vegetation cover in order to introduce his land use activities resulted in accelerated erosion. Accelerated erosion is soil loss or degradation in excess of geologic erosion, which can also termed as man-made erosion. Accelerated erosion takes places by the action of water causes the soil erosion through sheet flow, stream flow, wave action, & ground water flow, wind & gravity.

1.3.3. Soil Depletion

Soil depletion occur when the components which contribute to fertility are removed/not replaced through soil degradation (soil erosion), mismanagement of soil resources and the conditions which support soil's fertility are not maintained. This leads to reduction of crop yield. In agricultural context soil depletion can be due to excessively intense cultivation and inadequate soil management.

1.3.4. Effects of Soil Erosion

Accelerated soil erosion causes adverse agronomic, ecologic, environmental, and economic effects both on-site and off-site. Not only it affects agricultural lands but also quality of forest, pasture, and rangelands. Cropland soils are, however, more susceptible to erosion because these soils are often left bare or with little residue cover between the cropping seasons. Even during the growing season, row crops are susceptible to soil erosion. The on-site consequences involve primarily the reduction in soil productivity, while the off-site consequences are mostly due to the sediment and chemicals transported away from the source into natural waters by streams and depositional sites by wind.

❖ ***On-site Effects***

The on-site consequences involve primarily the reduction in soil productivity. The primary on-site effect of erosion is the reduction of topsoil thickness, which results in

- Soil structural degradation
- Soil compaction
- Nutrient depletion
- Loss of soil organic matter
- Poor seedling emergence, and
- Reduced crop yields

❖ ***Off-site Problems***

While the off-site consequences are mostly due to the sediment and chemicals transported away from the source into natural waters by streams and depositional sites by wind. Most of the suspended particles are transported off-site and are deposited 100 or even 1000 of Kilometers far from the source. Water and wind erosion preferentially remove the soil layers where most agricultural chemicals (e.g., nutrients, pesticides) are concentrated.

Thus, off-site transport of sediment and chemicals causes

- ➢ Pollution
- ➢ Sedimentation
- ➢ Silting of water resources
- ➢ Alters the landscape characteristics
- ➢ Reduces wildlife habitat and
- ➢ Causes economic loss

CHAPTER TWO: SOIL EROSION PRINCIPLES

2.1. Introduction

The soil is defined as uppermost weathered and disintegrated layer of the earth's crust which is composed of minerals and several organic substances. Soil as the principal growth medium for plants, shows both features of a (more or less) renewable resource and of an exhaustible resource.

In general, the depth of soil varies from place to place, for example some where it is to a great depth and some where it is nil. However, the top 30 cm soil depth is very useful both for human being and wild life. This top layer is continuously exposed to the actions of atmospheric activities. The water and wind are the two main active forces which always tend to dislodge the top soil layer and transport them from one place to another which is termed as soil erosion.

Soil erosion: is the displacement of soil by the agents of wind, water and ice or the process of detachment and transport of soil particles by erosive agents (water and wind). The process may be natural or accelerated by human activity.

Soil erosion is a three phase phenomena, consisting the detachment of individual soil particles from the soil mass and their transport by erosive agents such as running water and wind. When sufficient energy is no longer available with the erosive agents to transport the particles, the third phase known as deposition takes place.

The soil erosion may be defined as detachment, transportation and deposition of soil particles from one place to another under the influence of wind, water or gravity forces.

The severity of soil erosion depends upon the quantity of materials supplied by the detachment process and the capacity of the eroding agents to transport them. When eroding agents have sufficient capacity to transport more quantity of materials than the materials supplied through detachment, then the erosion is termed as detachment limited. But on the other hand, when materials supplied are greater than the materials transported, and then erosion is described as transport limited.

2.2. Factors Affecting Soil Erosion by water

Water erosion is resulted due to dispersive and transporting power of the water; as in case of splash erosion first the soil particles are detached from the soil surface by the raindrop force and then transported with surface runoff. There is a direct relationship between the soil loss and runoff volume. The major factors which affect the amount of soil erosion in large extent are grouped under:

1. **Energy/climatic factors**

The climatic factors which affect the soil erosion are the rainfall characteristics, atmospheric temperature and wind velocity. Rainfall characteristic is one of the most effective factors among them. While temperature and wind velocity are not so, they are secondary.

The rainfall characteristic includes amount, intensity, frequency and duration of rainfall. All these have a great effect on runoff and soil loss. A greater rainfall amount may not cause excessive erosion if the rainfall intensity is less than the soil infiltration rate. When amount and intensity of rainfall are greater of a given storm, then both the soil erosion and runoff will be more. High intensity of rainfall has bigger raindrop size, when falls over the land surface causes the detachment of soil particles in large amount, which is subsequently transported, by the surface runoff. In addition, the bigger raindrops also break the soil aggregates into finer; those are more susceptible to move with flow and resulted into generation of more soil loss.

Frequent rain maintains the soil moisture in a desirable range, which reduces the intake capacity of soil and thus the runoff as well as soil erosion, both are increased. Similarly, a uniform distribution of rainfall throughout the year always reduces the soil loss and runoff by maintaining the soil moisture with optimum range.

2. **Resistance/soil characteristics**

The soil characteristics which influence the soil erosion are the infiltration rate and soil cover providing resistance to the runoff. When infiltration rate is greater than the rainfall intensity, then whatever rain occurs over the land surface, is absorbed by the soil and thus surface runoff becomes reduced. The infiltration rate mainly depends upon the permeability of soil profile, surface condition and presence of moisture content in the soil. If permeability is more the runoff will be less and vice-versa. Similarly, the presence of sufficient moisture content in the soil reduces the infiltration capacity, which resulted into increasing of the runoff. The structural feature of soil also plays an important role on infiltration rate. A compacted soil has low infiltration rate and high runoff.

Soil characteristics that have been identified as primarily affecting soil erodibility are listed as follows:

- ✓ Particle Size Distribution and Texture;
- ✓ Permeability (structure); and
- ✓ Fibrous organic matter content (structure).

In general, soils containing high proportions of silt and very fine sand are usually the most erodible. Erodibility generally decreases as the plasticity (clay content) of the soil increases. However, once eroded, clays are readily transported.

Well-graded gravel and predominantly gravel mixtures with trace amounts of silt are the least erodible soils. The ability of a soil to absorb rainfall or surface runoff is best characterized by its permeability. The potential for erosion is reduced if the soil tends to absorb rainfall or surface runoff as this decreases the volume of water available to cause sheet or rill and gully erosion.

3. **Protection/vegetation**

In nature, the extent of vegetative cover determines to a large extent the erosion that takes place. Vegetative cover is a very durable and highly effective erosion control measure. It achieves its objective by:

- **shielding the ground from direct rainfall impact**

Vegetative foliage also reduces the impact of falling raindrops on the land surface; thereby the surface runoffs as well as soil erosion, both are reduced.in addition to this part of rainfall is intercepted by the vegetative foliage which never reaches to the soil surface but returns back to the atmosphere through evaporation process known as interception loss. This part of precipitated rainfall does not contribute to the runoff.

- **Improving the soil permeability**

Regarding biological point of view, vegetation also provides a great effect on soil erosion reduction. A soil which is under thick forest cover, the earthworms beetles and other lives make the soil more permeable by making the network of channels in the soil or by decomposition of dead materials . This reduces the surface runoff and soil erosion at both sides.

- **Holding soil particles in place with a root structure from living and dead vegetation (topsoil).**

Water goes down in the soil along the roots and thus net amount of rain water making the runoff and soil erosion, gets reduced. In addition, root system also makes the soil more porous and thus increases the absorption of water.

4. **Topographic factors**

The land slope, length of slope and shape of slope are the main topographic factors which influence the soil erosion. A flat land has not the problem of soil erosion, while the sloping lands are predominantly affected by the erosion. As the land slope increases from mild to steep, the erosion increases in large proportion. Land slope has a great effect on flow velocity, kinetic energy as well as on transportation of soil particles.

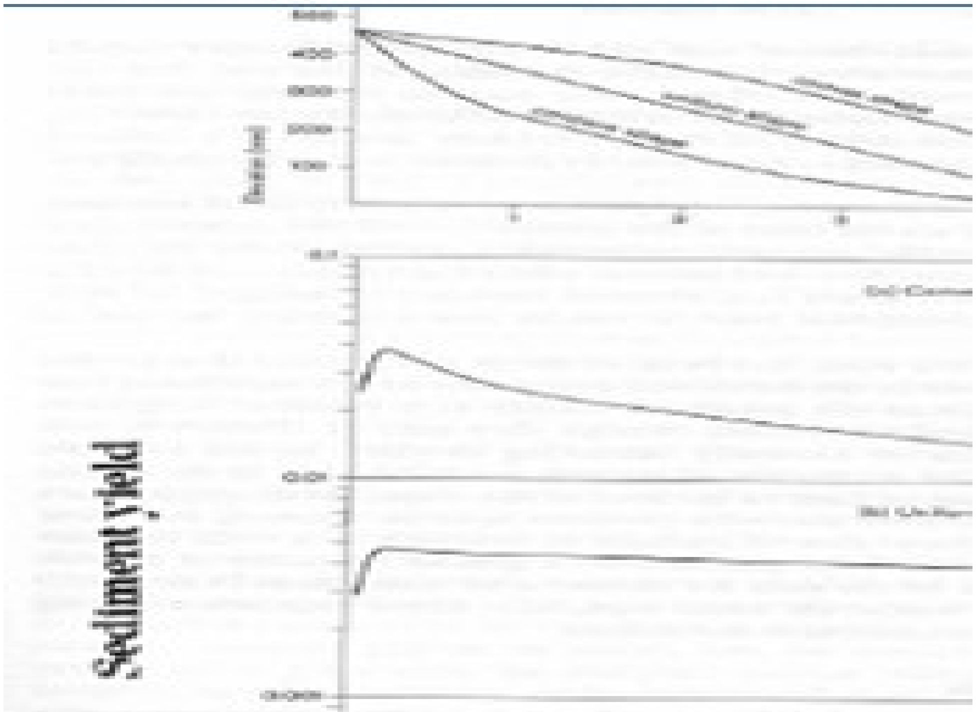
The land slope or slope inclination affects the erosion predominantly. As the slope increases, the runoff coefficient, kinetic energy and carrying capacity of surface runoff also increases, while soil stability and slope stability both decrease. The splashing erosion and the possibility of soil displacement in downward direction also increase with increase in land slope. Thus, it is clear that, the likelihood of soil erosion increases with increase in degree of land slope.

Apart from the effect of land slope on soil erosion, the length of slope also pronounces the effect on soil erosion. The slope length makes its effect on soil erosion mainly by increasing the velocity of water flow for longer duration and by degree of confluence created by that. As the quantity of water and degree of confluence increases, the velocity and transporting capacity gets change. The erosion losses tend to increase with distance down the slope.

The size and shape of watershed also affect the soil erosion. The fan type watershed yields higher peak runoff compared to leaf type watershed, as the time of concentration is less in fan type watershed than the leaf type. Similarly a watershed of smaller in size yields more quickly the peak runoff, while a large watershed takes longer time to yield peak runoff. The erosion is directly related to runoff and thus soil erosion also varies accordingly.

The slope shapes have greater influence on erosion potential. The side of a slope is more susceptible to erosion than the top and base, because runoff has more energy and is more concentrated as it approaches the base of slope. The slope may be roughly convex or concave. On convex slope the above phenomena is magnified, whereas on concave slope it is reduced, because in convex slope, the steepness increases towards bottom, while it is flattened towards bottom. In contrast, at concave slopes, the sediment carried by runoff, settles down at the bottom. In brief, on convex slopes there is no deposition but removal, while on concave slopes there is deposition, mainly. The order of soil erosion with respect to slope shapes is convex >concave.

Erosion decrease down slope and deposition will occur in concave slops but in convex slop the erosion will be increase and no deposition is occur. The erosion in convex slope is 5 times greater than uniform shapes of topography.



Figer shows how erosion is differ between the two shapes o topography

2.3. Types of Erosion

Depending on the disturbance of natural processes, there are two types of erosions namely Geologic Erosion, and Accelerated Erosion.

2.3.1. Geologic Erosion

It is a soil forming process that maintains the soil favorable balance or a normal process of weathering that generally occurs at low rates in all soils as part of the natural soil-forming processes. It occurs over long geologic time horizons and is not influenced by human activity. These types of erosion are assisting by the complex process of rock weathering. The process may take place as the result of the action of wind, water or gravity, the erosion can take the form of splash, sheet, runoff, concentrated surface flow, stream flow, wave action & subsurface water flow. Gravity causes mass movements, such as rock falls, landslides, soil creeps and mud flows, in which water plays a role as a lubricant or as carrying agent. However, under natural environment, there is always equilibrium between removal & formation of soil so that unless the equilibrium is disturbed by some outside agents, the soil preserves a more or less constant depth and character. It contributes to the formation of soil and their distribution on the surface of the earth, which resulted the present to geographic features. The various topographical features such as existing of stream channels, valleys, gulleys etc… are the result of geologic erosion.

2.3.2. Accelerated Erosion

It is caused primarily by water and wind which remove and transport soil particles. This type of erosion is triggered by anthropogenic (human activity) causes such as deforestation, slash-and burn agriculture, intensive plowing, uncontrolled grazing and biomass burning. Man's interference with the natural vegetation & upset of nature's balance by removing the protective vegetation cover in order to introduce his land use activities resulted in accelerated erosion. Accelerated erosion is soil loss or degradation in excess of geologic erosion, which can also termed as man-made erosion. Accelerated erosion takes places by the action of water causes the soil erosion through sheet flow, stream flow, wave action, & ground water flow, wind & gravity.

Agents of Erosion

Water starts with the splash effect. I.e. impact of raindrops, particular on the bare soil surface that destroys soil aggregates, transport soil particles through the air & prepares them for further transportation.

Wind:-high speed winds take up soil particles, particularly from a dry surface & also mechanically loosen other particles.

Gravity: - causes the mass movement such as soil creep, rock creep, rock slide & subsidence of the soil surface.

Glaciers: - Common on polar areas. It is the movement of mass of ice with soil particles slowly to lower (position) land.

2.4. Mechanics of Water Erosion

There are three mechanisms of soil erosion.

1. detachment
2. transport
3. deposition

1. Detachment is process of splitting soil particles in to smaller part and lifting up by the agent of erosion.

1. Transportation: It is the process, under which soil particles which dissolved in the running water are carried away from one place to another. The transportation particles, mainly depends upon following factors:

- ✓ Velocity at which water is running .it offers a force on the soil particles in the flow direction. At greater velocity comparatively large amount of soil particles are transported. In addition, large size soil particles are also transported at grater velocity.

- ✓ Load present in the water. Here load indicates the of amount of soil/rock existing in the flowing water, Flowing water containing less load can easily transported the mixed soil and vice-versa . Impediments/obstacles present in flow path of water. Actually, these constraints create an obstruction in the path of water flow; as a result the velocity of water gets reduced.
- ✓ Carrying capacity of running water also affects the soil transportation rate. A stream which has large flow volume, involves greater soil transportation and vice-versa.

Transportation process

In water erosion, the process of soil transportation by running water is completed under the following forms:

A. Solution

B. Suspension

C. Saltation and surface creep.

A. Solution

The water soluble contents present in the soil are transported by the water in solution form. Normally, certain dissolved chemicals such as calcium carbonate etc. which is derived from country rock are transported in solution form by the running water.

B. Suspension

Suspension process involves the transportation of fine soil particles, which present in suspension form in the flowing water.

C. Saltation and surface creep.

The saltation mechanism is responsible to transport the medium size soil particles, which are not all to stand in suspension form, but are mixed in water and flow over the stream bed in form of mud. The saltation and surface creep share a major part of sediment load, transported by the running water. The transportation of soil particles by the surface creep action is referred to the coarser soil particles, which is activated through the action of jumping collision and creeping.

3. Deposition is the process of settling detached and transported sediment.

Deposition occurs;

- ✓ If transport capacity suddenly deceased
- ✓ If the transport capacity is less than the sediment load
- ✓ It is also a selective process (coarse and dense particles are deposited first).

The process of water erosion begins with discrete raindrops impacting the soil surface and detaching soil particles followed by transport. Detachment of soil releases fine soil particles which form surface seals. The first two processes involving dispersion and removal of soil define the amount of soil that is eroded, and the last process (deposition) determines the distribution of the eroded material along the landscape. If there were no erosion, there would be no deposition. Thus, detachment and entrainment of soil particles are the primary processes of soil erosion, and, like deposition, occur at any point of soil when erosion starts from the point of raindrop impact, some of the particles in runoff are deposited at short distances while others are carried over long distances often reaching large bodies of flowing water.

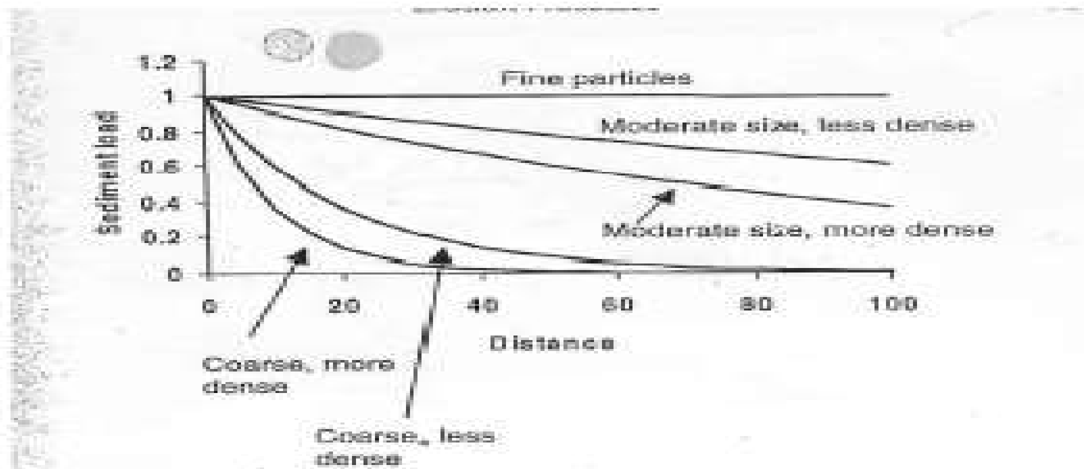


Figure 4.2 Deposition of various particle classes illustrating how deposition is a selective process.

2.5. Forms of Water Erosion

Water erosion results from the removal of soil material by flowing water from rain, runoff, snowmelt, and irrigation. Rainwater in the form of runoff is the main driver of water erosion. The forms of accelerated water erosion are commonly recognized: splash, sheet, rill, and gully and stream bank erosion. The classification is based on the nature and extent of soil removal.

2.5.1. Raindrop Erosion

It is also known as splash erosion. The process of rain drop erosion can be described as: when raindrops strikes on open moist soil surface, forms a crater. This is accomplished by forming a blast which bounces the water and soil up and returns back around the crater. The soil may splash into the air up to a height of 50 to 75 cm depending upon the size of rain drops. At the same time, the soil particles also move horizontally as much as 1.50 m on level land surface. On sloping land, more than half of the splashed particles move down with the runoff. Since the raindrops fall in rapid succession and strike the soil at all locations, thus the soil is subject to rigorous and repeated loosening and lifting action during heavy rains. In this way, the soil becomes more susceptible to water erosion.

The initiation of soil erosion by rain drop is due to detachment of soil practices from bulk soil. During rainfall occurrence, a part of finer detached particles enter into the pores and seal them, causing water accumulation over the soil surface. Remaining detached particles are mixed in to accumulated water. This water ultimately starts to move over the land surface. In this way, the detached particles are transported by running water over the land surface.

2.5.2. Sheet Erosion

Sheet erosion may be defined as more or less uniform removal of soil in the form of a thin layer or in "sheet" form by the flowing water from a given width of sloping land. It is an inconspicuous type of soil erosion because the total amount of soil erosion because the total amount of soil removed during any storm is usually small.

In sheet erosion there are two basic erosion processes are involved. First process, in which soil particles are detached from the soil surface by falling rain drops and in second process, the detached soil particles are transported away by runoff from their original place .The detachment process, is referred to the raindrop erosion or splash erosion and transportation of detached particles by flowing water is noticed as wash erosion.

When rate of rainfall exceeds the infiltration rate of the soil then excess water start to collect over the land surface and tends to flow over the surface of sloping land. At this point the second erosion process i.e. 'transportation' takes place .The flowing water also detaches the soil particles by scoring action and carries them along . The flowing water moves in the form of thin sheet over the soil surface called as "sheet flow".

In sheet erosion soil loss is comparatively more from a given area. The eroding and transporting power of sheet flow are dependent upon the depth and velocity of sheet flow for a given size, shape and density of the soil particles. From field studies, it has been found that, maximum movement of soil particles takes place, when depth of flow is about or equal to the diameter of soil particles.

The following changes made at the soil surface in a given field during sheet erosion process.

- Change of soil color
- Expansion of depression's size, if there,
- Presence of coarse particles (gravel like) on the soil surface.
- Enlargement of rills
- Exposure of unproductive sub soil or bed rock

The following variables make a particular land to be more susceptible for sheet erosion.

1. Topography of the land

The topography of the land indicates the land slope and its length.

Sheet erosion is more pronounced on steep land because sheet flow is accelerated as slope steepness and its length, increase.

2. Climate

The climate affects the sheet erosion by affecting the magnitude and rate fall of rainfall over the land surface.

In case of heavy or intense rainfall, the extent of sheet erosion is more, because such rainfall includes bigger size raindrops which cause surface sealing.

Development of this additional surface characteristic is more fruitful to make grater water head over the top soil surface.

This head of water tends to move over the soil surface and removes the top soil in form of layer or sheet.

The susceptibility of a particular land to cause sheet erosion also depends upon the soil conditions.

The nature of soil is the most important factor determining the degree of soil's susceptibility to the sheet erosion. The soil surface composed of loose soil particles, shallow soil layer overlain by a dense sub soil of low permeability etc., are most favorable factors to pronounce the sheet erosion.

2.5.3. Rill Erosion

The formation of rills and thereby the soil erosion, mainly depend upon soil composition and topographical features of the land. On impermeable or still heavier and more resistant formation, the erosion no longer creates rills, but forms ridges which are separated by sharply cut rillets and gullies. These rills are occasionally become so narrow that they resemble cracks. If the materials are more coarsely grained and less resistant, then geometry of the rills is likely to change.

Flowing water through these rills carries the soil particles very rapidly and formed triangular or trough shaped cross-section of the rill. In this specific case, the length of rill is greater, but the inter rills are thinner and edges are sharper. On the other hand, in permeable coarse-grained and non-resistance flovioglacial deposits, shallow and rapidly growing rills are developed with an huge production of silts. In general, more permeable soil, the rills will be formed for greater length from the head the land slope.

The formation of rills is less pronounced on the upper part of the slope. Rill erosion usually begins to appear in the lower part of the slope. This is true especially when the source of water is precipitation of low intensity. At greater rainfall intensity the velocity of surface runoff increases on sloppy land face, consequently the proportion of the total erosion from rills become greater, depending upon nature of the soil. At outset of rain period a certain portion of water is consumed in moistening of the soil surface and after this the desegregations and splashing of the soil, clogging of pores and decreases in infiltration rate, take place, as a result most of the rain-water takes a part in the erosive action of surface runoff.

Splash erosion plays an important part, both in the destruction of the soil surface and in the transport of soil particles over a short distance, while the sheet erosion responsible for flashing the loosened soil through the rills. The detachment and transportation of soil particles are comparatively greater in rill erosion than the sheet erosion due to greater concentration of flow in the rill which causes acceleration in the velocity of moving water. In rill erosion, detachment of soil particles mainly takes place by the energy of flowing water, not due to impact of rain drops as in case of sheet erosion.

Rill erosion is most effect, particularly when an intense storm occurs on the soils. Which have high runoff characteristics and where top soil is more susceptible to erosion. In this erosion the top soil is removed for some depth, but once the rills are formed and proper check is not followed, then they are extended into the sub soil and take the shape of gully.

2.5.4. Gully erosion

It is the advance and last stage of water erosion. In the other words gully erosion is the advance stage of rill erosion. If the rills have been formed in the field and are not avoided by the farmers, then they tend to increase in their size and shape with commencement of further rainfall. The channel/ rill of large size is termed as gully.

Gully erosion is the advance stage of channel or rill erosion in which the size of rills is so enlarged which cannot be smoothed by ordinary tillage implements. Process of gully formation follows sheet and rill erosions. It also occurs, when runoff volume from a sloppy land increases sufficiently or increases in flow velocity to cut deep inclusions or when concentration of runoff water is long enough in the channel. Gullies may also be developed from rills which are unchecked. Often, these are developed in natural depressions on the land surface where runoff water accumulates. Development of gullies also takes place by ruts or tracks formed by the movement of machineries, down the slope.

The rate and extent of gully development are closely related to the amount and velocity of runoff water. Because large amount of flowing water tends to detach and transport the soil relatively in large amount. The amount of runoff water available is dependent upon the size and runoff producing characteristics of the drainage area involved. The rate of gully erosion is further conditioned by the soil characteristics, size and shape of the gully and slope of the channel bed.

The process of gully formation depends mainly on:

- Resistance offered by top soil and underlying hard layer.
- Rainfall characteristics, which favor to increase the volume of the runoff over the land surface.
- Vegetation covers on the soil surface.
- Topography of the area including land slope.

2.5.4.1. Causes

What causes gully erosion*?* Gully erosion occurs when water is channeled across unprotected land and washes away the soil along the drainage lines. Excessive clearing, inappropriate land use and compaction of the soil caused by grazing often means the soil is left exposed and unable to absorb excess water.

There are several causes to activate the gully formation. Some of them are:

- ✓ Creating the land surface without vegetation.
- ✓ Adoption of faulty tillage practices.
- ✓ Overgrazing and other forms of biotic pressure on the vegetative cover, existing on the land surface.
- ✓ Absence of vegetation cover.
- ✓ Not smoothing of rills, channels or deperessions present on the ground surface.
- ✓ Improper construction of water channels, roads, rail lines, cattle trails etc.

2.5.4.2. How Gullies Develop

Gullies are developed by several processes which may be activated either singly or in combination at the same time. These processes are:

a) Scouring of the soil particles from the bottom and sides of the gully by flowing water plus abrasive materials such as hard soil particles or debris carried by the water.

b) Water fall erosion at the gully head which resulted the cutting of gully bank, and thereby extending of gully into non gullied lands.

c) Sliding or mass movement of the soil from gully banks due to seepage, alternate freezing and thawing or undercutting by flow.

The four recognized stages of gully development are:

Stage 1: During this stage, the channel erosion and deepening of the gully bed take place. This stage normally proceeds slowly, where the top soil is fairly resistant to erosion and it is the initial stage.

Stage 2: This stage is known as development stage, in which due to runoff flow from up stream portion of the gully head, the size of the gully i.e. width and depth is enlarged. The gully depth reaches up to the 'C' horizon and the weak parent materials are rapidly washed away. A waterfall often starts when flow plunges from upstream segment to the eroded channel, below.

Stage 3: This is the healing stage, in which vegetation's are started to grow in the channel. During this stage, there is no appreciable erosion in any form, from the gully section.

Stage 4: This is the last stage of gully development, in which the gully has been fully stabilized. No further change to develop the gully, unless healing process is disturbed. The channel secured a stable gradient and gully walls gain a stable slope. The vegetation begins to grow in abundance to cover the soil surface and also develops a new top soil. The healing stage is necessary to stabilize and to grade from one stage to another. During the lower two stages (i.e. 1 and 2) the gully head progressed towards the upper end of the watershed and resultant runoff entering into the gully becomes very less as drainage area is reduced. The remaining runoff enters at different points along the length of the gully.

2.5.4.3. Classification of Gully

Gullies may be classified as:

a) Based on shape (cross-section) of gully.

b) Based on state of the gully.

c) Based on dimensions of the gully.

a) Based on the shape of the gully

Gully cross-sections may be classified into following two shapes. It depends upon soil characteristics, climatic conditions, age of the gully and the types of erosion.

1) U-Shaped

These types of gullies are generally found in the alluvial plains, where surface and sub-surface soils are easily erodible. Under such conditions the runoff flow undermines and thus the gully banks are collapsed which result in the formation of vertical side walls and in this way a U-shaped cross-section of gully is being developed.

In brief, U-shaped gullies have the following main characteristics:

1. U-type gullies are recognized by their U-shaped cross-section.
2. Longitudinal slope of gully bottom is usually parallel to the land slope, through which gully is passes.
3. Develops in the land with low slopes, almost approaching zero.
4. The runoff contributing catchment area is large, causing the discharge passing through these gullies is large.
5. The velocity of flow is relatively less than in the V-type gullies.
6. The runoff enters the gully from the head (upper end) and from the sides at points, where adjacent land is slightly lower. In both the cases, the water flows over the vertical wall in cascade and drops onto the flat bottom, forming a deep pool.
7. U-shaped gullies are formed by undercutting and collapse of the bank. The collapsing of side walls along the length causes the gully section to make wider, but not deeper.
8. U-shaped gullies are continued to grow, head ward.
9. The lateral spacing of these gullies is large.
10. Active erosion from these gullies, is from sidewalls and headwall as a result of undercutting at the base of vertical cut.
11. These gullies do not grow deeper, but becomes wider and lengthened, headward.
12. Permanent drop structures are used to raise the bottom of such gullies.

2) V-Shaped

The V-shaped gullies are often developed where the sub-soils are tough to resist the rapid cutting of soil by runoff flow. In this case, as resistance to erosion increases with depth, the width of cut decreases accordingly and thus it resulted into development of V-shaped gully. V-shaped gullies are common in hilly regions, where land surface is accompanied with steep slope. At steep face of the flow velocity is high but flow volume is less, causing development of V-shaped gully.

However, apart from above points, the V-gullies also involve the following main features:

1. These are recognized by V-shaped cross-section.
2. Generally appear on sloping fields.
3. Longitudinal gradient of channel is greater than the land slope.
4. The erosion from these gullies is in the form of downward cutting at the center of gully, causing them to make deeper and to grow back ward i.e. up the slope.
5. Catchment area contributing the runoff is small.
6. The lateral spacing between these gullies is small.
7. The amount of discharge, passing through these gullies is small but with greater velocity.
8. The V-gullies make the contour cultivation difficult.
9. V-shaped gullies often develop from rill erosion, when water is concentrated from several rills into one.
10. The check dams are used to control V-shaped gullies, most commonly 'semi-permeable check dams' are preferred.

b) Based on State of the Gully

Based on state of the gully, the gullies can be divided into following types:

1. Active Gullies

Active gullies are those, whose dimensions are enlarged with time. The size enlargement is based on the soil characteristics, land use and volume of runoff passing through the gully. The gullies found in plain areas are active in nature.

2. Inactive Gullies

These are those, whose dimensions are constant with time. The gullies found in rocky areas, are inactive, because rocks are very tough to erosion by the runoff flow.

c) Based on the Dimensions of the Gully

The classification of gullies based on their size. These are:

1. Small Gully

Small gullies are those that can be easily crossed by farm implements and can also be removed by ploughing and smoothing operations and by stabilizing the vegetation.

2. **Medium Gully**

Medium gullies are those that cannot be easily crossed by farm implements. They can be controlled by terracing or ploughing operations. In medium gullies, the sides are stabilized by creating vegetation growth on them.

3. **Large Gully**

Large gullies are those which have gone beyond their reclaimable stage and where for reclamation, the cropping system or meadow is freely adopted. For controlling such gullies, tree planting is done as an efficient method.

2.5.5. Stream Bank Erosion

Stream bank erosion is defined as the removal of stream bank soil by water either flowing over the sides of the stream or scouring from there. The stream bank erosion due to stream flow in form of scouring and under cutting of the soil below the water surface caused by wave action is a continuous process in perennial streams.

Stream bank erosion is mainly aggravated due to removal of vegetation, over grazing or cultivation on the area near to the stream. Apart from scoring, the sloughing is also a form of stream bank erosion, which is caused when the stream water subsides after reaching at the peak. Sloughing is mainly due to movement of underground water from sides into the stream due to pressure difference.

The forms of soil erosion are nomenclature by the agents to cause them. Apart from water and wind as erosive agents, there are several other agents also available, which play some role to cause the soil erosion but not in pronounced quantity. These agents are glacial, snow, organic and anthropologic etc. the erosion caused by these agents are referred by their name as; glacial erosion, snow erosion, organic erosion and anthropologic erosion.

Chapter 3: Soil Erosion Assessment and Measurement

3.1. Soil erosion Hazard Assessment (Assessment of Current erosion damage (ACED))

The "Assessment of Current Erosion Damage" (ACED) provides a well-tested and cost-effective method of monitoring erosion and the impact of protective measures. Focusing on critical locations, ACED helps to estimate the severity of soil erosion, its causes and its consequences. It provides starting points for project personnel to enter a discussion with land users on erosion control.

ACED was tested in various studies in Ethiopia highland developed for two purposes:

1. To **supplement existing erosion measurement levels** such as test plots and river gauging stations.
2. To **provide practitioners with most cost-effective tool** to assess soil erosion and **draw conclusion about implementation of SWC**.

- Bing a rough method, ACED cannot have the same accuracy as test plot or gauging station measurements.
- Mapping of volumes and the number of rills and gullies can be carried out with and accuracy of + 15%, but it may decline to + 30% or more with inexperienced observers.
- The results of ACED are indicative, and are helpful for improving SWC measures. The sample considered only fields with rills and gullies, and did not include fields without damage. Therefore, the results do not represent an entire slope or a catchment, but only its critical locations (hot spots).
- ACED is carried out in **three steeps** after erosive storms, starting with the visible erosion features.

The **1st step** is to measure the volume of the erosion features and the management unit where they occur is the so called **damaged area**.

- Particularly on cultivated fields or other areas that are partly left without vegetation covers.
- Often be linked to causes located on the damaged fields itself
- On silt soils and soils with low organic matter with high erodability, on fields which are plowed up and down slop, etc.

The **2nd step** is to investigate the **upslope** area in view of its contribution to the features. The sources of runoff may be found outside the areas with actual erosion damage, that is above or upslope of the damaged area.

- Commonly, runoff is created on areas of low infiltration, such as the sealed surfaces of settlements, roads, footpaths and animal tracks. Interestingly, also grass and bush-land, which have a much better infiltration, can "produce" considerable runon if overland flow from these areas is not well drained. It is one of the most dangerous sources of erosion down slope.
- Where does run-on enter the damaged field, and where is it generated (along roads, small depressions or catchments, etc.)? The relevant answer to these questions can only be found if the mapping staff is in the field during a rainfall event!

The **3rd step** is to document the subsequent impact of the erosion features on the **down slope** area.

- Damaged areas can easily create consequent damage on the areas down slope. For example, the eroded material accumulates and buries plants and seedlings, or blocks roads and pollutes settlements. Field border erosion (gully) is a commonly observed phenomenon in humid areas where fields have to be drained. These gullies may also extend and destroy infrastructure such as roads or villages.

- Eventually, sediment that reaches the rivers can affect water quality and may lead to sedimentation of irrigation dams, while increased runoff can cause flooding or flash floods, a danger for downstream settlements.

3.2. Field measurements (erosion plots and catchments)

- The focus on soil erosion requires the development of a specific erosion measurement methodology which involves data collection on curious levels, with different devices and level of accuracy.
- **Rainfall** and **ersosivity shall be measured** for individual rainstorms **using an automated rain gauge** located in the vicinity of the **river gauging stations**.
- **River discharge** and **sediment yield shall be recorded with gauging stations** at the out-let of the research catchments.
- If rills and gullies are formed, usually during the main erosive events, they are mapped on farm.
- This methodology is known as the assessment of current Erosion damage (ACED)

3.3. Laboratory experiments (simulation)

- Soil loss assessment/erosion under laboratory condition can also be experimented using different factors of soil erosion such as slope, texture, and slope length, different level of cover and management practices using simulated rainfall.
- Simulated erosion/cutting of soil surface to various depths is also another method to determine the loss of nutrients and productivity of a field under consideration. This is also

helpful to understand the response of crop to various level of erosion and fertilizer application

- **Impact of stone cover on erosion** can also be studied under laboratory Condition

3.4. Predicting soil erosion (empirical models-USLE)

Although the USLE was not designed for rangelands, but for clean-tilled cropping systems, a brief discussion of the components of the equation illustrate the several factors, and their interaction, involved in accelerated soil erosion by water.

Universal Soil Loss Equation, a function of several integrated factors (**R˙ K˙ L˙ S. C. P)**, shows overland water flow energy, or the ability to detach and move soil particles.

USLE = Universal Soil Loss Equation

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

A = the predicted soil loss ($g \cdot m^{-2}$; t·ha-1)

R = rainfall amount and runoff erosivity (kinetic energy of rain)

K = soil erodibility (texture, structure etc.)

L = Slope length

S = slope gradient (inclination)

C = influence of land use (type of agriculture, forestry, groundcover and management,…)

P = erosion control practices (e.g. terracing,countour stripping etc.

Rainfall and Runoff Factor: The rainfall and runoff factor, R, is a measure of the erosive force of rainfall and runoff. The **kinetic energy of a storm is determined using the intensity and total amount of precipitation plus the average precipitation received during the 30-minute period of greatest intensity.** A sum of all storms at a location for the year provides an annual index and an average of several years indices is used in the USLE.

Soil Erodability Factor: The soil erodability factor, K, is a measure of the inherent erodability of soil and is based on soil loss from a 22m-long plot that is maintained in a continuous fallow state. Slope of the plot is 9% and infiltration rate and structural stability are the two most significant soil characteristics affecting erosion. Values range from near 0 for sandy soils to near 0.7 for tighter soils with lower infiltration rates.

Topographic Factor: The topographic factor, LS, demonstrates the effect of length of slope and the steepness of the slope and is a ratio of soil loss from an unknown field to that of the loss from the standard plot with a 9% slope and continuously fallowed. Values for LS range from 0.16 for a 2% slope only 15m long to 3.13 for 12% slopes 90m in length.

Cover and Management Factor: The cover and management factor, C, illustrate how cropping practices and management variable can effect soil loss and is the factor over which the producer has the most control. Values for C range from <0.10 for fields that are in permanent grass or legume cover to approximately 1.0 for fields that have little or no cover.

Support Practice Factor: The support practice factor, P, indicates the benefits of farming on a contour, strip cropping, terraces, and other practices that help minimize soil loss. Values are a ratio of soil loss from a field with a given support practice versus a field that has been farmed up and down the slope of a field. Support practice factor values range from 1.0 for a field where no support practices are used to <0.30 where support practices have been implemented. The benefits of management practices in conserving soil resources are evident when the factors included in the USLE are examined. Management decisions that include use of permanent ground cover or support practices in those instances where annual crops are part of the production system heavily effect the quantity of soil lost from a site. Likewise, if possible, fields with extreme slope should be avoided when using annual crops.

1. R: Rain fall ersosivity

Annual rainfall (mm)	100	200	400	890	1200	1600	2000	2400
Annual factor (R)	48	104	217	441	66	890	115	1340

2. K: soil Erodibility

Soil colour	Black	Brown	Red	Yellow
Factor K	0.15	0.20	0.25	0.30

1. **L: slope length**

Length (m)	5	10	20	40	80	160	240	320
Factor (L)	0.5	0.7	1.0	1.4	1.9	2.7	3.2	3.8

2. **S: Slope gradient**

Slope (%)	5	10	15	20	30	40	50	60
Factor (S)	0.4	1.0	1.6	2.2	3.0	3.8	4.3	4.8

5. C – factor (land cover)		6. P – factor (ma
Dense forest	0.001	Plough up and dow
Dense grass	0.01	Contour plough
Degraded grass	0.05	Applying mulch
Other forest	0.01	Strip cropping
Bad land	0.05	Inter cropping
Fallow (surface crust)	0.05	Grass strip
Fallow ploughed	0.06	Grass strip

Universal Soil Loss Equation (USLE)

A = R K LS C P

Where,

R is the rainfall factor

- R = SEI
  - E is the Energy in the Rainfall
  - I is the maximum half-hour rainfall intensity for the storm.
- R varies with the climate at a particular location

K is the soil erodability factor (tons/acre/unit of R)

- K depends on the type of soil
  - Texture
  - Clay and Organic Matter Content
  - Structure, Permeability, Drainage

LS is the field topography factor

- L is the slope length factor
- S is the slope degree factor
- L = 1 for a field length of 72.6 feet
- S = 1 for a field slope of 9%
- LS is a ratio of erosion for the given condition to erosion for the standard

C is the Cropping and management factor

- C is a ratio of the erosion rate for the given condition to the erosion rate for the standard condition
- The standard condition is a bare soil
- All other conditions will have C<1
- C also depends on rainfall timing

P is the factor for supporting conservation practices.

- The standard condition for P is direct up-and-down the slope cultivation.
- P will be less than one for all other conditions.
- P depends on field slope
- The P-factor is the ratio of soil loss under the given condition to soil loss from up-and-down-slope farming. Therefore it is a value between 0 and 1
- On nearly level land contouring has little effect, so the ratio is 1.0
- On very steep land contouring has little effect, so the ratio is 1.0
- The greatest effect of contouring on erosion is on slopes between 3 and 8 percent.

USLE: Example 1

Estimate the average annual soil loss for a field with a Silt Loam soil containing 2% organic matter and a 7% field slope for a 300-ft. slope length if the annual crop management factor is 0.42 and farming is parallel to the field boundaries (R = 170)

Solution

Use the Universal Soil Loss Equation: A = RKLSCP

- for Silt Loam Soil with 2%OM, K = 0.42 t/a.
- for 7% slope with 300-ft length, LS = 1.3
- Given C = 0.42
- for a 7% slope with contouring P = 0.5 and for farming up-and-down the slope P = 1.0. Parallel to field boundaries will be a mix. Use an average value of 0.8.

A = 170 x 0.42 x 1.3 x 0.42 x 0.8 = 31.19 t/a/yr

USLE: Example 2

If a change was made in Example 1 to farming on the contour, what would be the annual soil loss rate?

Solution: This would only change P in the above solution. Use the ration A2/A1 = P2/P1

- As shown above, the value of P for this condition is 0.5. Thus :
- A2 = 31.19 (0.5/0.8) = 19.49 t/a/yr.

USLE: Example 3

If the field in example 1 was altered by installing terraces at a 150-foot spacing, what would be the annual soil loss rate?

Solution: With terraces, the farming would be on the contour, so this solution just involves changing the topography factor, LS, from Example 2. Use the ratio A2/A1 = LS2/LS1. From Fig. 6.5, page 95 in the text, the new factor, LS2 for 7% slope and 150-foot slope length is 1.01. From Example 1, the old factor, LS1 is 1.3. Thus, the new estimate for the annual soil loss rate is:

- A2 = 19.49 (1.01/1.3) = 15.14 t/a/yr.

USLE: Example 4

With terraces installed some of the sediment removed from the soil surface by the erosion process will be deposited in the terrace channel. From example 3, above, estimate how much will be delivered off the field if the terraces have graded channel outlets.

Solution: From Table 7.1, page 108 in the text, for terraces with graded channel outlets, about 80% of the eroded sediment will be trapped in the terrace channel and 20% will be delivered to the outlet ditch or stream.

- Total off-site delivery = 0.2 x 15.14 = 3.03 t/a/yr.

CHAPTER 4. EROSION CONTROL MEASURES

4.1. Principles of water Erosion Control

Soil erosion by water occurs simultaneously in two steps: The detachment, which is principally caused by falling raindrops; and the transport of the detached particles, which is principally caused by flowing water. Therefore, soil erosion can be minimized by preventing the detachment and the transport of soil particles. A cover of vegetation and soil granulation helps to prevent the detachment of soil particles. The transportation of soil particles can be effectively minimized by artificial mechanical structures to control the effect of run-off principles in water erosion control and discussed in detail below:

4.1.1. Maintenance of soil infiltration capacity

When the rate of rainfall exceeds the rate of infiltration then there will be a likelihood of water run-off. Being dynamic property the infiltration rate is most affected by soil surface condition that varies with crop, climate and tillage practices. The greater the vegetation the highest will be the beneficial effect of plants in maintaining an open soil structure.

Long dry spell increases infiltration capacity of the soil because of the severe cracking of soil, which permits rapid entry of rainfall in to the soil. Tillage practices also affect infiltration capacity of soil. Tillage practices, which compact the soil decrease the infiltration capacity, and practice that loose the soil are likely to increase the infiltration capacity. Then raindrop strikes the bare surface, the soil crumb or aggregates disintegrate and choke the pore space making the soil virtually impermeable to water. Hence, the most successful method to keep soil permeable would be to prevent the rain actually hitting the soil. Practices that enhance the stability of soil aggregates strong enough to withstand impacts of raindrop also would help improving infiltration.

4.1.2. Soil protection from rainfall

Covering the soil would help the soil to be protected from the rainfall impact. The soil surface can be protected from the raindrops either by raising a close growing crop or by covering with straw, farmyard manure or leaf mulch. A soil devoid of vegetation is subjected to rainfall impact and begins to erode. Vegetation cover on the soil may reduce erosion by:

A) Interception of rainfall by vegetative cover;
B) Decreasing the velocity of run-off and cutting action of water;
C) Increasing granulation and porosity; and
D) Reducing soil drying

E) Improve water storing capacity

The interception of raindrop by canopy reduces the erosion in two ways. First, vegetative crop absorbs the kinetic energy of falling raindrops and reduces the risk of soil being impermeable due to beating action of falling raindrops. Second, part of intercepted rainfall does not reach the ground but, is evaporated from plant surface.

The amount and distribution of plant cover affects the impact of raindrops. Soil surface can be covered either by growing crops on it or by covering with straw or crop residues. Close growing crops with clean cultivation. In fact, soils with enough plant cover have practically little problem of erosion. The plant cover on soil surface shatters the kinetic energy of falling raindrops and thus little energy is available for breakdown of soil structure. A close growing crop not only slows down the velocity of water but also prevents concentration of water at a point. These two help in minimizing the cutting power of the water.

4.1.3. Control of surface run-off

The principal function of run-off in erosion is transportation of soil material. Controlling the concentration of run-off and regulating its velocity reduces damage caused by surface run-off. Hence, the fundamental principle of combating or reducing soil erosion by water is to reduce the amount of run-off as much as possible and insuring the whatever run-off occurs takes place as thin sheet of slowly moving water. The concentration and velocity of run-off water may be regulated by controlling the length and gradient of the slope. The velocity of run-off can be reduced and can be made to flow uniformly over the soil surface by mechanical barriers.

4.1.4 Safe disposal of surface run-off

Run-off water becomes available when rainfall intensity exceeds the infiltration rate of the soil. Therefore, from erosion control point of view, the ideal soil would be the one in which infiltration rate equals the rainfall intensity, even for rainfall of practically does not exist under field conditions. To minimise the loss of soil by erosion run-off can be diverted to a nearby well-protected slope.

4.2. Agronomic and Biological practices of soil and water conservation

4.2.1. Agronomic conservation measures

There are several principles of crop management and a number of agronomic techniques that have been developed to reduce erosion by ensuring adequate cover. A principle through which biological measures (agronomic and vegetative) control soil erosion is through the provision of adequate cover is space and time. Excessive soil loss mainly occurs under two conditions.

- ⇒ Firstly, when the existing vegetation does not provide complete ground cover, under this condition, the magnitude of soil loss depends on the total surface area and factors of erosion
- ⇒ Secondly, during the off seasons, when the ground is devoid of vegetative cover, particularly at the time of heavy storms.

The problem of soil erosion can be controlled by a well-designed application of various agronomic, vegetative and soil management practices. The common agronomic conservation practices are:

- ⇒ Strip cropping
- ⇒ Lay cropping
- ⇒ Alley cropping
- ⇒ Cover crop and green manual crops
- ⇒ Inter cropping
- ⇒ Relay cropping (Double cropping)
- ⇒ Crop rotation
- ⇒ Stubble mulching (crop residue management)
- ⇒ High density planting

If most of the above agronomic practices are well designed based on scientific application, they can maximize total dry matter and economic yields per unit area of land. An increase in the total dry matter yield (biomass) has an advantage of ***intercepting the force of direct raindrops, reducing the velocity of run-off and soil loss***. On the top of its physical effect, the higher biomass adds highest organic matter to the soil through roots and shoots.

Soil organic matter plays an immense role in the improvement of both physical and chemical property of the soil. Maintenance of optimum soil organic matter content aids in the formation of soil aggregates, which are less susceptible to erosion. The gradual release of nutrients from decomposing organic matter enhances vigorous crop growth resulting in better yields and ground cover. The following sketch illustrates this.

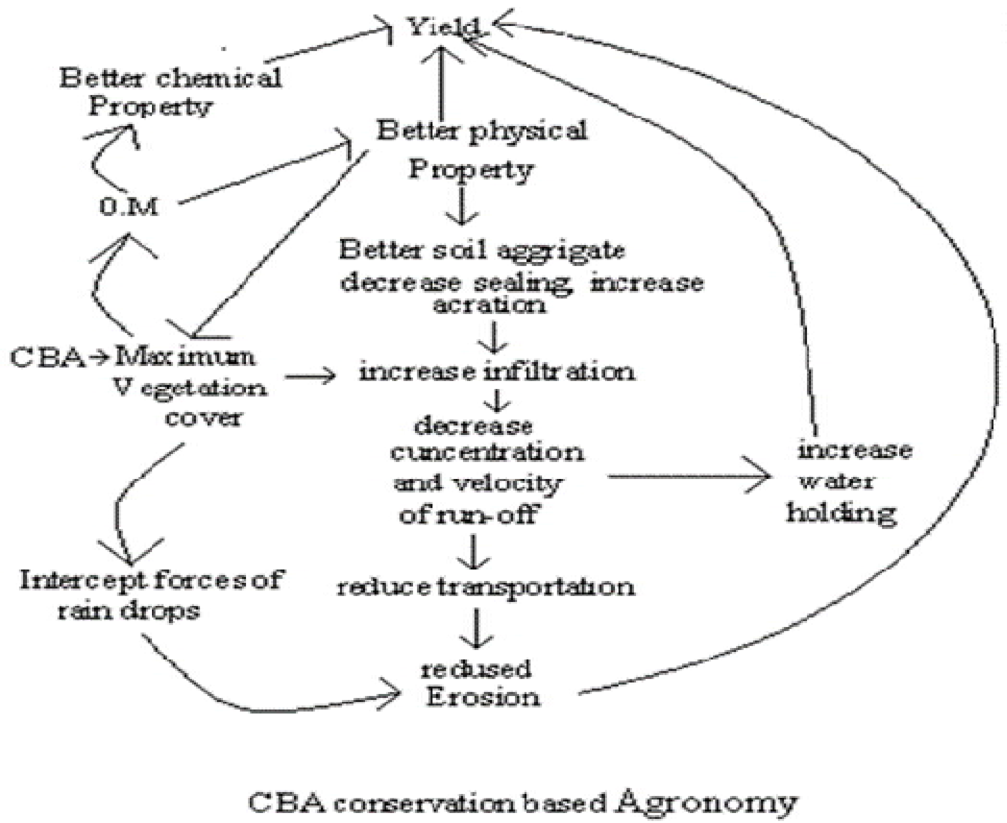


Fig1. The effect of agronomic practices on yield and erosion:

The type and role of each of the main agronomic practice is described in the forthcoming sections.

A. Strip cropping

Strip cropping is a cropping practice where strips of two of more crops are alternately established on the contour or, it is a system of establishing more than one crop in alternate strips following a certain pattern for the purpose of erosion control, crop diversification, and a decrease incidence of drought on one crop only (lower risks). This cropping system is designed as a defence mechanism against soil erosion in areas where the cropping system is dominated by row/sparsely growing crops that often exposes the ground to erosive forces. For instance, row crops like sorghum and maize are susceptible to erosion and need to be grown alternately with soil conservation crops.

When the purpose of strip cropping is soil conservation, it is essential that one of the two crops is soil-conserving crop. Therefore, in strip cropping row-crops (erosion permitting crops) is alternatively planted with close growing crops (erosion resisting crops). This strips cropping control erosion in two ways:

1) By slowing down of run-off water flows and trapping removed soil through the close growing strip): and
2) By increasing infiltration rate, which reduces total run-off volume. Erosion is largely limited to row crops strips and soil removed from these strips is trapped in the next strip planted with close growing crop.

When used to protect land against erosion, strip cropping is very effective in slope up to 10% if well designed and is not normally required on slopes less than 5%. However, on the steeper and badly eroded slopes it may necessary to retain buffer strips of 2 to 4m wide at critical slope (steep or highly eroded) what permanent vegetation (legumes, grasses or shrub) in addition to the main crop strips.

Technical specifications

- Crops are sown in strips, one strip being a soil depleting (erosion permitting) crop and the following a soil conserving (erosion resisting crops)
- If the main crop is maize or sorghum, the second crop can be a legume (e.g. beans, cowpea, chickpea, etc.) that forms good ground cover; in this case, maize is regarded as soil depleting /degrading crop, while the legume is soil-conserving crop. Erosion is largely limited to the row-crop of cereals and the soil removed from these strips is trapped in the next strip down slope planted with the legume row soil-conserving crop.
- This measure is effective against soil erosion on slopes 5 % if will design and is best suited
- The strips can be rotated to optimise the benefits of crop rotations.
- Design and establishment: strip width vary with the degree of erosion hazard but are generally between 5, 15, and 45 meter with narrower strips on steep slopes and wider strips on gentle slopes planting technique is traditional except that it is along the contour.
- On steeper slopes, it may be necessary to add grass buffer strips of 2 to 4m wide, placed at 10 to 20 meter interval.
- Integration with bunds, grass strips or any other conservation measure able to reduce run-off and increase storage is recommended.

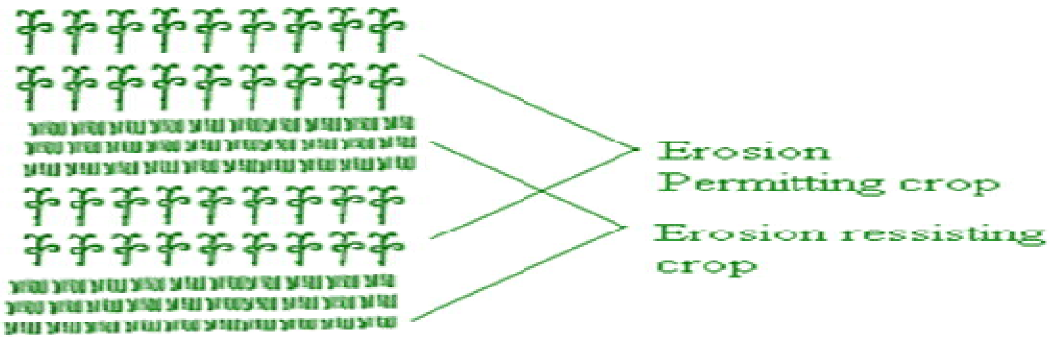


Fig., Alternate strip of soil conserving (A) and erosion susceptible crop (B) in a strip cropping practices.

B. Lay cropping

Lay cropping is cropping systems in which legume based pastures are rotated with purely grow crops. Legume based pastures are grown on fallow lands for some time to improve fertility of soil and thus yields of subsequent crops (mainly the cereal). Establishment of dense, productive forage crops during fallow period provided a thick ground cover during rainy season preventing the soil erosion. The substantial biomass produced is either harvested and fed to lives stock during dry season or maintained on the ground and incorporated in to the soil to raise fertility of the soil.

This system is believed to be feasible in the highlands of Ethiopia where fallowing is a common practice to restore fertility of the soil. In Ethiopia, this system has been studied at Shoa and Debre Zeit High land). Result show that vetch, Lablab, and some clovers are capable of leaving 30 to 60 kg N/ha, in the 20 cm of the soil profile, which are sufficient to meet the N requirement of subsequent cereal crops.

Technical specifications

- A pasture legume is sown after a shallow ploughing of the bare fallow. Normally, fertilization is not necessary but 0.5 to 1 quintal/ha of DAP would help the legume seed, to establish and develop their rooting system.
- In moisture deficit areas, the following legume crops are recommended
- Siratro (macroptilium uncinatum)
- Lablab purporcous (Lablab)
- Stylosanthes hamata (varano sylo), etc

These legumes would be appropriate conserving pasture crops able to restore fertility and provide feed of good quality. They can be planted in mix stands or rows with grass such as Rhodes, Boffle, Panicum, or improved native grass, etc. Row planting also reduces competition within and between the species. In case of mixed pasture, two-third legume seed is mixed with one-third of grass.

- The introduction of ley pastures in to fallow lands can be either with annuals or perennials species, depending upon the length of the fallow period.
- This measure can be integrated with rainfall multiplier systems for crop or grassland improvement, various forms of bunds and other agronomic measures such as stubble mulching before the return of the main crop.

C. Alley Cropping

Alley cropping is a farming system in which rows of trees or shrubs are planted along contours between rows of crops for soil and crop yield improvement. Alley cropping is one type of an agro forestry system.

Technical specifications

Design of the layout: To obtain the maximum possible benefit in alley cropping system, it is necessary to design the layout according to the objective of establishment. The main objective of alley cropping is to increase crop yields through maximum green manure production. To maximize the production of green material, it is essential to know and use the right spacing between the hedges and plants in the hedges.

- The important factor determining the effectiveness of hedgerows against erosion is the density of vegetation in the hedgerows and width of the hedgerows.
- The vertical interval for an alley cropping, designed for erosion control is 1 meter and the method could be effective for erosion control up to 5% slope range (up to 10% alternate with bunds)
- In general alley cropping should be limited to areas with rainfall >700mm, slopes not higher than 5% and good textured soils with depth >100cm. For higher slopes, hedgerows should be combined with physical structures.
- The optimum hedgerows spacing, optimum for green material production is 4m. Under most semi-arid conditions, to avoid competition for water, 8m spacing is suggested.

Selection of appropriate species:

Suitable trees and shrubs species for alley cropping should meet the following set of criteria:

✓ Establish easily
✓ Grow rapidly
✓ Have a deep root system
✓ Produce heavy foliage
✓ Regenerate readily after pruning

- ✓ Are easy to eradicate
- ✓ Provide useful by-products

Leguminous trees and shrubs are preferred over non-legumes because of their ability for fixing atmospheric nitrogen. Some examples of leguminous tree/shrubs for use in alloy cropping callinandra catothyrsos, Leucaena leucocephala, Sesbania sesban, pigeon pea, cassia siamea, etc.

Management of the hedgerows /Alley cropping

- Isolation of the livestock from the field
- Weeding
- Gap filling
- Low cutting
- Periodical pruning/ cutting

Benefits of alley cropping

- ⇒ Provide green manure or mulch for companion food crops and so plant nutrients are recycled from deeper soil layer
- ⇒ Provide pruning, applied as mulch, and shade during the fallow period to suppress weeds.
- ⇒ Provide favourable conditions for soil micro organisms
- ⇒ When planted along the contours of sloping land, provide a barrier to control soil erosion.
- ⇒ Provide pruning for brows, staking material and firewood.
- ⇒ Provide biologically fixed nitrogen to the companion crop.

D. Cover crop and green manure crop

Cover crops are crops grown for the purpose of ground protection under row plantation crops such as pigeon pea or as a conservation crop on fallow lands during the off-season.

Cover crops provide proper ground cover to protect the soil from the direct impact of erosive agents, they can also play additional role in replenishing soil organic matter and nutrients. The replenishment of organic matter and nutrients arises from additional of decaying roots and shoots of the cover crops. Maximum benefits can be obtained if the cover crops are legumes and periodically ploughed in. Green manure crops are crops grown to maintain or increase the soil organic matter and nitrogen content of the soil, Before reaching their maturity or start competing for moisture with the row crops, their biomass is incorporated in to the soil they also protect the soil against erosion but not as much as cover crops. The major distinction between green manure and cover crops is the main objective for which they are grown. Green manure crops mainly grown to enrich the soil with organic matter and essential nutrients while, the aim of growing cover crops is to provide protection against erosive agents.

Technical specifications

- Suitable cover crops should be easy to establish, cover the ground quickly and should be aggressive enough to exclude weed growth but not too aggressive as to cover its companion crop or compete adversely with it for light, water and nutrient.
- The biomass should be incorporated in to the soil by light ploughing at the end of the rainy season. Green maturing crops may be planted also in the middle of the rainy season or on the residual moisture of the late rains and grow during the first few months of the dry season until they can be ploughed in and be of use for the next season crops.

E. Intercropping

It is a practice of growing two or more crops along the contour simultaneously in the same plot in a fixed pattern in one season. The aim of intercropping is to increase crop production and provide protection to the soil against erosive forces. Different planting times and different length of growth periods spreads the labour requirement of planting and harvesting.

The various leaf arrangements of different plants allow light to be better intercepted over time. The contrasting patterns of root growth, which utilise different soil layers, optimise the use of available soil moisture and nutrients. Mixed stands of crops suffer less from insect damage and diseases, and they normally protect the soil surface more effectively than pure stands. Overall output per unit area can be greater from intercrops than single crops, and chances of total crop losses are lower than in pure stands.

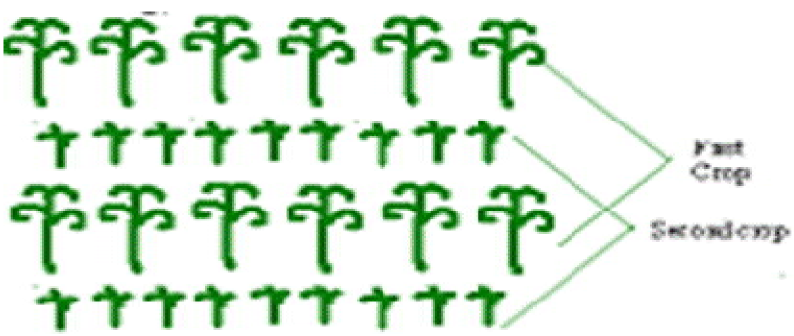
Technical specifications

- In moisture deficit areas, the practice seems to be more feasible for row crops such as maize and sorghum, or cotton. These crops do not form a good ground cover at an early stage from establishment. At a later stage, when crops begin to form a denser cover, the canopy is higher above the ground level and run-off is free to move in between plants and erode the soil.
- At the same time, these crops have bulky biomass, which is not often returned to soil. The big stalks are often removed for various purposes. There is very little return to the soil. To contrast this nutrient mining system, suitable legume species should be planted in spaces left between row.
- Fodder legumes tend to produce more biomass than food legumes and the amount of nitrogen fixed is proportional to the biomass produced by the crop. The effect of N-fixation is not much felt by the current crop but rather by the crop planted next season and often for more than one year.
- Attention should be paid to maximize the benefit from intercropping depending on the interest of the farmers. In most cases, farmers want to minimize the reduction of yield of the main

crop. Then, adjustment to the sowing date should be made to minimize competition between the main crop and the legume (companion crop). In this regard, companion crops should be sown 2 to 3 weeks after the main crop.

F. *Relay cropping:*

Relay cropping is a practice of growing two or more crops during the same growing season, with a certain overlap between planting of the second and harvesting of the first crop. (Sowing of one crop during the maturity stage of the other crop is called Relay cropping.). This is usually practiced to take advantage of the residual moisture left in the soil and the open space between matured plants. The intention is to make the soil in better conditions for the next season crops. For instance before sorghum is harvested some legume crops may be sown in between rows and then grow on residual moisture once some biomass or grain is produced the crop residue are incorporated in to the soil for future use.



Technical specification

There are two conditions for the implementation of the practice.

- ✓ Firstly, the residual moisture should be reliable enough to support growth of the second crop
- ✓ Secondly, the first crop should be a row crop with adequate space between rows to allow planting of the second crop.

This technique is suitable when the first crop is planted at an early stage, benefiting from early rains. Then the second crop would have better chance to grow and produce sufficient biomass.

In case the first crop is not row crop or farmers refused to plant the first crop in row or if they used broadcasting, there would be the possibility of planting the second crop immediately after the harvest of the first crop if the residual moisture is sufficient. In this case, the cropping system is called S**equence Cropping** instead of relay cropping. Sequence cropping is also called **<u>double cropping</u>**

G. Crop rotation

Crop rotation is a practice of growing different crops one after another on the same piece of land. The crops in rotation may be cereals, legumes, and a grass or grass legume mixture.

Benefit

- Help to maintain soil productivity. Plants of the same crop develop their roots at the same depth of soil profile, therefore, if the same crop is grown on the same land year after year, the soil nutrient in that stratum depletes sharply and the crop yield declines. However different crops have different morphological characters, if more crops are rotated, the intensity of nutrient depletions is not severe as different crops proliferate their roots over a wider range of soil profile;
- Improvement of plant cover and soil structure: Crops differ a great deal in their root activity and amount of crop residues added to the soil;

Crop rotation in addition to fertility restoration and soil and water conservation is a popular traditional practice of controlling disease, pests and weeds infestation. It is well known that different crops are not equally susceptible to the same kind of pests or diseases. Growing the same crop year after year will provide an opportunity for pests to multiply and outbreak virulently after two or three years of continuous cultivation, eventually leading to serious loss of crop yield. The same problem holds true for weed infestation.

- Crops also differ in terms of their effect to the soil fertility -some crops restore or build fertility while others deplete fertility.

Technical specifications

- The specifications are left to farmers and agronomists who have to decide the best alternative between crops and other affects on soil loss and fertility based upon local conditions.

H. Stubble mulching/crop residue management

Mulching is the covering of the soil with residues such as straw, maize/sorghum stalks or standing stubble. Maintaining crop residues on the farm or applying mulches has a number of advantages in controlling soil erosion and fertility of the soil. Any material on the ground protects the soil from direct impact of raindrops, which otherwise detach the soil particles for ease transportation by run-off. Such ground cover also slows down the speed of run-off. The prevention of these two actions obviously minimizes the risk of Erosion

Mulching in deed is one of the most effective methods to minimize erosion. A crop residue covering the ground decreases raindrop erosion; slowdown the water flows and increases the infiltration rate, as the pores of the soil are not clogged through surface sealing by clay particles after rain. It also encourages insects and worms to make holes in to the ground, thus increasing the permeability of the soil largely. The second major advantage of mulching /crop residue maintenance is its potential for sustaining productivity. Any plant material going back to the soil has a potential of increasing/ maintaining soil organic matter depending on various conditions. When the soil is rich in organic matter content, the soil will have a potential of supplying nutrients from a gradually decomposing organic matter that release nutrients.

Mulching in addition to its positive effect on soil structure also aids in reducing evaporation and maintain soil moisture.

Slop %	Percent run off Bush fallow	Percent run-off under maize	
		Un mulched	Mulched
1	1.3	6.4	2.0
5	1.4	40.3	7.7
10	1.7	42.3	7.9
15	2.0	67.6	10.9

Technical specifications

1) Surface mulching

- Different crop residues can be applied (based upon availability), especially for fallow lands. Materials from lays can be used at the end of their cycle. Other possibility is to bring such grasses and roughage from hillside closures.
- It is recommended to scatter the residues over the whole surface in a 2.5 in thick layer. At least 40% cover is recommended to reduce erosion by 60-70% based on slopes and type of soils.

2) Vertical mulching

- This activity is very useful to safely mulching materials and to increase water infiltration at regular intervals between crops.
- It consists in opening shallow furrow every 120-200cm, 20cm deep and along the contours. Then the straws or mulch's is buried with 20cm of height standing over the soil surface.

I. High density planting

Plant population has a marked effect on the rate of loss of soil moisture in crop production.

In dry zones, the population density should not be too high in order to optimise the use of limited moisture. In situation of low plant population evaporation from soil surface is high but more water is available to plants and yields are normally higher than in a situation of high crop density, where not all plants may reach maturity or overcome dry spells between showers. These measures should be integrated with water harvesting systems such as tie, riding, on tour cultivation and other agronomic measures such as mulching in order to increase the water availability to plants and ensure both good yields and soil protections.

4.2.2 Soil management practices

The ability of the soil to support a good crop and increased production depends on the soil type and, and its management. Inappropriate land-use activity often causes change in ground cover and soil physical and chemical conditions, which intern contribute to accelerated soil erosion. Soil management practices refer to the practices applied to *restore or maintain the fertility and structure of the soil*, *keep the soil in an optimum conditions* for crop growth. Highly fertile soils result in high crop yield, good cover and therefore, which minimize the erosive effects of raindrops, run-off and wind. The soil management practices are here divided in to two:

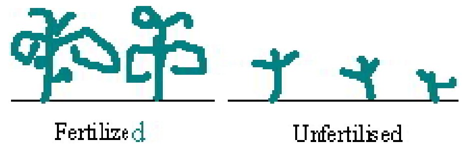
- **Cultivation practices**: these practices include farm operations that would improve the moisture retention capacity of the soil, control erosion and hence improve yields. Most of these measures should be integrated with physical structures for soil and water conservation. Contour Ploughing and planting, deep tillage and tide ridging are some of the examples in improved cultivation practices.
- **Fertility improvement practices**: they include all practices aimed to increase the amount and quality of organic matter content in to the soil by improving the transformation of plant and animal residues. Compost making, farm, yard manure collection, management, and efficient use of fertilizer application are some of the examples in fertility improvement cultivation practices.

Some of the soil management practice will be discussed here:

- Fertilization and green manuring
- Compost using
- Reduced tillage and zero tillage
- Contour cultivation
- Tide-ridging
- Improved pits

4.2.2.1 Fertilization and green manuring

Fertilization refers to application of chemical fertilizers, while manuring is the application of green manure or farmyard manure. In the absence of chemical fertilizer, or when farmers do not afford to purchase chemical fertilizers, manuring could be common practices. Fertilization promotes quicker and denser biomass production, which in turn ensures a good ground cover. The same crop planted on the same date and soil, at the same wowing rate can be stunted without fertilization, when the soil nutrient is inadequate to maintain vigour plant growth.



E.g. Relative growth rate and biomass production of fertilized
(A) Unfertilised (B) crops

4.2.2.2 Green manure

It is a plant material (leaves and tender branches) collected / prepared to be incorporated in to the soil green or, is a crop or forage plant material ploughed under while the crop is steel green to improve fertility of the soil. Green manure serves as readily available nutrients or as a material that increase organic matter content of the soil. Soil rich in organic matter have good structure. Soils with good structure provide the best condition for supplying water and nutrients to plants vetch, cowpea and nung, bean are among the crops, which can be used as green manure. Application of chemical fertilizers or manuring (farmyard manure or green manure) of crops in addition to increasing yield provides faster plant cover to protect the soil from erosive rainfall

4.2.2.3 Compost using

Compost is a natural product, which consists of a practically decomposed mixture of organic residues: crop residues, weeds, waste vegetable material, usually mixed with animal dung and some soil. Compost is used for fertilizing and conditioning the soil. Composting is the process of decomposition or breakdown of organic waste by a mixed population of microorganisms in a warm, moist and aerated environment. They final product of this process is called ***compost or humus***. Good compost contains a proper mixture of available nutrients for the crops and well-decomposed materials. The application of compost would improve soil fertility, water storage, and reduce run-off.

4.2.2.4 Reduced /Zero tillage/ conservation tillage

In many countries, farmers believe that clean cultivation is effective method of crop production. Now days, the bad effect of over cultivation on the land and its eventual productivity is beyond doubt. Cultivation has a great impact on the breakdown and deterioration of soil organic matter. Cultivation also accelerate rates of nutrient nitrogen release, hence it has immediate benefits of providing nutrients for the crop and disadvantage of depleting the nutrients for future. Conservation tillage systems aim to:

- Improve soil structure
- Reduce the amount of soil inverted during cultivation
- Leave residue on the surface

- Disturb the soil no more than required to promote infiltration of water and germination of seeds.
- Reduce the cost of cultivation

4.2.3 Tillage practices used for soil conservation

1. Conventional tillage – a standard practice of ploughing with disc or mould board plough, one or more disc harrow a spike-tooth harrow, and surface planting.
2. No / Zero tillage- soil undisturbed prior to planting, which takes place in a narrow, 2.5-7.5 cm, wide seedbed. Crop residues cover 50 to 100% retained on surface. Weed control by herbicides. The technique can increase the percentage of water- stable aggregates. It is not suitable on the soil, which compact and seal easily.
3. Strip tillage- the soil is prepared for planting along narrow strips with intervening area left undisturbed. Typically, up to one third of the soil tilled with a single plough-plant operation. Weed control by herbicides and cultivation.
4. Mulch tillage:- Soil surface disturbed by tillage proper to planting, operating with large amount of residue. At least 30% residue cover left on surface protective mulch. Weed control by herbicide and cultivation. This system can be used successfully to control wind erosion and conserve moisture in driver areas.
5. Minimum tillage: - Any other tillage practices which retains a 15 to 30%-residue cover.

4.2.3.1 Contour Cultivation

This is the practice of contour cultivation (farming entails ploughing, harrowing, planting and weeding) along the contour, i.e., across the slop rather than up and down. This practice is very simple and inexpensive to realize the concept. Furrows and ridges created by contour cultivation will help to trap rainwater and allow it to infiltrate, there by reducing surface run-off and erosion. Experiments have shown that contour farming alone can reduce soil erosion by as much as 50% on gentle slopes. However, on slopes over about 10 other supporting measures must be used, as contouring alone is inadequate. The effectiveness of contour farming depends on the infiltration capacity of the soil. Greater storage of water and more effective erosion control can be achieved by connecting the ridges with cross ties, there by forming a series of rectangular depressions, which fill with water during rain. Contour cultivation is normally used on well-drained soils.

If applied to clay soils, water logging is likely to occur. If excess moisture is expected on poorly drained soils, the contours should be graded to drain excess moisture to waterways.

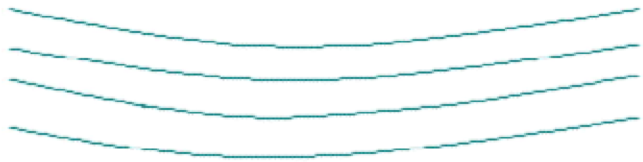
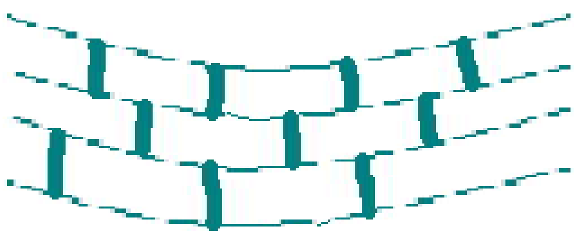


Fig- A diagrammatic sketch on contour cultivation

4.2.3.2 Tide- ridging

Tie- ridging are manipulations of the soil surface meant to increase surface roughness, waterstorag and reduce run-off. First, furrows are made and then blocked with ties or small mounds at regular intervals, based on crop stand and requirements. Tide ridging is widely applied in several arid and semiarid areas and affects on crop yields are generally good. Good responses are commonly reported for sorghum, millet and maize. Tie ridging cannot take place on slope >3% or in case of slopping lands, only on bench terraces preferably medium deep or deep soils with good permeability are suitable to provide sufficient moisture storage and absorb quickly the contained flood water. The ties should be lower in height than the furrows so that, in case of excess run-off the files fail along the follow before the ridges overtop in the direction of the slope.



Tie ridging

4.2.3.3 Improved pits

Improved pits are variation of normal pits in moisture deficit areas. Improved pits are larger excavations along the contour & staggered alternatively for maximum water harvesting and retention. The water harvesting capacity of pits is limited & not all run-offs may be checked, however, the measure is suitable for dense plantation of species such as some acacia spp, leucaena leucocephala, sesbania etc. The improved pits are better than normal pits but less effective than ditches or other water harvesting measures and not effective in controlling excess run-off. Improves pits are not appropriate for soils prone to water logging. Pits should be dug in areas with slopes <30% and soil with depth >75cm. The collection pit should have 1.2 - 1.5 m length, depth 50cm and width 50cm. The plantation pit is 30cmx 30cm x 30cm the pits should be 2m vertically and lateral spacing between pits 60 cm.

- Construction of soil or stone bunds between 10 or more lines of improved pits is recommended.

4.3. Mechanical measure

Design and construction of soil and water conservation measures

⇒ **Terrace**

Terrace is defined as:

1) A strip of level of nearly level land formed between embankments of earth or stonewalls. Such terraces are known as **developed terraces**. or
2) A nearly level strip of land formed by cutting and filling of earth on steep slopes such terraces are often known as **bench terraces**.

4.3.1 General principles

Terraces can be designed to either retain or discharge run-off. They can also be designed so that part of the run-off is retained but the excess, during heavy storms, is discharged. In the higher rainfall areas (over 100 mm per annum) , Where crops are rarely short of water, or where there is risk of water logging at certain times, it is usually necessary to design structures to discharge run-off . However, it would be a mistake to design structures to discharge run-off if there is no suitable outlet such as a natural waterway, artificial waterways or grassed slope. Discharging water on to a footpath, road or existing gullies will aggravate the problem of erosion.

In the drier areas (less than 750mm per annum), it is usually desirable to keep rainwater in situ and prevent run-off. Other factors that must be considered in reaching a decision, besides the availability of *discharge area* or *waterway*, include the *soil type*, *soil depth*, *land slope* and the risk, if any, of *retaining water* in situ. When there is a need, to discharge water but no suitable place can be found and no water way can be installed, there are two options. One is to charge the land use to a permanent crop or fodder grass that does not require conservation structures. The other is to use contour barriers such as narrow grass strips that impede run-off and promote infiltration.

4.3.1.1Effectiveness

To be effective, they must be used in combination with other practices, such as proper agronomic and vegetative practices. Contouring and strip cropping are the best techniques to be used with terracing.

4.3.1.2Applicability

They are normally to be used on cultivated lands. However, some badly eroded lands may be so severely gullied that it would be difficult to establish grass. In such instances, terraces are necessary on grassland. Terraces are of value on practically all soils except those that are too stony, sandy or shallow to permit practical and economical construction and maintenance. It is not advisable to terrace lands with very gentle slope) (except where water retention is required) or also on very steep slopes or where the topography is very irregular. In drier areas, the construction of terraces even in gently lands would be essential because the ultimate goal of conservation structure is to create maximum water retention opportunity.

4.3.1.3 Objective and Goals

The general objectives to be considered in planning terrace are:

- Erosion control
- Topographic improvement
- Moisture conservation
- Removal of excess water

4.3.1.4 Selection of out lets

First step in planning terrace systems is the selection of proper out lets or disposal areas.

Outlet types include:

- Natural drainage ways
- Cut off drains
- Permanent pasture or meadow
- Road ditches
- Concrete or stabilized channels and stabilized gullies.

4.3.1.5 Terrace location

Location of terraces is the next step to be followed after selection of the outlets.

Criteria for good terrace location:

- Minimum maintenance requirement
- Reasonable investment cost
- Ease of farming
- Adequate control of erosion

- ♣ Not at far distances from out let
- ♣ Better alignment of terraces can usually be obtained by placing the terrace ridge just above eroded areas such as gullies and abrupt changes in slope.
- ♣ Better roads and fences be located on the ridge
- ♣ Top terrace should be laid out first, starting from the out let end.
- ♣ Top terrace should be properly located so that it will not over-top and cause failure of other terrace below.

General rules for the location of the top terrace are-

- The top terrace should normally be better aligned and strongly constructed to avoid easy breaking
- When short, abrupt change in slope occurs, the terrace should be placed just above the break. The above-mentioned rules and criterion are applicable to both the level terrace and graded terraces.

4. 3.1.6 using the line level

- When using a line level for laying out a level contact:

You need to have:-

- A line level or two (for checking)
- Two graduated staffs (pole)
- A nylon string 11 meter long and
- Four men

Steps in the layout and construction:

- Always start from the top or immediately after a diversion ditch or a cut off drain.
- Tie the string at 1m heights from the ground on both the poles.
- The man attending the line level should hang it right at the centre of the string and make sure that the sable at the level is between the two marks, showing that it is level.
- When the right location of the pole is found then it is pegged.
- After the pegging the two poles are moved in the front direction to align.

- Then the process repeats until the desired contour line is completed.

N.B. To start with 2nd contour line, you have to select the proper vertical interval for spacing.

- Construction starts with digging a channel/trench and placing the soil downhill.
- A berm of about 5cm should be left between the trench and the embankment.
- Compacting the embankment I necessary
- The embankment should be planted with grass during rainy seasons
- The last most important operation is to check that- the top of the embankment through its entire length is perfectly level.

* The formation of bench terraces occurs normally after 2 to 7 years based upon slope, spacing, type of soil and farm willingness to speed up the process.

Integration requirement:

The following are but a few activities that should supplement and integrate soil bunds.

- Bund stabilization
- Agronomic practices
- Control erasing
- Cut off drains construction above bunded fields.

4.3.2 Terrace classification

Depending on the gradient used to make contour lines, a terrace could be:

– **Level terrace**

_ **Graded terrace**

Furthermore, based on the material used for construction different types of terrace classification are known:

- **Soil bund (embankment bund)**
- **Stone bund**
- **Stone faced soil bund**

- Digging a channel and throwing the soil down slope or upslope (channel and embankment bund, (**Soil bund or fanyajju**)

- In putting stone walls along the count out (**stone bund**)
- Placing a stone wall at the down slope side and supporting it by earth at the upslope side (**stone faced soil bund**)

4.3.3 Bund spacing

What is the appropriate spacing for bunds?

Experience from past activities in soil and water conservation shows that it is not possible to recommend a unique spacing rule. In spacing bunds, the following conditions are important to be considered.

- Buds should allow adequate space for farming
- Should not unnecessarily be far apart, so that there is high run-off, which breaks the structure
- The VI should not exceed 2m. If it is more than this it affects the stability of the bund
- A vertical interval of 1m is very appropriate to land with slope less than or equal to 12%
- The cultivable land should not be less than 7m for ox plough farming conditions.
- In slope, 20% the V.I should be from 1.5 to 2m. The following formula could be used for spacing of bund. The spacing is expressed as the vertical interval (V.I)

V.I = (S D) / 100

Where V.I – Vertical interval

S – The ground slope in percentage

D – The cultivable strip in m (the horizontal ground distance) Or

V.I = [0.305(2+ (slope% /2)]

e.g.; If slope 5%

VI= [0.305 (2 + (5/2)] = 1.3725

Where 5%, the ground slope in %

1. For instance if the slope % is 9%, then

VI = [0.305 (2 +9/2)]

= 1.525

2. If D=8m and slope % given to be 20%

   Then V.I = (8x20)/100

   = 1.6m

In order to avoid calculation and for ease of work it is advised to use the information given in the table below. Table- Spacing of bunds expressed in vertical interval (V.I and HI)

Slope %	Soil depth75 cm		Soil depth50-75cm		Soil depth25-50cm	
	VI m	HV m	VI m	HV m	VI m	HV m
5	1	20	0.7	15	0.5	10
6	1	17	0.7	12	0.6	10
7	1	14	0.8	12	0.7	10
8	1	12	0.8	10	0.7	9
9	1	11	0.9	10	0.8	9
10	1	10	0.9	9	0.8	8
11	1.1	10	0.9	8.9	0.9	8
12	1.1	9	1	8.8	0.9	8
13	1.2	9	1	8.8	1	8
14	1.2	8	1.1	7.8	1	7
15	1.2	8	1.1	7.7	1	7
16	1.3	8	1.1	7.7	1	6
17	1.3	8	1.2	7.7	1.1	6
18	1.3	7	1.2	6.7	1.1	6
19	1.3	7	1.2	6.6	1.1	6
20	1.4	7	1.2	6.6	1.1	6

The data in the above table is established from the analysis field report, survey & research results.

E.g. – On 15% slope, the V.I is 1.2m for soil depth of 75cm or more.

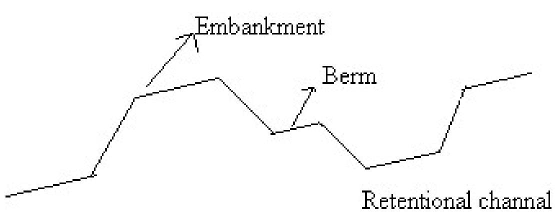
For the same slope, it is 1.1m V.I for soil depth of 50 to 75cm and it is 1m for soil depth of 25 to 50 cm.

4.3.4 Channel retention bund

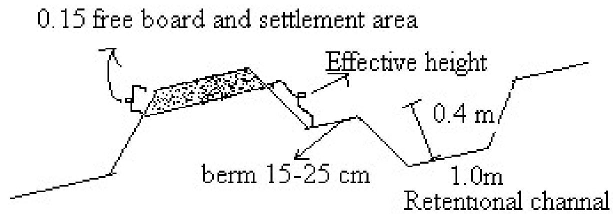
It is called channel retention bund because the formation of the bund includes the digging of a ditch and embanking of the soil or stone at the down slope side. It is also known as TRENCH RETENTION BUND. The ditch is commonly provided with tide ridges of 3-5 meter apart to ensure maximum retention of rainwater in the channel. In this case, it is assumed that all rainwater is trapped in the channel so that plants make use of the stored water. Practically however, crops near the bunds are seen to benefit more from the run-off collected but plants at some distance are seen to benefit less.

Spreading evenly the run-off water in the space between bunds would be necessary to ensure, uniformity in plant growth so to ensure evenly distribution of run-off it is advisable to dig a shallow trench and scrap some soil from sides of the bund and form the embankment.

Tide ridges should not be very big in size. For practical purpose the ridges should not be more than 0.25 to 0.40m in width.



Fig, Cross section of retentional channal bund



Fig, Dimention of retentional channal bund

Channel retention bunds are constructed either of will or stone or by the combination of both. The following are the types known commonly: These are

- Channel retention soil bund
- Channel retention stone faced soil bund
- Channel retention stone bund

Design and layout

The design of channel retention bund considers

- Determination of proper dimension (height, bottom width and side slope
- Spacing: spacing gives on how apart should the bunds be placed one from the other.
- Gradient: gives whether the bund is laid out on level contour or graded contour.
- Vegetative cover: vegetation to be grown for stabilizing and production.

Factors affecting design of bunds

- Climate (rainfall and temperature)

- Slope
- Soils (texture depth)
- Land use

Climatic factors important in the design are rainfall and temperature

- Rainfall intensity of greater than 25mm/hr is considered as erosive and 40 to 50% of the rain fall in Ethiopia is considered as erosive
- Amount of rainfall is the most important factor in the design of bunds.

The maximum daily rainfall amount is most important.

Spacing

Proper spacing of bunds is very essential. Narrowly spaced terraces take away land from cultivation but put considerable area out of production, increase cost of construction and binder farming operations. While widely spaced terraces do not effectively control erosion. In widely spaced terraces the bund often breaks due to over topping. This situation accelerates gully formation. N.B. For choice of spacing of retention bunds refer table.

4.3.5 Level soil bund

Technical specification for level soil bund

Slope range – soil bunds are suitable within 3 to 30% slope range.

- For higher slopes, stone faced or stone bunds and bench ferraces are preferred.
- In dry zones above 5 to 10% and soils with limited infiltration capacity (shallow, crusted soil etc) it is recommended to provide soil bund with spillway.

Type of soil – soil texture and soil depth influence the design and construction of soil-bund.

When soils have a loose texture and high infiltration rate the bunds may be spaced further apart than those a heavy soil with low infiltration.

- Knowledge of the soil depth is required, as the vertical interval between the bunds should not exceed twice the topsoil depth. If this is exceeded then the resulting terrace will be partly exposed to the subsoil.

V.I = [0.305 (2 +(S% / 2)] Where S- slope.

4.3.6 Stone faced and reinforced soil bunds

Definition: Soil bunds are further strengthened on one or both sides of their embankment with a stone wall or riser.

Technical specification

Slope range: The slope range may increase up to 35 to 40% slope as compared to soil bund. Besides, above 30% slope the stone riser of the downstream embankment should have a deep foundation (30cm)

Type of soil – It can be used in all types of soil excluding sandy soil. The stone should be available from the field itself or from adjacent areas.

Spacing apart –

V.I = [0.305 (2 +(S% / 2)] Where S- slope in %

Types of stone rain forced soil bunds

(1) Single faced stone protection wall +/ - collection trench.

Stones are placed on the downstream, well in cline to offer maximum resistance.
The collection trench is dug on the up streamside of the bund.

(2) Double faced stone /soil bund +/- collection trench

- Both faces are rain forced with stones
- This type of bund is rather resistance against excess run-off
- Stones must have good foundation

N.B. Exclude rounded shape and small stones for bunding.

4.3.7 Level stone bunds

<u>Definition: -</u> A level stone bund is an embankment made of stone constructed along the contour (points of the same elevation) across sloping lands, without a collection channel or basin at its upper side. Bench terrace will be formed within 3-7 years.

Technical specifications

Slope range – slope range between 5% and 50%, following the relationship between vertical intervals, bund height and slope % shown in the table below.

Table: – Recommended height, vertical interval, and distance apart for stone bunds.

Ground slope	Height of bund (m)	Vertical interval (m)	Distance apart (m)
5	0.5	1.0	20
10	0.5	1.5	15
15	0.75	2.2	12
20	0.75	2.4	10
25	1.00	2.5	8
30	1.00	2.6	8
35	1.00	2.8	6
40	1.00	2.8	5
50	1.15	2.8	4

Type of soil – stone bunds will be constructed in areas with stoniness is 15% and 50% and with soil depth of at least 50 to 100 cm. For shallower soils stone bunds can be contracted but would not farm a bench terrace.

<u>Dimensions</u>

- The height is given in the table above
- Top width 30 to 40cm
- Lower face should have slope 1.3
- The foundation, placed at the lower side, has a width of 30cm and a depth of 3cm.

4.3.8 Level fanyajuu Bunds

Definition: - A level fanyajuu bund is an embankment constructed along the contours (points of the same elevation), made of soil with a collection channel or basin at its lower side.

- Advantage of faynajuu over soil bund is it develop bench rapidly.

Fig- fanyajuu

Technical specification

Spacing – is the same to that of soil bund. In addition fanyajuu should have.

- The embankment should be preferably higher than common standards with perfectly accurate layout and protection with stone faced embankment on downstream side or both.
- To decrease the possibility of breakage the spacing should be reduced by 10 to 20 % compared to soil bund.

Dimension

Height – A minimum of 60cm height after compaction is recommended.
Top width – of the bund is 30cm on very stable soil and 60cm on unstable soil.
Space between the berm and the channel is minimum 25cm.
Base width – also vary with soil texture and hence its stability.
For unstable soil (sandy loam) the width of the bund at the base should be 1.4 to 1.7 (embankment gradient 1:1) and supported by stone riser.
For stable soil (clay loam, sandy clay, loams) the width at the base should be 1.2 to 1.4m (embankment gradient 1 to 2m).

The collection ditch – or excavated are below bund embankment vary with the size of the faynajuu embankment.

- Deep and narrow ditches (60cm wide x 50cm deep)
- For unstable soil, 70cm wide x 50cm deep) ditch is preferred

- This should be placed at 3-6m interval based upon distance apart and type of terrain, i.e closer spacing if infilitration rates are slow in order to better control lateral movements of run-off.

The heights of the ties are 14cm lower than the total depth of the ditch to facilitate lateral movement of water within the collection ditch. Faynajju should wing up internally and be provided with a stone pitch at the end of the lateral wing for evaluation of excess run-off.

N.B. – The compaction of bund embankment is compulsory

4.3.9 Graded terrace (Graded Bund)

Definition: - A graded bund is defined like a level bund, with the only difference that it is slightly graded sideways, with or radiant of 0.4% up to a maximum of 1% towards a water way or river. The gradient is for surplus run-off to be drained if the retention of the bound is not sufficient. Tide ridges with top heights lower than the bund height serve to control flow and to provide small basins for water storage.

Design: -

The design of a terrace system involves specifying the proper spacing and location in the design main consideration taken are –

⇒ Channel with adequate capacity
⇒ Farmable cross-section
⇒ Run-off most be removed at no erosive velocities in both the channel and outlet.
⇒ Soil characteristics, cropping and soil management practise climatic condition are important.

Channels with low capacity are over topped and cause further erosion problems such as gulling and on the other hand, ever designed channels incur unnecessary costs. In order to design proper channels it is recommended to determine the amount of overland flow to be accommodated by the channel.

Planning

In planning graded terrace consideration should be given to:

- Location of out let
- Land use
- Field boundaries

4.4. LAND MANAGEMENT AND RUN-OFF

4.4.1. Run off estimation

Run-off rate

- It is the maximum expected run-off rate from the maximum rainfall of a given period of time.
- Run off is part of the rainfall that does not infiltrate in to the soil but moves down slope to join streams, rivers lakes.

Run-off= Rainfall –infiltration

- If you are planning to design SWC structures to discharge a given amount of run-off, you ought to know what quantity of the water, which has to be conveyed, and at what rate.
- The reason why the peak run-off rate is used to determine the capacity of SWC techniques is to avoid risk of designing low or high capacity channels.
- Low capacity channels allow overtopping and high capacity channels are not required either, because they entail unnecessary costs.

4.4.1.1 Estimating run-off from a small catchment's area: -

i) Cook's method: -

Cook's method is suitable for estimating run-off rate from small catchments area and is based on the run-off area characteristics related to run-off. The rainfall intensities used up in this case range from 75-100 mm/hr, and thus quite safe with in the maximum peak rain fall intensities likely to occur. If the cook's method is applied, add 10-20% for safely purposes to the run-off values indicated in the table:

The run-off area characteristics are examined under the following categories.

- Vegetation cover
- Infiltration
- Topography (slope %)

- Therefore, for estimating run off, the role played by each of these factors has to be valued and summed up to get the summarized catchment characteristics of the run-off producing area under consideration.

ii) Rational method

For large catchments and for better accuracy, the rational method described for run-off estimation is strongly recommended,

4.4.2. Cut-off drains.

Definition: *A cut off drain is a channel constructed a cross the slope and given a slight gradient to divert the run off to a safe outlet. It serves as the 1st line of defence.*

Cut off drains are mainly used for the following purposes: -

- To divert the run off which flows down to the cultivated land.
- To divert the run off out of active gullies in to a safe out let

TECHNICAL SPECIFICATIONS:

Location:

- Along the break points of the slope.
- In the middle points of the slope.
- Avoid large catchment areas, or make several cut-off drains instead.
- Avoid areas, which are difficult to layout, construction, and other technical considerations

Discharging point

- In to natural water ways
- On to non-erodible stony-rocky ground
- In to artificial water ways.

DESIGN PROCEDURES

1. Determine the run-off area above the cut-off drains in ha.
2. Find the probable maximum rate of surface run-off (m^3/sec)
    - Using Cook's method

i) Summarize the characteristics of the run-off area by adding appropriate values from table 1.

ii) Estimate the run-off to be expected using the run-off area (ha) and summarized run-off area characteristics (CC). Or

- Using Rational method

3. Find the maximum velocity of flow in (m/sec) i.e. this can be obtained from table 3 considering:

   i) The soil type

   ii) The degree of grass cover expected in the channel after 2 years.

Table: maximum velocity of flow (M/sec)

Soil type	**Medium for normal use**		
	Sparse for dry area	**Medium for normal use**	**Good suggested for high lands**
Silty sand	0.3	0.75	1.5
Sand	0.5	0.9	1.5
Coarse sand	0.75	1.2	1.65
Sandy soils	0.75	1.5	1.95
Loam	0.9	1.5	2.1
Clay loam	1.0	1.65	2.25
Clayey	1.5	1.8	2.4
Gravel	1.5	2.1	-

4. Decide the gradient of the channel of the cut-off drains depending on the soil type.

Table: Safe gradient for graded terrace

Soil	**Safe Gradient**
Erodiable soil - **Silt and fine** - **Sandy soils**	**0.25%**
Moderate erodiable - **Loam soils**	**0.50%**
Less erodiable - **Clay soil**	**1.00%**
Gravel and Stone - **Non erodiable**	**>1.0%**

5. Find the depth of the channel of the cut off drains (from table) using maximum permissible velocity and gradient.

Depth of channel in meters

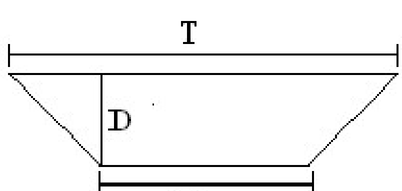
Channel slope /Gradient		Maximum allowable velocity m/sec								
Height : Length	%	*0.3*	*0.5*	*0.6*	*0.9*	*1.2*	*1.5*	*1.8*	*2.1*	*2.4*
1:1	1	-	-	-	-	-	0.3	0.4	0.5	0.6
1:2	0.5	-	-	-	-	0.3	0.5	0.7	0.9	1.0
1:4	0.25	-	-	0.3	0.4	0.6	0.9	-	-	-

6. Find the discharge in m^3 /sec using the table below. These values are determined by the use of the gradient of the channel and depth of the channel.

Discharge in m3 /sec

Depth of channel in meter (m)	Gradient		
	1.0%	0.5%	0.25%
0.3	0.6	0.4	0.25
0.4	0.9	0.65	0.45
0.5	1.3	0.95	0.65
0.6	1.8	1.3	0.95
0.7	2.28	1.7	1.2
0.8	2.8	2.15	1.5
0.9	3.4	2.65	1.8

7. Decide the slope of the channel cross-section and make calculations to find the top width and



bottom width of the channel.

Normally trapezoidal cross-section 1:1 side slope is selected.

For trapezoidal cross-section top width

T= B + 2D   Or   B= T – 2D this formula is to be used when the side slope is 1:1

Maintenance of cut off drains

Regular maintenance of the channel, i.e. removal of sediments and obstacles is required. It should have also its embankment stabilized with grasses or other shrubs.

Example

Determine the size of the channel for a cut of drains if:

I) Area of the land is 200m x 250m (5000m^2)

II) Area of the land is 50m x 1000m (5000m^2**)** wider along a slope

Characteristics of the land for both area is described as follows

- Slope - 20% and hilly
- Soil - clay type
- Cover - grass land medium

Solution for part I

Catchment's characteristics   Slope =15

Soil=40

Cover=15

Summarized soil characteristics =15+40+15=70

Peak rate of run off for (5ha, 70 cc) = 1.7 m^3/sec from the table

Maximum allowable velocity for clay soil and medium grass cover is 1.8m/s (from the table)

Safe gradient for clay soil is 1% (from the table)

Depth of the channel for the cut off drain (for safe gradient 1% and Maximum allowable velocity 1.8m/s) would be 0.4m from the table.

Discharge for 0.4 depth and 1% gradient would be 0.9m^3/sec

Top width of the channel for trapezoidal or parabolic channel would be

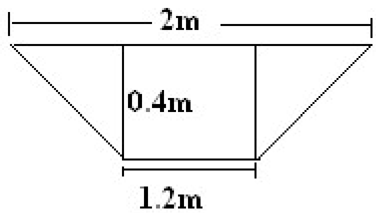
$T = {}^{er}\!/_{d}$ Where er - estimated run-off in m^3/sec

d – Discharge in m^3/sec

$$T = {1.7m^3/\sec}\Big/{0.9m^3/\sec} = 2m$$

Bottom width

B= T – 2D; B =2m-(2*0.4) = 1.2 m



4.4.3. Water Ways

- Waterways could be natural or artificially constructed drainage areas. Artificial waterways are usually wide and shallow drainage ways constructed along the slope of the land.

The purpose of waterways;

- To receive run-off from cut off drains, and or graded terraces and carry it away to rivers safely without creating erosion.

  TECHNICAL SPECIFICATIONS:

  - It can be implemented in various kinds of slopes, but for higher slopes;
    - Drop structured;
    - Paved with stones;
    - The drainage area should not be bigger than 10-15ha;
    - A series of small water ways are preferable than single and large structure
    - The most ideal location point of artificial waterways is a natural depression where water tends to drain naturally.
    - It can also be located along farm boundaries.

N.B.

- One difficulty in constructing waterways is that protective grasses cannot be established in the first year or two years. Consequently it would advisable to construct artificial waterways and plant grass two years before the construction of the cut-off drains and graded terraces.

Design procedure:

1. Determine the drainage area which leads run off to water ways to be constructed
2. Find the peak rate of surface run off (m^3/sec) based on the characteristics of the run off producing area.
3. Select a suitable maximum permissible velocity of flow for various conditions;
   - Grade of waterways (%)
   - Erodibility of the soil

Tables: - Maximum permissible velocity of flow for grass water ways:

Soil Type	**Maximum permissible velocity M/sec)**		
	Slope (0.5%)	**Slope (5-10)**	**Slope (10%)**
- Soil resistant to erosion	2.0	1.75	1.5
- Erodiable soils	1.75	1.5	1.25

Source SWC Norman Hudson, 1981

4. Compute the cross-sectional area of flow by the formula:

Where, V is permissible velocity determined under step 3

A= Q x V   Q= peak rate or run-off (M^3/sec); using Cook's or Rational method

A= Cross sectional area of the channel (m^2)

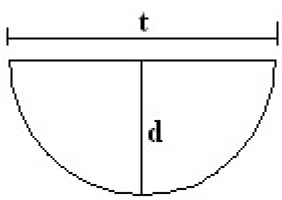
5. Find the width of the channel: It can vary depending on the site of the catchment area and the steepness of the slope.

Table 5:- The relation between drainage area, steepness of the slope and the width of the channel.

Catchment area of	**Width of the water ways (cm)**		
The water ways (ha)	**Slope (0-5%)**	**Slope 6-12%**	**Slope (12%)**
1	1.5	1.5	1.5
2	1.5	2	2.5
4	1.8	2.4	3
6	2.1	3.3	5.1
8	2.40	4.50	6.9
12	2.7	6.9	10.20
16	3.60	9.0	13.20
20	4.80	11.40	16.80

6. If the waterway is covered with stones, the width shown in the table above can be decreased by about half.
7. Decide the shape of the channel and make calculations to find the dimensions.

Normally parabolic shaped waterways are recommended, because it nearly approaches the shape of the natural waterways.



$$A = \frac{2}{3}td$$

Where A; Cross sectional area of the channel (m^2): t; Top width (m) d; Depth of flow

Fig, Cross section of water way

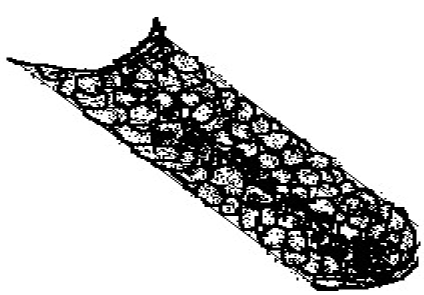
Table: - Relation between depth (m) of water ways and width (m)

Width in meters	Depth in meters
0-3	0.3
4-6	0.4
More than 6	0.5

LAY OUT AND CONSTRUCTION PHASES:

The construction starts by digging the ground. The soil is piled on both sides if the side ground is level or one side if it is gently sloping. The whole bottom width and sidewalls are either's reinforced with stones or grassed. For higher slopes drop structures are placed at regular intervals.

Waterways with stone paved and drop structures.



CHAPTER 5: GULLY EROSION CONTROL

5.1 GULLY EROSION

Gully erosion is a serious problem, especially in areas where vegetation cover is poor. Many hectares of productive land is being lost due to the expansion of gully erosion. The control and treatment measures are based on an understanding the process and stages of gully erosion.

COMMON CAUSES OF GULLY EROSION:

Some of the common causes of gully erosion includes:

⇒ Improper land use;

⇒ Excessive clearing of vegetation cover;

⇒ Poor farming practices

- Up and down cultivation on steep slopes
- Lack of improved agronomic practices.

⇒ Improperly located road drainage structures

⇒ Unprotected soil conservation structures

- . Waterways
- . Cut-off drains
- . Bunds

⇒ Over grazing

5.1.1. PROCESS OF GULLY EROSIONE:

Main components of the process;

I. Head cut- due to waterfall.

. The head cut results in the extension of gully.

II. Gully bed erosion

. Result in deepening of the gullies

III. Bank erosion or lateral erosion

. Results in widening of the gullies

Thus, effective gully control must aim at stabilization of the gully gradient, on all sides of the gully wall.

5.1.2. STAGES OF GULLY EROSION

I. Formation stage;

. The rills enlarge as the run off concentrates,

II. Developments stage;

. Upstream movement of the fully head and enlargement of the gully in width and depth

III. Healing stage;

- Here, there is no significant erosion problem
  - Vegetation begins to grow
  - The channel can accommodate the run off getting in to the gully with out further expansion.

IV. Stabilization stage,

- Gully reaches a stable gradient
- Gully wall attains a stable slope
- Sufficient vegetation cover develops over the gully.

5.1.3. DAMAGES CAUSED BY GULLY EROSION;

✓ Land damage,

- The gullies often dissect the fertile land

✓ Effect on land productivity,

- Undamaged land adjacent to the gullies suffers from declining productivity. This results from the lowering of ground water table.

✓ Sediment damage,

- The sediment, which is transported by the gullies, is deposited down stream on productive land, roads, bridges and irrigation structures.

Gully Control plans.

For an effective programme of gully ventral, proper planning is necessary, a gully treatment plan should be prepared not only for the treatment of gully itself but also of the quarter shed area of the gully.

A well thought of gully control plan must accomplish the following objectives,

Maximum ret nation of rain fall fun off on the watershed area, by using proper soil conservation and management practices

Interception and diversion of runoff above the gullied area, with a cut off drains

Re-vegetation

Either naturally or through planting.

Construction of grade stabilization structure to control the channel **erosion and encourage sedimentation behind structures,**

Exclusion of all kinds of grazing

N.B: Filling and shaping this is not practicable except for small gullies in the cultivated lands.

GULLY CONTROL MEASURES

The control measure will also depend upon the size of the gully. Based on the gully depth and the drainage area, the gullies may be classified as under.

Description	Gully depth (M)	Drainage area (ha)
Small Gullies	<1	<2
Medium Gullies	1-5	2-20
Large gullies	>5	>20

5.3.1. Control of Run off

If the erosive water can be controlled, vegetation can regenerate in the gully. The first step is to identify the catchment of the gully; there are three ways of dealing with the water.

- ✓ Diversion of the water from following in to the gully.
- ✓ Conveyance of the water through the gully.
- ✓ Conservation of the water with in the catchment of the gully.

If the catchment can be treated to retain more of the water the control and reclamation of a gully will be easier. The conservation measure to be undertaken is,

- Agronomic practices
- Vegetative measures
- Structural; measures
- Good pasture management.
- Proper management of road.

5.3.1.1. Diversion of water from following in to the gully

The run-off must divert from the gully head by use of cut off drains. Careful consideration should be given to the disposal area. Unless a safe disposal area can be provided no attempt should be made to construct a cut off drain as it could cause other gullies.

Cut off drains should be located away from the gully edge, at a distance equal to at least three times the gully depth. Locating them closer to the gully edge will endanger the diversion due to the extension of the head cut.

The depth of water channel (after the freshly disturbed earth has settled down) should seldem be less than 45 cm. Minimum water cross sectional area of 0.68 m^2 (width of channel multiplied by its average depth) is suggested for watersheds of 0.5 to 2.5 ha. There are of course many variations from the indicated cross sections, because of local variations of soils, slopes and rainfall intensity. Watershed of 2.5 to 4 ha will require a channel depth of at least 60cm and a minimum cross section of 1m^2. For watersheds exceeding 4ha the depth can be up to 70 cm but the top width increases accordingly. The diversion should be located away from the gully edge, at a distance equal to at least three times the gully depth. Locating them closer to the gully edge will endanger the diversion due to the extension of the head cut.

Diversion drains should generally not exceed 400 meters in length. The gradient of the drain should not exceed one percent. Generally, a hand dug diversion drain for a small catchment should have the following dimension.

- Top width 1.5m
- Bottom width 0.9m
- Depth 0.6m
- Cross section 0.7 sq. m

5.3.1.2. Conveyance of water through the gully

If it is not possible to infiltrate the water in the catchment or divert it away from the gully head, it must be conveyed through the gully with out causing any further erosion.

Gully stabilization

Stabilization involves the use of appropriate structural and vegetative measures in the head, floor and sides of the gully. The structures will get stabilized while vegetation becomes established.

Use of vegetation in gully control

The use of vegetative material in gully control offers permanent protection. Vegetation will protect the gully floor and banks from scouring. It an also slows down the velocity of the run off and causes deposition of silt.

The establishment of vegetation either naturally or artificially has to contend with a hostile environment. The topsoil has been eroded away leaving subsoil that is usually lacking in plant. Nutrients and organic matter and has poor water holding capacity.

To plant the side of the gully the following steps are to be followed

- Shape the side of the gully by hand or bulldozer
- Spread topsoil over the sides
- Seed or plant the sides
- Cover with net made from fibre
- Staple down with wire staples or spikes

Structural measures for gully stabilization

Structures are used in gully control either to facilitate the establishment of vegetation or to provide protection for those critical sections, which cannot be adequately protected by other measures. Structures for gully control can be classified as temporary and permanent depending on their duration of functions. Temporary structures are intended to functions only until vegetation becomes well enough established to provide necessary protection. Their main objective is to trap silts and slow down flood velocity but not to store water. They are porous check dams made of brushwood, wire poles, logs, bricks, or loose rocks. A temporary dam should not exceed an overall height of 75cm and an average effective height about 50 to 75cm usually will be more satisfactory. Temporary dams are especially adapted to gullies with small watersheds.

Permanent structures are used in gully control where temporary structures are either inadequate or impractical. They are frequently necessary in gullies with large contributing watersheds and in gullies that must be retained as permanent waterways. The most frequent permanent structures used in gully control measures are silt trap dams, gully head dams and gabions.

Filling and shaping

This method is applicable only for small discontinuous gullies, in their early stages of development, for larger gullies, this method is not economically feasible. When this method of treatment is used, the gullied area is shaped and smoothed so that the vegetation can be established over the area or even be restored to farming.

During the filling processes, the soil should be well compacted with shovels or trampling. The filling operation should be done just before the start of the rains. To protect the freshly filled area from erosion, a close growing crop should be seeded immediately. The entire work of shaping and filling should be done in one operation. Piecemeal filling and shaping can result in increased erosion, due to over falls.

Check dams

Check dams for gully stabilization are required in order to again sufficient time to put the vegetation plan in to action. Check dams once built help in trapping silt deposit behind them. This deposit of silt greatly helps in establishing the vegetation in the gully.

I) Use of check dams

- Grade stabilization
- Protection of bank erosion
- Energy dissipation
- Silt deposition

Care is needed inn the design and construction of check dams to avoid waste of resources and to ensure that they function as intended.

II) Design criteria for check-dams

Regardless of their material used, the following points will be considered:

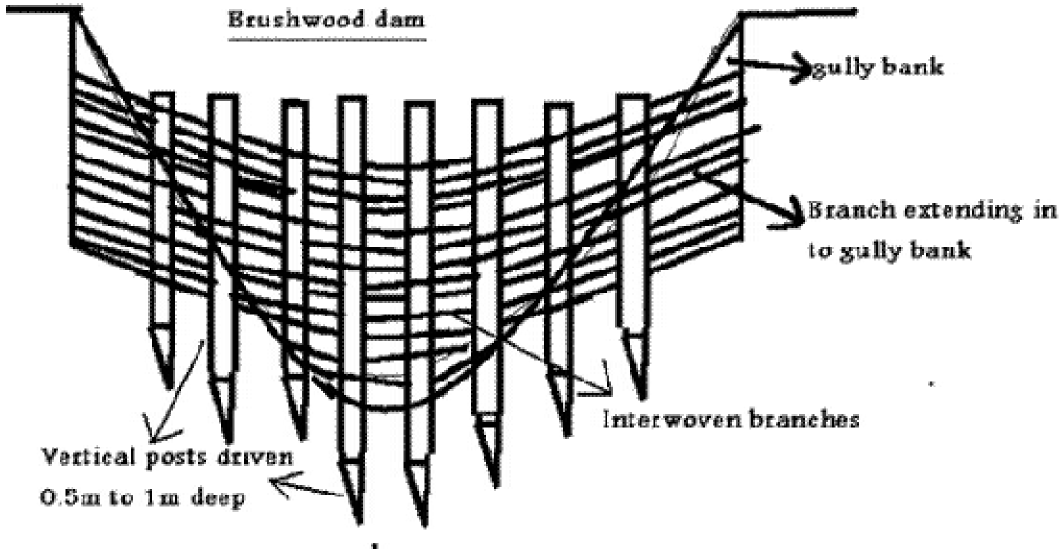
- Low check-dams are less likely to fail than high check dams
- Proper spacing between the successive check dams should be ensured.
- The check dam should be properly keyed to the floor and sides of the gully to improve stability.
- An apron of non-erodible material should be provided at the base, to dissipate the energy of water falling through the spillway.
- An adequate spill way should be provided for safe disposal of water.
- An adequate spill way should be provided for safe disposal of water.

- The height should be properly planned.
- Construction should start at the upper end to produce the fish of failure if water enters the gully before all check dams have been constructed.

Brushwood dams

These are temporary structures constructed with tree branches, poles and twigs. Plant species which can easily grow vegetative through shoot cuttings are ideal for this purpose. Brushwood dams are suitable only for small gullies of less than two meter depth. The objectives of this dam are to retain sediment and to detain the runoff temporarily and allow it to filter through slowly. Such dams are built across the gullies, either in single or double rows. Brush wood dams built from materials which do not propagate vegitaitvely, do not normally last longer than three to four years. The untreated wood material when exposed to water gets rotten easily. The expected life of these check dams, however, depends upon the type of wood and its susceptibility to insect damage.

Design and construction of Brushwood dams: planted material required for brushwood check dams should be sorted out into relatively thicker, straight branches, 3tor cm in diameter. The thicker branches will be used as vertical posts driven into the soil to at least 60 cm depth and spaced about half to one meter apart. The spacing between the posts will depend upon the height of the check dam. The higher the dam, closer the distance between the posts will be. If tow row brushwood dam is constructed the minimum distance between the rows should be about 50 cm. After the posts are driven into the soil, the thinner branches should be pushed into the banks, up to 50cm. The soil at both ends of the dam is carefully packed down with feet. No soil should be dumped in the middle part of the dam. For a double row check dam, brush and other debris should be packed between the walls formed by the vertical posts and interwoven branches.



III. Design and construction principles of stone wall check-dam.

A) **Check-dam spacing:-**The spacing of the check dam is determined using method:

I) The spillway of one check dam is level with the base of the next check dam up stream.

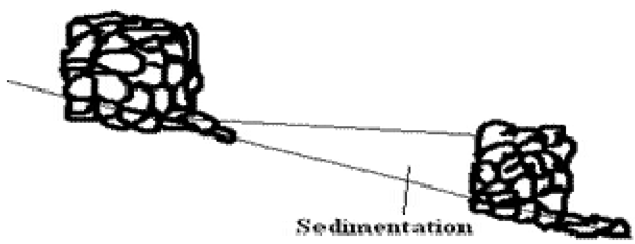


Fig.1. Check Dam spacing & crest height design to cause sedimentation and levelling of gully floor

II) The rule of them b may be used for computing the spacing between the check-dams.

Where

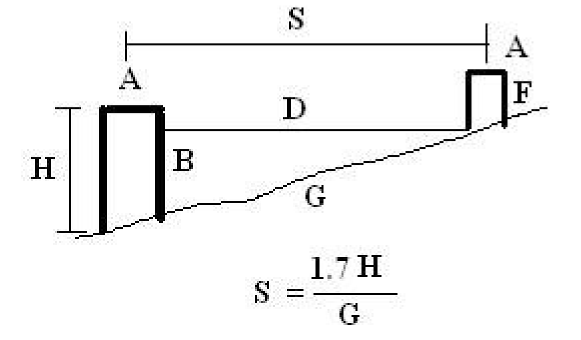
A; check dam

B; effective height

G; existing channel grade

D; sediment grade

F; first check dam



Design of key

A trench key, 0.5 to 1 meter in depth should be first constructed while digging, this trench should give a 10% reverse a radiant.

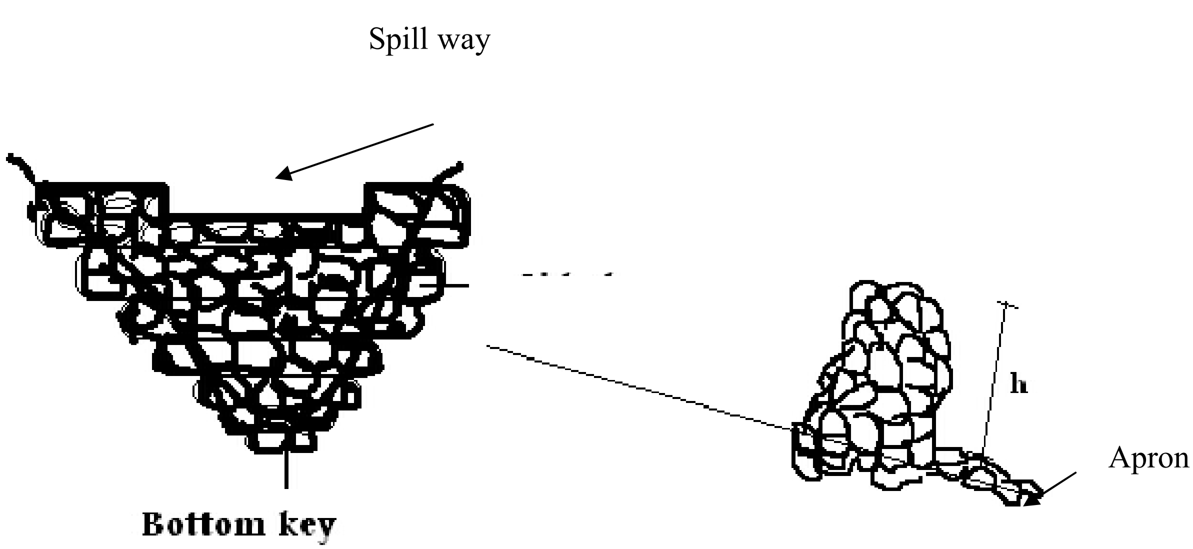
The width of the key trench should be 1 to 1.5 meters, depending up on the width of the dam wall.

1. Bottom key (0.5-1m)
2. Side key (1m)

The bottom, middle and to width of the dam should be property designed.

As a rule of thumb,

- Button width = 0.6*h
- Mid width = 0.5*h
- Top width = 0.4*h



According to their functions, check dams can be classified as:

Retention Dams: When a check dam functions to retain the runoff which can be used for domestic water-supply, cattle watering or irrigation,

Detention Dams: A structure built to detain runoff temporarily and discharge th stored eater at a controlled rate over a period of time. By regulating the runoff volumes, peak discharge rate is lowered and stream gets regulated.

Based on the type of construction, the check dams, can be classified in to the following categories:

Loose rock check dams: this type of dam is built by loose stones and is most commonly used engineering structure in gully control. These dams being porous , release part of the flow through the structure, thereby decreasing the head of the flow over the spillway. Once the sediment basin of the dam is filled , the base level of the gully gets higher.

Gabion: Gabions are rectangular boxes(2m x 1m x 1m) made of galvanized steel wire woven in to a mesh. The boxes are tied together with soft wire and filled with stones and placed like building bocks.

Brash dams: kA brash dam is constructed of small wood branches and poles, interwoven together, either by wire or sisal ropes.

Gully plug: a gully plug is a low check dam, 1m high placed gin a gully and is made of earth, rock, brush or a combination of these.

Drop structures: are generally built from stone. They drop the water at a lower level so as to dissipate its surplus energy.

Gullies fail to function well because of the following reasons:

- No spillway or inadequate spillway
- No foundation key
- No apron
- No bank protection
- Incorrect construction material

CHAPTER 6:Wind Erosion and its Control

6.1. WIND EROSION

Wind is formed by air flow from higher pressure area to lower one results from the pressure difference of air, which due to uneven distribution of quantity of heat on the surface of earth. Erosion by wind is most common in arid and semi-arid regions. It is essentially a dry weather phenomenon, and is accelerated wherever

1) The soil is loose, dry and reasonably finely divided;
2) The soil surface is relatively smooth and vegetative cover is either absent or sparse;
3) The field sufficiently large; and
4) The wind is sufficiently strong to initiate soil movement.

Wind takes up soil from one place and deposits at another. If unprotected, the wind would slowly remove organic matter, fine silt and clay fractions leaving sand and gravel behind.

Although wind has been active as an erosive agent throughout geologic times, it has become much more destructive because of *defective methods of handling the land*. As water erosion, the soil material in order to be transported by wind must first be loosened from its position on the surface of the land. It may then be lifted, rolled or bounced along the surface of the ground.

These processes are largely the result of wind turbulence, mainly eddies and irregularities of wind movement. Turbulence adds vertical component to the wind and makes it more erosive. The ability of wind to move and pick up soil particles varies **square to cube** of the **velocity**.

Table- Wind velocities and wind erosion hazard

Descriptive Word	Velocity Miles/hour	Specifications for estimating velocities	Wind erosion hazard

Calm	Less than 1	Smoke rises vertically	None
Light	1 – 3	Direction of wind show by smoke but not by Wind vanes	
Light	4 – 7	Wind felt on face; leaves rustle; ordinary vane Moved by	Begins in
Gentle	8 – 12	wind	muck soil
Moderate	12 – 18	Leaves and small twigs in constant motion; Wind extends light flag	
Fresh	19 – 24	Raises dust and loose paper; small branches are Moved	Slight
Fresh	25 – 31	Small trees in leaf begin to sway; crested Wavelets form on inland water.	>>
		Large branches in motion; whistling heard in telegraph	
Strong	32 – 38	wires; umbrellas used with difficulty	Considerable
Strong	39 – 46		
		Whole trees in motion; inconvenience felt in walking	
Gale	47 – 54	against the wind	
“	55 – 63	Breaks twigs off trees; generally impedes progress	
Whale gale			
Hurricane	64 – 75	Slight structural damage occurs Trees uprooted;	
	> 75	Considerable structural Damage occurs	Severe
		Rarely experienced; accompanied by widespread damage	
		Sever damage to life and property	

1 mph = 1.61 km/h = 44.7 cm/sec, 100 cm/sec= 2.24 mph

6.1.1. Mechanics of wind Erosion

Wind erosion is mainly a surface phenomenon and is influenced directly by wind velocity in various strata near the ground through which soil particles rise in saltation.

Wind structure near the ground

The erosion causing wind is always turbulent; that is, its flow is characterised by eddies moving in all directions at variable velocities. Measurement shows that zero velocity is somewhere above the roughens elements of the surface, usually less than 1cm for a bare, relatively smooth surface. Above this level, the flow of air is smooth, laminar, and end into turbulent flow at higher elevation.

The average forward velocity of a turbulent wind increases exponentially with height above Zo, where velocity is zero.

Wind force causing soil movement:

Moving air exerts three type of pressure on the soil grain resting on the ground.

1-The first is the direct pressure facing in to direction of movement of the wind.

2-The second, viscosity pressure on the lee side of the grain and

3-The third is negative pressure on the top of the grain caused by the Bernoulli Effect.

The former pressure forms drag force; the latter pressure forms lift Force to the grain. Movement of soil grain by wind occurs normally by the maximum lift and drag action of the turbulent airflow. Lift and drag on soil grain change rapidly as the grains move up from the surface of the ground. Lift decrease with height, the greater the ground roughness and drag velocity of the wind, the higher is the lift due to velocity gradient. Drag increase with height just as the wind velocity increases with height, due to the direct pressure of the wind against the grain.

Initiation of soil movement

A certain minimum velocity is needed to initiate the movement of soil particles; this minimum velocity is known as ***Minimum Fluid Threshold Velocity***. The minimum fluid threshold velocity depends on the **size** and **weight** of soil particle and the **friction** provided by neighbouring particles. If the particles are sufficiently large or attached to other particles, they may resist the force of strong winds. If they are unattached and are not too heavy, wind may lift them from the surface initiating the soil movement. Fine dust particles are lifted after high resistance to movement by wind partly due to **cohesion** among the particles (which raises the threshold value) and partly to fact that the particles are **too small to protrude** above the laminar and viscous layer of the air over the ground surface. Fine dust particles therefore, are, ejected in to the atmosphere mainly by impacts of larger grains. The threshold velocity for grains of 0.1 to 0.15 mm diameter is from 12 to 14 km/hr at 15 cm height above the ground. Observation shows that surface winds exceeding about 3km/hr velocity are turbulent and are responsible for initiating the process of wind erosion. The determining factors of soil movement are those related to **size** and **density** of detachable soil particles and the **turbulent** force on them.

Soil movement by wind

Types of movement

Three distinct kinds of movement occur, depending upon the size of the soil particles.

1. Suspension – is the movement of very fine particles, mainly less than 0.1 mm diameter. The falling speed of small particles is so low that once lifted they can remain suspended for long period of time by the turbulence and eddy currents of the air. Dust storms are fine particles in suspension and can result in large amounts of soil being moved long distances.

2. Surface creep **– it** is the movement of particles at the other end of the size scale and which are rolled along the surface of the ground, pushed by the force of the wind and other particles moving with the wind. Theoretically, there is no upper limit to the size of particle, which could be rolled, but in practice, most rolling particles are found to be in the size range 0.5mm to 2mm diameter. The movement of particles by surface creep causes an abrasion of soil surface resulting in to breakdown of non-erodible soil aggregates due to impact of moving particles. Laboratory studies have shown that surface creep may move about 7% to 15% soil. In addition, 3% to 36% of soil loss by wind may be moved by suspension.

3. Saltation – is the kind of movement where the soil particles skip or bounce along the surface of the ground. After being pushed along the ground surface by wind, the particles suddenly leap almost vertically in the first stage of saltation movement. Some grains rise only a short distance; others leap about 30 cm or more depending up on the velocity of rise from the ground. The higher the grain rise, the more the energy they derive from wind. This energy is liberated in bombarding action of the particle on other particles. The variation in air velocity near the ground causes a substantially higher rate of airflow at the upper than at the lower surface of grain at rest on the ground surface. Consequently, if the total difference in pressure between the upper and lower surface is greater than the force of gravity then the grain will rise in a vertical directions. The soil moved by saltation chiefly consists of fine grains ranging in diameter 0.05 to 0.5mm. Saltation is by far the most important of the three forms of movement. For one thing more soil is moved in this way than either of the other two, and also neither creep nor suspension occur without their being saltation.

6.1.2. Factors Affecting Wind Erosion

Major Factors that affect the amount of erosion from a given field are soil clodiness, surface roughness, wind, soil moisture, Field length, organic matter, barriers, vegetative cover, topography, soil, and wind velocity See details in chapter 3.

Damages caused by wind erosion

- Soil damage – fine material, including organic matter, soil structures may be degraded, adversely affecting productivity
- Crop damage – mechanical damage
- Others damage – affects human respiratory health, etc.

6.2. Wind Erosion prevention

Stubble mulch and minimum tillage

- The residue and rough surface increases the drag or friction of the soil surface an so reduce wind velocity
- They also trap soil practices moving by saltation.
- Minimum tillage technique also reduce wind erosion, as they minimize soil pulverization and the destruction crop residues y tillage operation

Wind strip cropping

- Line or strips of crops can be planted at right angles to the direction of the wind which causes most erosion
- The method consists of planting a strip of an erosion resistant crop (such as small grains, small legumes, or best of all grasses which can be cut for fodder) and then a strip of erosion susceptible crop (such as ground nut).
- Maize, sorghum and millet are intermediate susptabel

Wind break

- Ideally wind breaks or shelter belts consist of several crows of trees perpendicular to the direction of the prevailing wind
- The use of wind breaks reduces wind erosion for a distance of up to 20 times the height of the wind break on the leeward (downwind) side and up to 5 times the height on the windward side
- The distance between each line of wind break should be more than 20 times the maximum height of the wind break

- Good wind breaks can decrease evaporation and increase yields by as much as 10 to 20% in average

Chapter 7. Water Conservation

7.1. Introduction

Water is a very important resource in our life. Water is becoming scarce due to increase in population, industries and agricultural activities and due to poor rainfall. A report of 2009 suggested that by 2030, in some developing regions of the world, water demand will exceed supply by 50%. Water plays an important role in the world economy, as it functions as a solvent for a wide variety of chemical substances and facilitates industrial cooling and transportation.

❖ Goals of Water Conservation

1. Sustainability: To ensure availability for future generations, the withdrawal of fresh water from an ecosystem should not exceed its natural replacement rate.

2. Energy conservation: Water pumping, delivery and wastewater treatment facilities consume a significant amount of energy. In some regions of the world over 15% of total electricity consumption is devoted to water management.

3. Habitat conservation: Minimizing human water use helps to preserve fresh water habitats for local wildlife and migrating water flow, as well as reducing the need to build new dams and other water diversion infrastructure.

❖ Water harvesting and conservation

Water conservation refers to reducing the usage of water and recycling of waste water for different purposes like domestic usage, industries, agriculture etc.

Methods of Water Conservation:

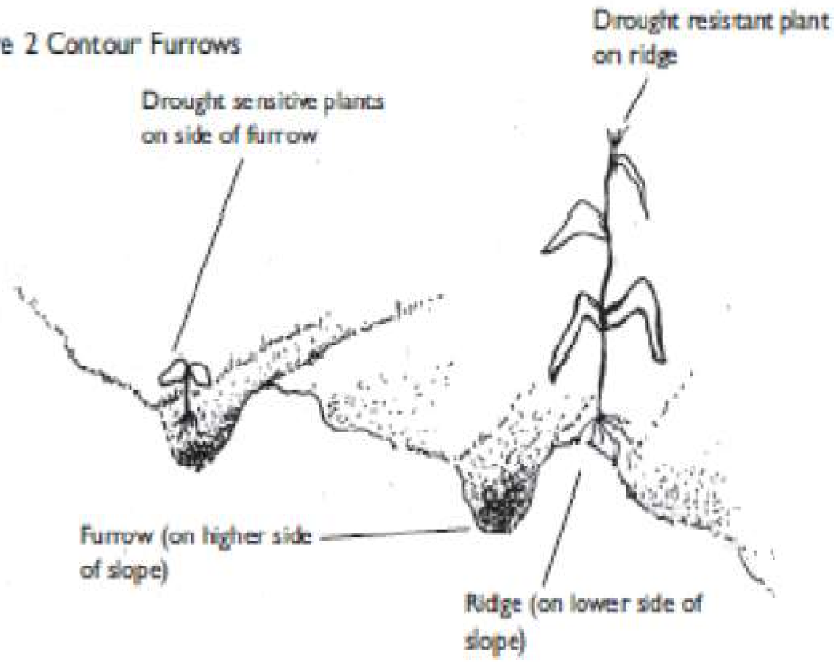
- ※ Protection of Water from Pollution;
- ※ Redistribution of Water
- ※ Rational Use of Groundwater
- ※ Renovation of Traditional Water Sources
- ※ Use of Modern Irrigation Methods
- ※ Increasing Forest Cover
- ※ Change in Crop Pattern
- ❖ Contour Farming& Contour Ploughing
- ❖ Conservation of water by Municipal authorities
- ❖ Use rainwater effectively
- ❖ Make effective use of soil water reserves
- ❖ Take measures to avoid run off
- ❖ Avoid wasting water through evaporation
- ❖ Reduce water losses through drainage

- ※ Flood Management
- ※ Conserving Water in Industries
- ❖ Plan your irrigation

➢ Water Conservation Practices

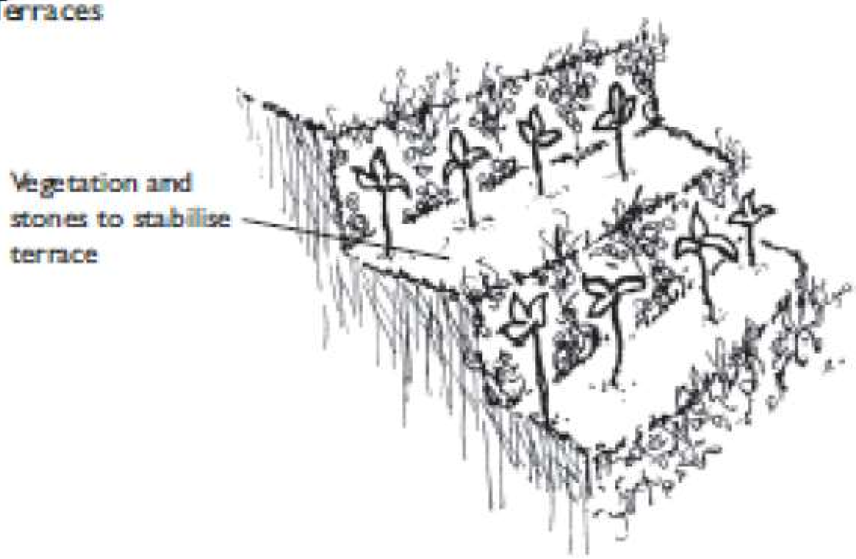
Contour Furrows

Figure 2 Contour Furrows



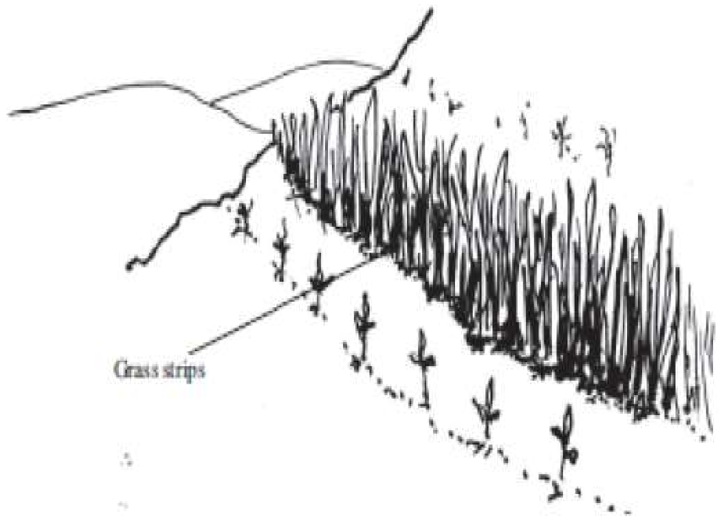
Bench Terraces

Figure 3 Terraces



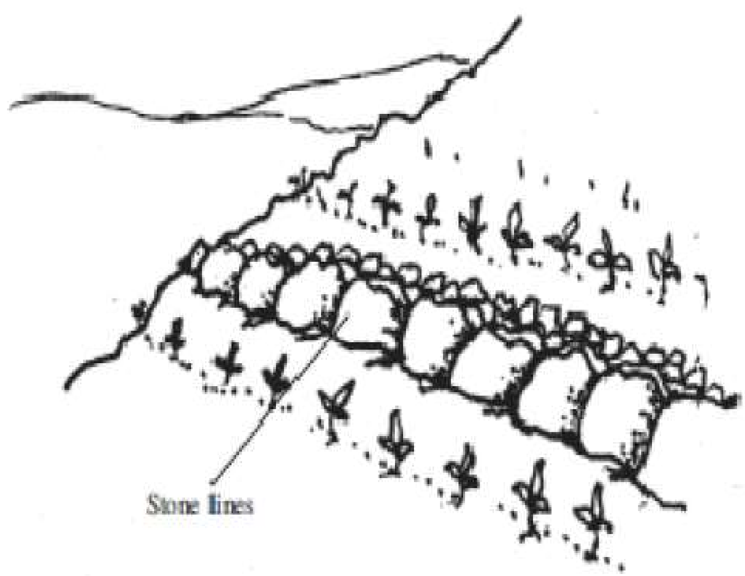
Grass Strips

Figure 4 Grass Strips



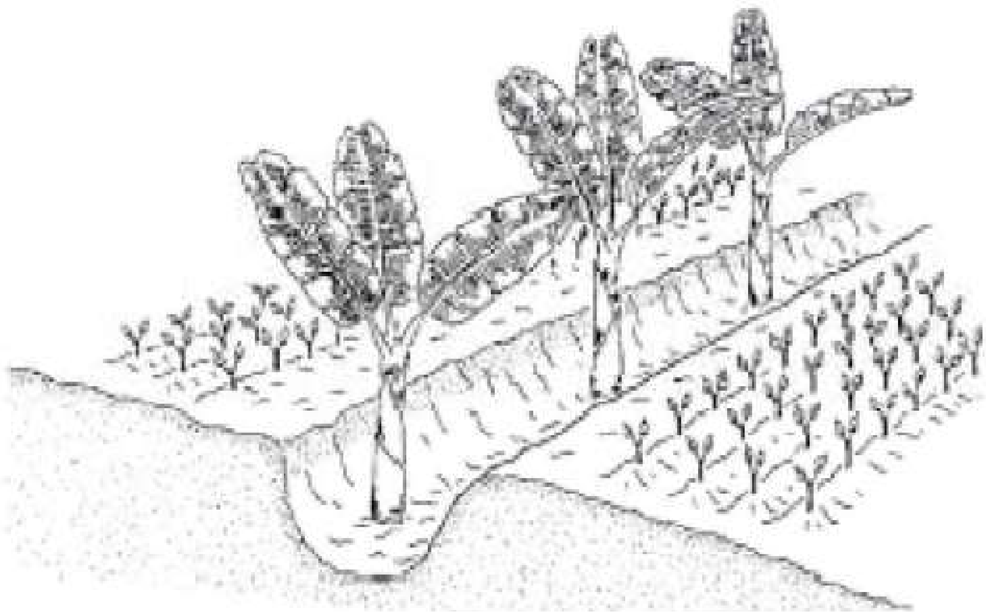
Stone Lines

Figure 5 Stone Lines



Retention Ditches

Figure 6 Retention Ditches 2

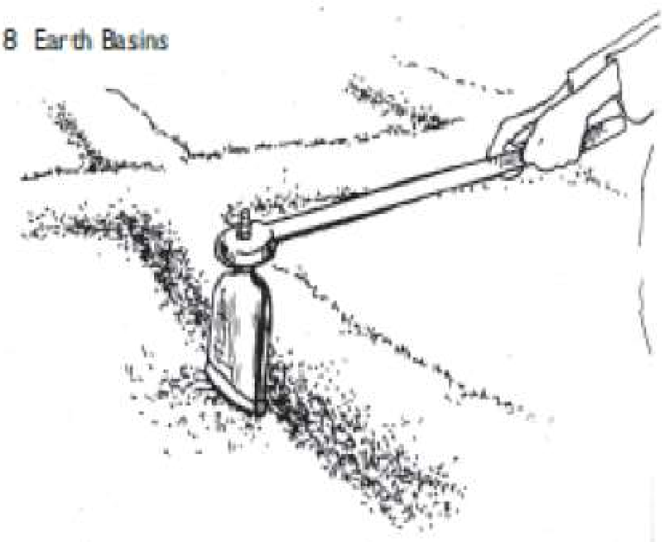


Planting Pits

Figure 7 Planting Pits

Earth Basins

Figure 8 Earth Basins



Semi-Circular Bunds

Figure 9 Semi -Circular Bunds [3]

Cover Crops/Green Manures

Figure 10 Cover Crops / Green Manures

Mulching

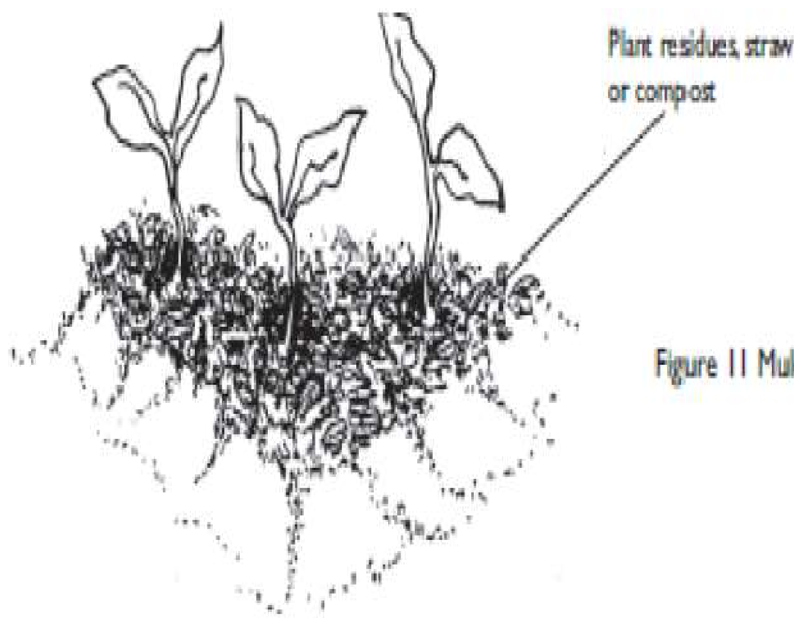
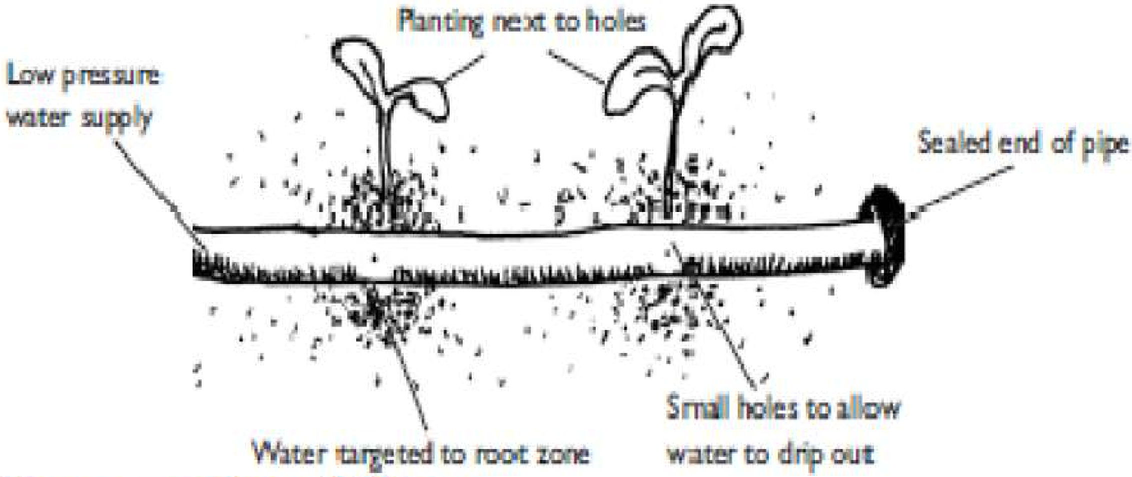


Figure 11 Mulches

Drip Irrigation

Figure 12 Drip Irrigation



Conservation Tillage

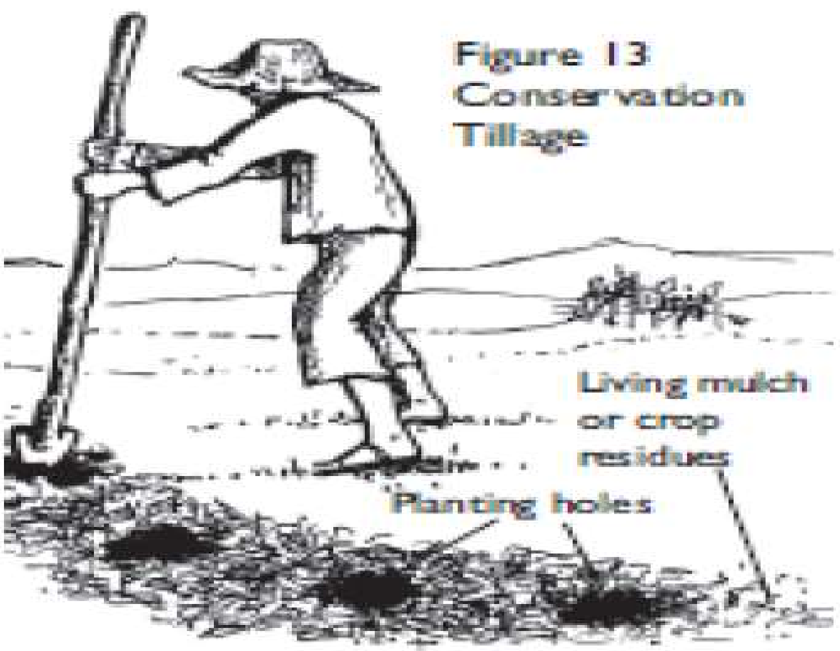
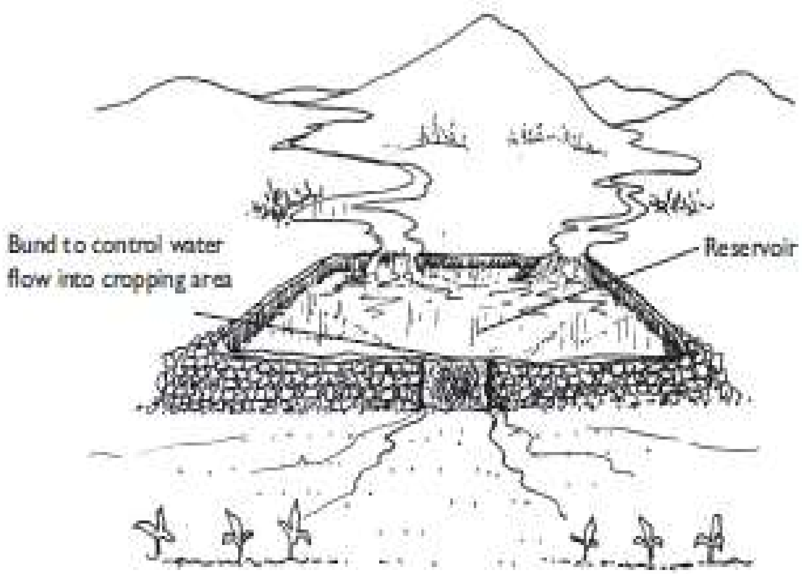


Figure 13 Conservation Tillage

7.2. Water Harvesting Techniques

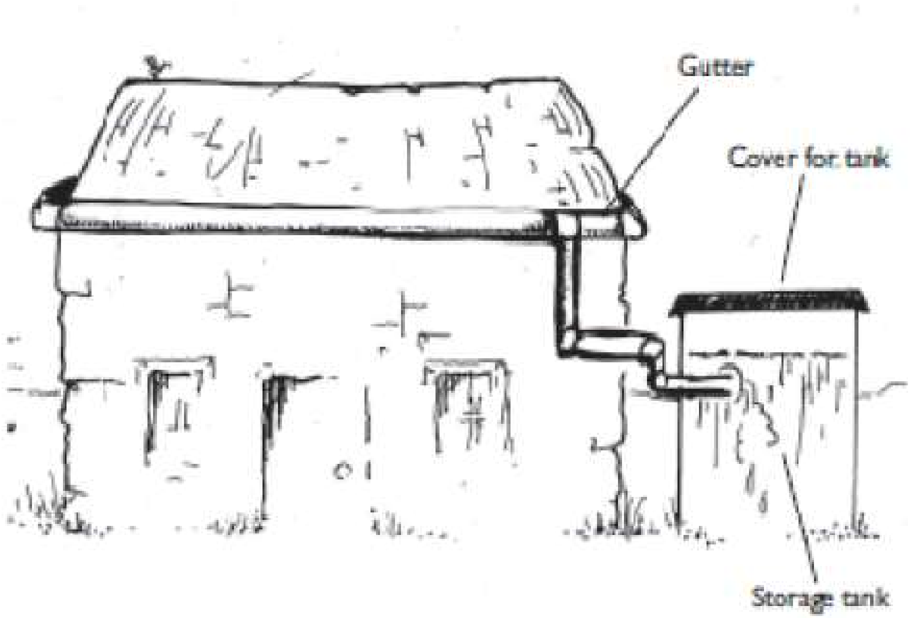
Water Harvesting from External Catchment

Figure 14 Water Harvesting from External Catchment



Roof Top Harvesting

Figure 15 Rooftop Harvesting



※ **Rainwater Harvesting**

Rainwater Harvesting is an effective method and a simple method of collecting water for future usage. Rainwater harvesting is the process of collecting, filtering, storing and using rainwater for irrigation and for various other purposes.

Rainwater is collected when it falls on the earth, stored and utilized for various purposes. It can be purified to make it into a drinking water facility in some islands and dry land regions.

Rainwater harvesting (RWH) is a simple method by which rainfall is collected for future usage. The collected rainwater may be stored, utilised in different ways or directly used for recharge purposes.

Techniques of Rainwater Harvesting

Rooftop rainwater harvesting (RTRWH) is the most common technique of rainwater harvesting (RWH) for domestic consumption. In urban and rural areas, this is most often practiced method at a small-scale. It is a simple, low-cost technique that requires minimum specific expertise or knowledge.

Rainwater is collected from the roof top and transported with gutters in to a storage reservoir, where it provides water at the point of consumption or can be used for recharging a well or the aquifer.

Collected rainwater can be the best supplement to other water sources when they become scarce or are of low quality like brackish water, saline groundwater or polluted surface water, in the rainy season.

The technology is flexible and adaptable to a very wide variety of geographic and geomorphic conditions. It is used in the developed and the developing societies.

Roof Top Rain Water Harvesting

Basic design principles

Each rainwater harvesting system consists of at least the following components:

- ※ A catchment area in the roof surface to collect rainwater.
- ※ A delivery channel (gutters) to transport the water from the roof or collection surface to the storage reservoir.
- ※ Storage tanks or reservoirs to store the water until it is used.
- ※ An extraction device (depending on the location of the tank).