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Overview
One of the main causes of food insecurity is thought to be environmental degradation particularly soil erosion. Therefore, rehabilitating the environment is very crucial if the PSNP dependant households are to be self reliant. Considering this fact most of the activities of PSNP’s PWs revolve around the biological and physical soil and water conservation activities.

By the end of this module you should learn that:
- What causes erosion and how?
- What can be done to reduce erosion?
- How to implement agronomic, biological and physical soil and water conservation techniques
- How to construct moisture conservation techniques
- How to conduct some simple laying out of soil and water conservation structures

Objective: To give participants clear picture of the processes of erosion, soil and moisture conservation techniques and procedures

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<td>Biological soil conservation techniques</td>
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<td>Explain the processes of gully erosion and control mechanisms</td>
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<td>To increase knowledge and skills of participants on runoff farming (in situ moisture harvesting) techniques</td>
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1 Processes of Erosion

Soil erosion is one form of soil degradation which refers to the decline in the soil’s capacity to support life due to various reasons; e.g. salinity, soil erosion, fertility exhaustion, compaction, chemical pollution, etc. Soil erosion is the process of removal of the top fertile soil from agricultural, grazing, forest or other land units.

1.1 Agents of Erosion

Close understanding of the processes of erosion will help us to design a proper conservation strategy and selection of appropriate measures. There are many practical problems in the field that is not given due emphasis for the clear understanding of the processes of erosion and its phenomenon.

Water, wind and gravity, in the order of their importance, are known as agents of erosion. It is to be noted that wind erosion occurs only during dry seasons in the absence of soil moisture. Fine tillage, cattle hoofs and people’s feet on traffic routes create favourable condition for wind erosion. Gravity can accelerate both water erosion and wind erosion. Broadly erosion can be classified in to two categories i.e. geological/natural erosion and accelerated erosion. Since this manual is prepared for highland areas it focuses on erosion by water.

1.2 Wind Erosion

1.2.1 Introduction

Wind Erosion processes includes the erosion, transport, and deposition of earth material owing to the action of wind. It is most pronounced in dry areas that lack effective ground cover in the form of solidly rooted, prevalent vegetation.

Wind erosion in some ways is less forceful than the erosive influence of water. Water, after all, can lift heavier and larger particles than can the winds. Wind, however, has a much greater frictional component in certain situations. This is particularly true when the wind carries sand, every grain of which is like a cutting tool. In some desert regions the bases of rocks or cliffs have been sandblasted, leaving a mushroom-shaped formation. The wind could not lift the fine grains of sand very high, but in places where it has been able to do its work, it has left an indelible mark.

In Ethiopia wind erosion is more pronounced in lowland areas inhabited by pastoralists and in the rift valley areas. Often the existence of wind erosion on fine textured soils is wavy structures on the surface as shown on the picture below.
Wind erosion physically removes the lighter, less dense soil constituents such as organic matter, clays, and silts. Thus it removes the most fertile part of the soil and lowers soil productivity (Lyles, 1975). This loss in productivity has been masked or compensated for over the years by improved crop varieties and increased fertilization being promoted by the Ministry of Agriculture and Sasakawa Global 2000. Thus wind erosion reduces potential soil productivity and increases economic costs. Blowing soil impacting plants can also reduce seedling survival.
and growth, depress crop yields, lower the marketability of vegetable crops, increase the susceptibility of plants to certain types of stress, including diseases, and contribute to transmission to some plant pathogens (Ambrust, 1982 and 1984; Claflin, et al., 1973; Michels et al., 1995). In the long run, the cost of wind erosion control practices can offset the cost of replanting a blown out crop. Some soil from damaged land enters suspension and becomes part of the atmospheric dust load. Dust obscures visibility and pollutes the air, it fills road ditches where it can impact water quality, it causes automobile accidents, fouls machinery, and imperils animal and human health (Skidmore, 1988). Wind erosion is a threat to the sustainability of the land as well as the viability and quality of life for rural as well as urban communities.

Wind erosion in Ethiopia is most widespread on agricultural land in the rift valley area, lowland areas inhabited by pastoralists and semi pastoralists such as Afar and Somali regions or Borena and South Omo zones. It is a major cause of soil degradation in arid and semiarid areas throughout the country.

1.2.2 Effects of Wind Erosion

Strong and sustained winds along with dry, bare soils contributed to serious soil loss. Wind erosion is the detachment, transportation and redeposition of soil particles by wind. The most familiar result of wind erosion is the loss of topsoil and nutrients which reduces the soil's ability to produce crops. Topsoil loss can be seen as rocky or gravelly knolls, thin soils mixed with lighter colored subsoil, or the presence of calcium carbonate in surface soils. Topsoil redeposition can be seen as raised fence lines, sand deposits and ditches filled with soil.

Soil productivity is affected by wind erosion in various ways. Areas of erosion and deposition within a field increase the variation in soil characteristics, requiring more costly and less efficient soil management practices. Wind removes the smaller clay particles and organic matter from the soil while coarser materials are left behind. The continued loss of fine particles reduces soil quality. In shallow soils and soils with a hardpan layer, wind erosion also results in decreased root zone depth and water-holding capacity. Such changes may occur slowly and go unnoticed for many years especially if mixing by tillage masks the effects of wind erosion.
1.2.3 Factors Influencing Wind Erosion

A sparse or absent vegetative cover, a loose, dry and smooth soil surface, large fields and strong winds all increase the risk of wind erosion.

Vegetation protects soil from wind erosion by reducing the wind speed at the soil surface. The vegetative cover can be improved by growing crop, standing stubble or other crop residues. Most soils require a 30 per cent ground cover to prevent wind erosion. In the case of cereal crop residues, this is equivalent to about 900 to 1100 kg/ha of residue. Highly erodible soils could require double this amount of residue.

Soil texture and structure also affect wind erosion risk. Loams, clay loams and silt loams are generally more resistant to aggregate breakdown, and thus are more resistant to wind erosion. Soil structure is the combination of individual soil particles into aggregates. Aggregates are heavier than individual particles and so are harder for wind to move. Organic matter helps to hold aggregates together and so soils with more organic matter are more resistant to wind erosion. Sandy soils are very susceptible to erosion. Clay soils which have been pulverized by human feet and animal hooves are easily eroded.

1.2.4 Wind Erosion Control by Crop and Pasture Management

One can reduce wind erosion and maintain production by maintaining a protective plant cover for the soil. The best way to conserve soil moisture and prevent wind erosion is to leave as much crop residue cover as possible during the fallow period. The crop residue cover reduces evaporation, and standing stubble traps dew for extra moisture. At the same time, crop residues reduce wind speed at the soil surface, and standing stubble anchors the soil.

To maintain a crop residue cover, some farmers choose to delay the first cultivation during the dry season until the beginning of the rainy season. Also, one may carefully weed so as not to disturb the residue cover.
Reducing or eliminating tillage will maintain a residue cover for erosion control with the added benefit of soil moisture conservation. If you decide to till an area prone to wind erosion make sure not to pulverize the soil.

Reduced or zero tillage systems must include crop residue management. Residue management starts at harvest by evenly spreading chopped straw and chaff over the entire width of the cut. Uniform spreading helps to reduce problems such as plugging in seeding equipment and uneven crop emergence. Avoid burning crop residues even immediately before cultivation. Burning destroys soil humus and organic carbon, and leaves soil prone to erosion.

Planting cover crops at the end of the rainy season could also provide some protection to the soil.

1.2.5 Shelterbelts

Field shelterbelts can provide extra protection against wind erosion no matter what cropping system is used. They are especially important in dry years when low crop yields result in insufficient residue cover.

Field shelterbelts reduce the wind velocity for distances up to 30 times the height of the trees. They also trap dew, increasing soil moisture and protect the crops from frost damage for increased crop yields. This yield increase helps to offset yield losses associated with taking land out of crop production for the shelterbelt plantings.

![Figure-4 Field shelterbelts reduce wind erosion and conserve soil moisture](image)

To get the maximum benefit from shelterbelts, one has to plan the design and species selection, site preparation, weed control for the first years, and pruning and other tree maintenance.

Shelter belts should be planted on the border perpendicular to the predominant wind direction. Shelter belts should not be completely air tight as this will lead to the development of eddies.
After about 20 times the height of the trees the wind velocity at the soil surface returns back to the original so belts should be spaced accordingly. Trees suited for shelterbelts are those species that are resistant to wind, as the velocity at the top is very high.

The main design requirements for shelterbelts are: spacing, length, shape, porosity and plant species. With the objective of maintaining the wind velocity at a maximum of 70% of the open wind velocity the following formula could be used to determine the spacing:

\[ \text{Spacing} = 17H \frac{(V_t)}{V} \cos \Theta \]

Where \( V_t \) = Critical threshold velocity for particle movement; 34km/hr

\( V \) = Actual velocity or design velocity which can be maximum velocity say once in so many years

\( \Theta \) = is the angle of deviation of the prevailing wind from the perpendicular line to the shelter belts

This formula assumes for a well managed and ideal shelter belts. But actual field observation and research has shown that they are not actually protecting for more than 12 to 14 times their height. The length of protection should be at least 24 times the height of the hedge. One should try to avoid breaks along the hedge line as this causes funnelling.

### 1.2.6 Emergency Control Measures

Wind erosion may still occur even if preventive measures are taken. Dry soil, poor residue cover from low-yielding crops, and persistent strong winds make controlling erosion a formidable challenge. Emergency controls are used when wind erosion is imminent or has started. Increasing the surface roughness of a field or covering the soil with straw or manure are the two basic emergency measures.

**Increasing surface roughness**

A rougher surface reduces wind speed at the soil surface so the wind is less able to move soil particles.

*Ripping clay soils*: Rough cultivation especially immediately after rain leaves clods on the surface. If the clods are likely to break down quickly, then the distance between passes should be about 5 m (15 feet). This way, the procedure can be repeated later on the untreated strip if necessary.
Ripping is an emergency measure to reduce wind erosion on clay soil.

Listing sandy soils:

Listing is used for sandy soils because they do not produce durable clods. Listing ridges the soil and brings up firmer subsoil. It must be perpendicular to the eroding wind, and should always start on the upwind side of the field. Treating the entire field will greatly reduce erodibility. Properly listed, the flat surface of a field can be changed so that ridges are 25 to 30 cm (10 to 12 in.) higher than the troughs, and about 90 cm (36 in.) apart. For listing to be successful, the shovels must be able to penetrate to a depth of 15 to 20 cm (6 to 8 in.).

Covering soil with manure or straw

Manure is preferred as a soil cover because it also enhances soil fertility and tilth. Depending on the soil, a rate of up to 30 tones/ha is required to protect the soil. Spread the manure evenly, and do not work it into the ground. Spreading straw at 2 to 4 tonnes/ha also protects eroding soil. The straw should be shredded, not used in small bales.

Wind erosion control measures also benefit crop and pasture production system by conserving soil moisture for better yields.
1.3 Physical Processes of Erosion by Water

Erosion by water involves two physical processes i.e. **detachment and transportation**. The detaching forces include:

- Raindrop/rain splash
- Flowing water
- Animal’s hooves
- Human activities such as cultivation
- Wetting and drying of the soil due to weather variations

In water erosion the main transporting agents/forces are: Surface and Sub surface runoff as well as gravity

1.4 Types of erosion

Erosion by water can be classified into raindrop erosion/splash erosion and wash erosion

a) Raindrop erosion/splash erosion: soil splashing is resulting from the impact of water drops directly on soil particles. There is tremendous energy involved in raindrop impact than in other forms of erosion (see Table 1). If a raindrop strikes a land covered with a thick blanket of vegetation, the drop breaks into a spray of clean water - it then slowly finds its way into soil pores. The soil cover in this case acts as an energy dissipating or absorbing agent. But if it strikes bare soil the falling drops break down soil aggregates and detach soil particles. The principal effect of splash erosion is detaching the soil. The number and size of drops and the velocity of drops determine the impact of raindrops per unit area. Large drops may increase the sediment carrying capacity. On the other hand, the velocity of raindrops is affected by its size, height of fall, wind velocity and air resistance. It has been observed that a single raindrop may splash wet soil as much as 60cm high and 150cm from the spot where the raindrop hits. Assume you are washing your hand on a bare soil and wearing white trousers. You would immediately see the splashing effect of the fine soil particles raised to a certain height on your trousers.

Continuous bombardment (Figure-7) in a rainstorm by raindrops causes damage by beating the bare soil into a flowing mud. The factors affecting the direction and distance of soil splash are: presence of wind, land slope, and soil surface conditions (vegetative cover and mulches)

As far as erosion by water is concerned splash erosion is the worst form of water erosion as it marks the beginning of erosion. Experimentally it has been discovered that the velocity of re-flushing (Rain drop) is much higher than the incoming velocity. That means the incoming velocity is 6 – 9m/sec while flashing or going back velocity is 12 – 18m/sec. This is due to the impacting action of the raindrop mass (m), free fall due to gravity and impacting on a bare soil.
Figure-7 A single raindrop impact under high speed photography is seen as an action of a bomb dropped from the airplane, hitting the ground and disintegrating into pieces.

Table 1. Efficiency of Forms of Water Erosion

<table>
<thead>
<tr>
<th>Form</th>
<th>Mass*</th>
<th>Velocity (ms⁻¹)</th>
<th>K. Energy †</th>
<th>Energy for Erosion ‡</th>
<th>Obsrd. Sed. Transport ¥</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raindrops</td>
<td>R</td>
<td>9</td>
<td>40.5R</td>
<td>0.081R</td>
<td>20</td>
</tr>
<tr>
<td>Overland flow</td>
<td>0.5R</td>
<td>0.01</td>
<td>0.000025R</td>
<td>0.00000075R</td>
<td>400</td>
</tr>
<tr>
<td>Rill</td>
<td>0.5R</td>
<td>4§</td>
<td>4R</td>
<td>0.12R</td>
<td>19000</td>
</tr>
</tbody>
</table>

*Assumes rainfall of mass R of which 50% contributes to runoff; † Based on 1/2MV²
‡ Assumes that 0.2% of the kinetic energy of raindrops and 3% of the kinetic energy of runoff is utilized in erosion
¥ Total observed on 19% slope, sandy soil, over 90 days. Most of the energy of raindrops contributes to detachment rather than transport.
§ Estimated using the Manning equation of flow velocity for a rill, 0.3m wide and 0.2m deep, on a slope of 11° (19%), at bank full, assuming a roughness coefficient of 0.02.

b) Wash Erosion: running water causes wash erosion. The erosive power of running water is related to the quantity and velocity of flow. The velocity increases with the depth of water.

  a. Forms/stages of erosion
  Based on the nature and extent/form of soil removal, wash erosion is classified as:
  i. Sheet erosion
i) **Sheet erosion**

Sheet erosion is the removal of a fairly uniform layer of soil from the land surface. This type of erosion is extremely harmful to the land as it selectively transports the fertile top soil. It is usually so slow that farmers are not conscious of its existence. It is common on lands having a gentle slope. Areas where loose, shallow topsoil overlies a tight sub-soil are most susceptible to sheet erosion. The following indicators depict the existence of sheet erosion is taking place: exposed roots, exposed stones, Deposits of eroded soils at bottoms of slopes, mixing up of sub soil with topsoil and gradual decline of crop yields.

![Figure-8 Typical example of total topsoil removed by erosion –Harla – Dire Dawa, Ethiopia](image-url)
Please note that the roots depict the original top soil layer

ii) Rill Erosion

Rill erosion is the removal of soil by running water forming shallow channels (<30cm depth) - “Maresha”. It can be smoothed out completely by normal cultivation operation. But if the rills can’t be obliterated by normal cultivation i.e. “Maresha” the rill is said to have grown to the next stage called gully erosion. This progress of rill erosion hinders the movement of farm implements, reduces the actual area under crops and results in declined crop yield. Rill erosion is more serious in soils having loose shallow topsoil. It may be regarded as a transition stage between sheet erosion and gullying (Figure-9).

Figure-9 Rill erosion on the way to gully – Hintalo Wajirat

iii) Gully Erosion

Gully erosion is the removal of soil by running water. Gully channels cannot be smoothed out completely by normal cultivation. It is an advanced stage of rill erosion. It is associated with accelerated and concentrated overland flow. Cattle trafficking lines, foot paths, earth tracks, dead furrows, tillage furrows, or other small depressions down a slope favour concentration of water. Gullies apart from removing fertile soil they are the major causes of sucking and transporting it away soil moisture and groundwater. Where there are gullies it is difficult to
sustain hand dug well, and springs. Gullies also hinder cultivation operation and accessibility (Figure-10). Runoff leaving culverts and bridges if not taken safely to the final natural water course causes gully immediately on the downstream side of the road.

![Gully erosion on the way to Shone (SNNP)](image1)

**iv) Stream Bank Erosion**

Under cutting, sliding, slumping, collapsing stream banks, land slide and mass movement are scenarios of stream bank erosion. Piping and saturated pore water pressure can also lead to gully and stream bank erosion (Figure-11).

![Stream bank erosion combined with piping and land slumping](image2)
1.5 Factors Influencing Erosion by Water

**Climate:** The most important climatic factor influencing erosion by water is rainfall characteristics. The ability of rainfall to cause erosion is referred as erosivity. Intensity, amount, duration, and frequency of rainfall can directly affect rainfall erosivity.

In high intensities, rate of rainfall exceeds infiltration capacity of soils; thus increasing the overall overland flow or flood. When rainfalls are too frequent, the soil is always nearly saturated and can absorb less water; hence, there will be more runoff and more erosion. On the other hand, if the soil has a chance to dry between showers it can absorb more water.

**Topography:** the degree of slope and the length of slope are the two main features of topography affecting erosion. The steepness of a given land influences the rate of soil erosion because water accelerates over steeper slopes and carries more soil than water running off over gentle slopes. Also due to gravity influence, rainwater will not have enough time to infiltrate into the soil. Therefore, in general, the steeper the slope of the land, the greater will be the amount of runoff, and the higher will be the velocity of the runoff. If the land slope is doubled, the velocity of flow is increased approximately four times.

Experiments have shown, when the velocity of runoff is doubled, the amount of material of a given size that can be carried is increased about 32 times: and the size of particle that can be transported by pushing or rolling is increased about 64 times. Hence, carrying capacity of the runoff, for both larger quantities and bigger particles of soil gets too high. The length of slope is also another important factor as more runoff water accumulates with an increase in slope length.

**Soil:** we know from observation that the same storm causes more erosion on one field than on the other. This is due to the differences in soil erodibility, which is the vulnerability or susceptibility of soil to erosion. The soil properties influencing erosion by water are the infiltration rate of soil and the resistance of soil to dispersion during rainfall and runoff. Texture and structure of a soil influence the infiltration rate and resistance to splash and wash erosion. Moreover, soil depth also affects erodibility as the infiltration rate is also affected by it.

**Vegetation Cover:** a good vegetative cover, at least 20-40 percent of the ground cover, can nearly avoid erosion due to the effects of climate, topography and soil erosion. The following are the major effects of vegetation on soil erosion:

- Interception of raindrops
- Decreasing runoff velocity
- Root effects
- Biological influences
- Transpiration effects

**Man Induced Factors:** the activity of human beings to fulfil different purposes can induce soil erosion danger. Some typical examples are:
Overgrazing of grasslands
Cleaning of the vegetation cover.
Poor farming system e.g. ploughing up and down
Removal of crop residue and animal dung from farm fields.
Badly designed and constructed culverts, canals, drains, etc.
Badly sited paths, roads and cattle tracks.
Badly designed and constructed conservation measures.

The major factors affecting water erosion can be summarized using the following descriptive equation:

\[ A = f(R, K, L, S, C, P) \]

Where,
- \( A \) = Rate of erosion
- \( R \) = Rainfall Erosivity
- \( K \) = Soil erodibility
- \( L \) = Slope length
- \( S \) = Slope gradient
- \( C \) = Land cover
- \( P \) = Management practice

Table 2. Universal soil loss equation: \( A = R \times K \times L \times S \times C \times P \) (Tons/ha/Year) adopted for the Ethiopian condition

<table>
<thead>
<tr>
<th>Erosivity</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Annual Rainfall</strong></td>
<td></td>
</tr>
<tr>
<td>mm</td>
<td>100</td>
</tr>
<tr>
<td>Factor (Annual)</td>
<td>48</td>
</tr>
<tr>
<td><strong>Soil Erodibility</strong></td>
<td>K</td>
</tr>
<tr>
<td><strong>Soil Color</strong></td>
<td>Color</td>
</tr>
<tr>
<td>Factor</td>
<td>0.15</td>
</tr>
<tr>
<td><strong>Slope Length</strong></td>
<td>meter</td>
</tr>
<tr>
<td>Factor</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Slope gradient</strong></td>
<td>%</td>
</tr>
<tr>
<td>Factor</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Land Cover</strong></td>
<td>C</td>
</tr>
<tr>
<td>Dense forest</td>
<td>&quot;</td>
</tr>
<tr>
<td>Other forest</td>
<td>&quot;</td>
</tr>
<tr>
<td>Badland (Hard)</td>
<td>&quot;</td>
</tr>
<tr>
<td>Badland (Soft)</td>
<td>&quot;</td>
</tr>
</tbody>
</table>
Equation: $A = R \times K \times L \times S \times C \times P$ (Tons per ha per Year) – adaptation of USLE to Ethiopian Condition (Hurni 1985b)

<table>
<thead>
<tr>
<th>Erosivity</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum, maize</td>
<td>0.10  Ethiopian Teff 0.25</td>
</tr>
<tr>
<td>Cereals, pulses</td>
<td>0.15  Continuous fallow 1</td>
</tr>
<tr>
<td>Management P</td>
<td></td>
</tr>
<tr>
<td>Up/down plowing</td>
<td>1 Contour plowing 0.9</td>
</tr>
<tr>
<td>Strip cropping</td>
<td>0.8 Intercropping 0.8</td>
</tr>
<tr>
<td>Applying mulch</td>
<td>0.6 Dense intercropping 0.7</td>
</tr>
<tr>
<td>Stone cover (80%)</td>
<td>0.5 Stone cover (40%) 0.8</td>
</tr>
</tbody>
</table>

The erosion factors stated above (Table 2) contain two types of variables, those that can be controlled and those that are directly uncontrollable. Climate, slope and certain physical characteristics of the soil cannot be directly controlled. Their effects, however, can be modified indirectly. For example, the use of bunds and terraces can reduce the length of slope.

## 2 Principles of Soil and Water Conservation

### 2.1 Defining Conservation

Soil conservation can be defined as the proper utilization of the soil resource to ensure sustained production. Soil conservation endeavours to maintain sustained level of production by keeping soil loss below a threshold level i.e., the natural rate of soil formation. Different practices have been developed to accomplish soil conservation work, though not all of them are applicable in all regions. Yet, the principles on which the practices are based are the same everywhere.

These principles are:
- Reduce raindrop impact on the soil
- Reduce runoff volume and velocity
- Reduce wind velocity and
- Increase the soil resistance to erosion

All the practices that affect one or more of the above principles and help to minimize erosion hazard can be summed up as follows.

The main aims and objectives of soil conservation are: controlling erosion, maintaining soil fertility and productivity, reducing offsite impacts such as sedimentation and water quality deterioration as well as improve the soil conditions such as salinization, water logging, nutrient depletion, degradation of soil structure as well as pollution.
2.2 Proper Land Use

The combination of different types of soil, the varying slopes and all the variations of climate are endless. These three factors make the difference in sorts of land and types of use to which the lands are best suited. The use of land to which the land is best suited in terms of its sustainable utilization, is defined as the capability of land. Proper land use is using each piece of land within its capabilities. Practicing proper land use is the first and most important step in soil conservation. Grouping land into different kinds according to their most intensive safe use, their management requirements and their permanent limitations is called Land Capability Classification.

2.3 Adapting Conservation Measures to Local Situation

There is no single approach to soil and water conservation that is best suited to all situations. The main biophysical and socio-economic factors to be considered when making recommendations on conservation are:
- Climate
- Soil characteristics
- Slope
- Farming system
- Conservation tradition of the community
- Availability of labour and construction materials

Based on the above biophysical and socio-economic conditions major areas of soil conservation can be clustered into:

Soil Management: this includes several improved practices of soil management through which maintenance of soil structure and fertility can be assured. These include:
- Appropriate tillage practices - e.g. conservation or minimum tillage, etc.
- Application of organic manure and mineral fertilizer, manure etc.
- Mulching and the use of crop residues
- Contour ploughing

Biological or Agronomic Soil Conservation Measures: biological soil conservation measures include those practices which:

a) Help to maintain soil in a high state of fertility and in good physical conditions. This helps to increase the absorption of rainwater where it falls and prevents the accumulation of water on the surface;

b) Put soil under good surface cover, because erosion, especially water erosion, often takes place when rain falls on bare soil and then moves over the surface as a runoff.

Physical Soil and Water Conservation Measures: physical or mechanical conservation measures are those practices, which call for the construction of some kinds of earthwork. They
are usually needed to dispose-off excessive storm energy safely and/or to assist infiltration of soil. Physical conservation measures are not ends in themselves; they are only aids to proper land use and biological conservation measures. Physical or mechanical protection works are expensive, time consuming and dangerous at times of failure. Thus, they should be considered only where other conservation practices cannot provide adequate control.

3 Biological Soil and Water Conservation

3.1 Introduction

This biological conservation measures training material is developed with the aim of providing detail information on the application of biological soil and water conservation practices. The biological soil and water conservation practices and techniques discussed in this section are expected to be implemented in an integrated and combined manner with the physical conservation measures based on the watershed development approach. The staffs engaged in natural resources management are strongly advised to carefully select and adapt the recommended biological conservation measures to the specific conditions of their areas.

Biological soil and water conservation measures are categorized: (1) Agronomic measures, which include soil and crop management practices that could help in controlling surface runoff, reduce soil losses and improve soil fertility; (2) Vegetative measures including agroforestry and forestry and (3) area closure.

This module has four main parts. Part one mainly deals with this introduction section where role and principles of biological conservation, types of biological conservation measures are discussed in depth with their objectives, design and management aspects. Part two covers agronomic conservation measures followed by part three that deals with the agroforestry practices and techniques for soil and water conservation and forage development. In part four the main emphasis is given to tree seed collection, handling, processing and storing, sowing and nursery management and cares that should be taken at the time of seedling transportation, planting and subsequent management practices at the permanent planting sites.

3.1.1 Role of Biological Conservation Measures

- Biological soil and water conservation measures include:
  - agronomic practices,
  - vegetative measures and
  - area closure
- Biological SWC measures are recommended to be used in combination with physical SWC;
- SWC practices are one of the priority focus areas to improve production and productivity;
- In the past, more emphasis was given to physical soil and water conservation measures;
- Considering the gaps biological SWC practices are getting more attention currently;
- Biological SWC practices are not new to Ethiopia, existing within the old farming systems;
• Appropriate biological measures need to be selected & integrated with physical SWC measures;
• SWC will be more effective when applied timely and properly implemented;
• Soil erosion can be prevented easily at the initial stage by efficient management;
• Preventive measures need to be applied timely to reduce soil erosion adequately.

3.1.2 Benefits of biological conservation measures

Biological SWC measures have the following advantages:

- Provide plant covers on the land to prevent direct impact of raindrops and reduce soil splash,
- Increase soil roughness, which further reduce the velocity of surface runoff and reduce soil erosion,
- Reduced surface runoff facilitates infiltration rates and enhance in-situ water conservation,
- Better accumulate soil particles by reducing and protecting soil particles from being washed away,
- Produce biomass on the land, which could be used as source of food, fuel wood and fodder,
- Increased SOM improve properties of soil, reduce soil erosion and improve soil fertility,
- Biological SWC measures are simple, inexpensive and part of regular land management practices,
- Biological SWC measures can bring immediate benefits to users in a short time on a large area,
- Reduce pollution and provide clean environment and
- Prevent soil erosion and enhance effectiveness of physical measures when applied properly.

3.1.3 Points to be considered in effectively implementing BCM

In properly implementing biological conservation measures the following points need to be considered:

- The communities can play significant role in selecting appropriate conservation practices;
- Focus on techniques and technologies, which are well accepted and tested by the communities;
- Develop appropriate strategies for their multiplication and distribution of quality planting materials;
- Integrate biological conservation measures with physical soil and water conservation structures;
- Establish close M&E systems to monitor and evaluate the effectiveness of BCM and
3. Identify gaps to be considered in designing appropriate strategies for implementation of BCM;

- Periodically update recommendations based on field experiences and new research findings.

3.2 Agronomic Conservation Practices

Agronomic measures are practiced to enhance the benefits of physical SWC measures. It is through an integrated approach a more sound and successful soil and water conservation measures could be applied and obtained the maximum output. The agronomic conservation measures are effective on gentle slopes of up to 9%. Reduction in runoff is achieved by appropriate selection of crops, proper land preparation (conservation tillage & contour ploughing), mulching, green manuring, application of manures, fertilizers and appropriate cropping systems (include crop rotation, intercropping, alley cropping, stripe cropping, ley cropping and double cropping).

The main objective of implementing agronomic practices is to contain soil degradation by proper tillage practices and producing optimum biomass for increasing productivity per unit of land while reducing soil erosion and consequently maintaining soil fertility.

As it has been explained above agronomic measures include soil and crop management practices. Of which the following are considered as part of soil management practices:

- Conservation-based land preparation: conservation tillage and contour ploughing,
- Implementing of soil and water conservation practices on farmlands,
- Improve soil organic matter content and soil fertility management practices,
- Improve soil fertility and management through manuring, fertilization and crop rotation,
- Promote water harvesting practices to enhance moisture availability to crops

The following are improved crop management practices:

- Growing of various crops such as food crops, fodders, vegetables, fruits and multipurpose trees with the objective of meeting the human needs and simultaneously prevent soil erosion;
- Establishing various cropping systems that maintain soil fertility and reduce crop yield losses, due to insect pests and diseases;
- Planting of crops across the contour;
- Maintaining proper planting time and depth;
- Maintaining optimum plant population and density;
- Application of appropriate pest control practices, such as integrated pest management,
• Practicing crop rotation including legume crops,
• Application of irrigation water for better crop establishment and optimum crop yields,
• Maintaining proper harvesting procedures, cleaning and good storage facilities and
• Reducing post- harvest losses, due to improper handling during transportation and storage.

Biological soil and water conservation measures are categorized:

(1) Agronomic measures;
(2) Vegetative measures including agroforestry and forestry;
(3) Area closure.

• Agronomic measures have to be considered in integration with biological and physical measures;
• BCM in combination with physical SWC measures can bring maximum output;
• The agronomic conservation measures include:
  ✓ appropriate selection of crops,
  ✓ proper land preparation (conservation tillage & contour ploughing),
  ✓ mulching and cover/green manuring,
  ✓ application of organic and inorganic fertilizers in a more integrated manner and
  ✓ establishing of appropriate cropping systems (include crop rotation, intercropping, alley cropping, strip cropping, ley cropping and double cropping).

The main objective of implementing agronomic practices is to:
• increase biomass and productivity per unit of land and reducing the impact of raindrops through interception and thus reducing soil erosion;
• increasing infiltration rates and thereby reducing surface runoff and soil erosion;
• reducing soil erosion and ultimately improving soil structure and maintains soil fertility;

• careful planning of soil and crop management practices is essential to ensure their effectiveness;
• agronomic measures need to be implemented in combination with biological and physical SWC.

As part of agronomic measures the following are the main soil management practices:
• Conservation- based land preparation: conservation tillage and practicing contour ploughing,
• Implementing of soil and water conservation practices on farmlands,
• Improve soil organic matter content and soil fertility management practices,
• Improve soil fertility and management through manuring, fertilization and crop rotation,
Promote water harvesting practices to enhance moisture availability to crops and other vegetation.

The following are also included as part of improved crop management practices:

- Growing of various crops to meet the human needs and prevent soil erosion,
- Establishing various cropping systems to maintain soil fertility and reduce crop yield losses,
- Practicing planting of crops across the contour, including row planting,
- Maintaining proper planting time and depth,
- Maintaining optimum plant population and density,
- Application of appropriate pest control practices, including integrated pest management,
- Maintaining of crop rotation including growing of legume crops in the rotation cycle,
- Application of irrigation water if available for better crop establishment and optimum crop yields,
- Maintaining proper harvesting procedures, cleaning and good storage facilities and
- Reducing post- harvest losses, due to improper handling during transportation and storage

3.2.1 Conservation Based Tillage Practices

Conservation tillage

- Conservation tillage is implemented in steep areas susceptible to soil erosion;
- Land preparation is aimed at creating favourable condition for good seed germination;
- Conservation tillage is aimed to reduce tillage operations and initiate reduce compacting of soils;
- Conservation tillage includes zero tillage, minimum tillage for controlling soil degradation and improving soil productivity.

Definition of some terminologies

- Zero tillage is a practice where farm land is left untilled and furrows are opened at planting,
- **Minimum /reduced tillage** is a tillage practice where minimum tillage operation is maintained to break up hard pans to increase infiltration and water holding capacity of soil and to minimize resistance to root development;

- **Mulch tillage** is a tillage operation, which follows the principles of least soil disturbances and maintaining of maximum crop residues on the field to reduce soil erosion and improve soil fertility.

**Contour cultivation**

- Contour farming (e.g., performing farm operations across the contour to reduce soil erosion;

- Contour cultivation and planting/sowing along the contour are recommended agronomic practices and techniques in order to reduce runoff and to enhance infiltration and reduce runoff;

- Contour cultivation practice in dry areas can be adjusted to standard opened and ridged furrow system to make it effective to control erosion and conserve moisture;

- Ridging is a widely used tillage practice for SWC in dry areas and this practice can be performed by using tie ridger and/or using wide spaced local sole for opening and tying up of ridges;

- Contour farming alone is not sufficient to control erosion on steep, long slopes, erodible soils and during erosive rains and these need to be supplemented with physical SWC practices;

- In high rainfall and steep slopes, land preparation needs to be carried out with reduced frequency in order to improve accumulation of organic matter, reduce soil erosion and improve its fertility.

- Careful soil cultivation can improve the soil’s capacity to retain water, its aeration, capacity of infiltration, warming up and reduce evaporation.

Soil conservation based land preparation has different benefits and among others includes:

- Reducing soil erosion caused by rain water and wind;

- Reducing erosion hazards using different physical soil erosion prevention methods;

- Rehabilitating of eroded land and then use for cultivation;

- Increasing alternatives for growing of different crops;

- Improving soil moisture utilization;

- Increasing soil organic matter and ultimately improved soil structure;

- Improving soil fertility as a result of increased organic matter and

- Adjusting soil temperature to more favourable conditions.
The principal aim of soil cultivation using local maresha or mouldboard is to make a flat turning of the top soil and loosening of the medium deep soil without mixing soil layers and maintaining the soil structure.

Key
A- Stilt
B- Sheath
C- Sole
D- Share
E- Shealth
F- Leather strap
G- Beam

Figure 12 The Ethiopian ard plough, which is called locally “Maresha” and its parts

### 3.2.2 Soil Fertility Improvement and Management

Soil fertility improvement and management is a practice of applying a set of soil management practices that could restore soil fertility and enrich the soil with additional essential plant nutrients, which are required to support the normal growth and development of crop plants combined with the knowledge on how to adapt these management practices with the local conditions, aiming at maximizing the agronomic use efficiency of the applied nutrients and increasing crop productivity and production on a sustainable basis.

The main guiding principles of soil fertility management are: (i) Replenishing soil nutrient pools by adding back organic and inorganic fertilizers; (ii) Maximizing on-farm recycling of nutrients - maximize use of organic materials; (iii) Reducing nutrient losses to the environment - minimizing losses of water and nutrients and (iv) Improving external input use efficiency through improved crop management practices.

Soil fertility management include:

- crop rotation,
- composting,
- green manuring,
- farmyard manure,
- mineral fertilizers
- management of soil organic matter (including crop residue management - mulching) and
- efficient management of these practices with improved other agronomic practices.

Immediate advantages of using inorganic fertilizers:

- Inorganic fertilisers have an immediate effect and quickly release nutrients to the plant;
- Uptake of nutrients from chemical fertilisers is more efficient and offer large amount of nutrients;
- Chemical fertilizers can lead to an impressive increase in yields;
- Chemical fertilisers will also increase soil organic matter through increasing plant biomass;
Roots and crop residues left as mulch will contribute to improve the soil organic matter balance; 

Increased fertiliser use can also improve water use efficiency and the vice versa.

Chemical fertilizers have the following negative impact on soil and plant health:

- About 50% of nitrogen fertilizer usually gets lost through runoff, leaching, and volatilization;
- Increased supply of nitrogen leads to susceptible nature of plants to pest attack;
- Chemical fertilizers reduces colonisation of plant roots with the beneficial root fungus mycorrhiza;
- High nitrogen fertilization stops symbiotic nitrogen fixation by rhizobia bacteria;
- Exclusive use of NPK- fertilizers leads to depletion of micro- nutrients in the soil;
- Chemical fertilizers can bring potential side effects to human health aspects;
- Decomposition of SOM enhanced, which leads to increased rate of soil degradation;
- Due to runoff and leaching effects of nitrogen ground water may become polluted.

In comparison with chemical fertilizers, the following are advantages of using organic fertilizers:

- The supply of nutrients is more balanced, which helps to keep plants healthy;
- Soil biological activity is enhanced, which improves nutrient mobilisation;
- Mycorrhiza colonisation is enhanced, which improves the supply of phosphorus;
- Compost has the potential to suppress soil borne pathogens, when applied to the soil;
- Due to improved soil structure root growth is enhanced;
- Humus improves the exchange capacity of nutrients and avoids soil acidity.

In principle, there are 16 plant elements that have been recognized as essential nutrients for normal crop growth and development. Carbon, hydrogen and oxygen are derived from the air and water and considered as non- mineral form of elements essential for crop growth. However, of the major soil nutrients Nitrogen, Phosphorus and Potassium are used in large quantities by the plants, which are called primary nutrients, whereas Ca, Ma and S are required relatively in smaller but appreciable quantities and hence named as secondary nutrients. In addition, Fe, Zn, Mn, Co, B, Mo and Cl are needed in small quantities and are called as micro- nutrients/ trace elements. In addition, there are also some beneficial elements required by plants such as Nickel, Selenium, Cobalt, Iodine, Aluminium, Silicon, etc. The main objective of inorganic and organic fertilizers application to the soil is therefore, to add these nutrients to the soil, which are essential for crop growth and development and obtained optimum crop yields.

The most common soil fertility management practices recommended as part of integrated crop management practices and have roles in reducing soil erosion are discussed in more details hereunder.
3.2.2.1 Mulching/Crop Residue Management

Mulching is the process of covering the topsoil with plant materials such as leaves, grass, twigs, crop residues, straw, and the like. These mulching materials are spreading over the ground between rows of crops or around the trunks of trees. This practice helps to retain soil moisture, prevents and suppresses weed growth and enhances the activity of soil organisms such as earthworms that have the potential to create a good soil structure, which encourages infiltration of rainwater and thus, reducing surface runoff. In addition, as the mulch material decomposes, it increases the content of organic matter in the soil. Soil organic matter in its turn helps to create a good soil with stable crumb structure. Thus, the soil particles will not be easily carried away by the runoff water. Therefore, mulching plays a crucial role in preventing soil erosion and for the control of weeds and to some extent in improving soil fertility. Mulching reduces soil loss considerably by protecting the soil from direct impact of raindrops and reducing the sediment carried with the runoff water. A minimum plant residue ground cover of 30% is necessary to keep runoff and soil loss to the minimum within acceptable limits.

The choice of materials for mulching mainly depends on the availability of the materials locally and the cost of the materials. In some places, materials such as plastic sheets are used for covering the soil, particularly for growing of high value crops (plastic sheets are used mainly in developed countries for the growing of high value vegetable crops). However, in Ethiopian condition, particularly under subsistence farming, mulching refers only to the use of organic, degradable materials and more preferred to use locally available materials. As it is discussed earlier these mulching materials can be cuttings from hedges, pruned materials from trees, weeds, grasses, cover crops, crop residues such as pineapple tops, maize stover, wheat straw, and wastes from agro-processing plants such as coffee pulp, and forestry by-products, which can be used locally without transporting them long distances. This will significantly reduce transport cost.

![Figure-13 Crop residue management /mulching/](Source: SCW Guideline, MoA, 2001, Addis Ababa)

The following are limitations of mulching:

- It serves suitable habitat for crop pests and diseases such as snails, ants, termites, stalk borer, etc;
Limited availability of organic materials locally, which are suitable for mulching;
- Collection and preparation of mulching involves labour and may compete with production of crops;
- Some grass species that can be used for mulching can develop root and become a weed problem;
- Carbon rich mulching materials such as straw or stalks may enforce micro-organisms to use nitrogen from the soil for decomposition, which can deplete plant available nitrogen;
- Not applicable in wet conditions, due to aggravation of insect pests and diseases;
- Suited to areas with limited or irregular rainfall;
- Farmers are used to burning crop residues instead of returning them to the soil.

3.2.2.2 Crop Rotation

Problems of mono- cropping
- mono- cropping leads to depletion of nutrients at the same soil depth;
- due to mono- cropping crop yields decline significantly;
- mono- cropping encourages building up of soil borne diseases and insect pests;
- Weeds can compete for light, nutrients and moisture and may spread and control will be costly.

What is a crop rotation?
- Crop rotation is a practice of growing different crops one after another on the same piece of land.
- Crop rotation is one of the oldest agronomic practices to maintain sustainable crop production.
- Crop rotations are fundamental to sustainable cropping systems.
- Crop rotation system creates farm diversity and improves physical soil conditions and fertility.
- But in Ethiopia crop rotation practice is limited, due to know-how and limited availability of land.

The basis for adopting crop rotation- based farming systems are:
- High cost of off-farm inputs,
- The growing incidence of pesticide and fertilizer contamination of water sources,
- The increasing resistance of certain weeds and insects to pesticides,
- Soil conservation requirements for farm programs, and
- Surplus production of major crops.

Benefits of crop rotation
- Prevents soil erosion
- Crop rotation maintains soil fertility
- Reduces soil erosion
Diversifies crop production
It inhibits the growth and spread of crop pests, including weed infestation
Helps sustain crop production
Reduces nutrient drain
Promotes income diversities
Improves soil and water utilization
Improves organic matter content of the soil, which improves soil structure, reduce soil erosion & improve soil fertility
Improves crop quality and yields
It serves as a management tool for conservation-based agriculture
It reduces dependency on chemical pesticides and associated costs.

In planning crop rotation system the following factors need to be taken into account:

- **Agro-climatic consideration:** Soil, climate & rainfall are major factors for establishing crop rotation.
- **Farmers’ preferences:** Farmers have their own preferences in terms of crop values to food security and other purposes such as for fodder, oils, and vegetables for sale and home consumption.
- **The role of crop in improving soil fertility:** Legumes and other crops with different rooting characteristics should be rotated with shallow rooted ones.
- **Marketing value of crops:** Crop rotation is a practice strongly influenced by economic factors.
- **Nature of resistant to diseases and insect pests:** Crop rotation prohibits crop diseases and pests.
- **Availability of seeds and other inputs:** Availability of seeds is very crucial for the crops to be considered in the crop rotation cycle, including other inputs such as fertilizers and chemicals.

Farmers are advised to apply:

- Crop rotation needs to be applied in integration with improved crop management practices such as:
  - moisture retention,
  - fertility management,
  - fertilizer application and
  - manure application.
- Rotate legumes with cereals and compost applications;
- Incorporate forage legumes to reduce removal of crop residues and improve animal feeding.

**Sample crop rotation guide**

- In five years rotation cycle recommended to grow potato; onion and garlic or leeks; legumes; vegetables like cabbage, cauliflower, and broccoli and root vegetables like carrot, beetroot.
Y1: onions, Y2: legumes (peas, beans) or brassicas such as cauliflower, cabbage and broccoli, on third year tomatoes, eggplant, capsicum (pepper), and on the fourth year sweet corn, cucurbits.

In a 6 year rotation: Year 1: Legumes; Year 2: Brassicas; Year 3: Root crops, carrots, potatoes; Year 4: Corn, cucurbits; Year 5: Tomatoes, capsicums, eggplant and Year 6: Green manure crop.

Table 3. Recommended crop rotation cycle for vegetables

<table>
<thead>
<tr>
<th>Production year</th>
<th>Crop rotation cycle per field blocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Onion Cabbage Tomato Swiss Chard Beans, green Onion</td>
</tr>
<tr>
<td>2</td>
<td>Cabbage Tomato Swiss Chard Beans, green Onion Cabbage</td>
</tr>
<tr>
<td>3</td>
<td>Tomato Swiss Chard Beans, green Onion Cabbage Tomato</td>
</tr>
<tr>
<td>4</td>
<td>Swiss Chard Beans, green Onion Cabbage Tomato</td>
</tr>
<tr>
<td>5</td>
<td>Beans, green Onion Cabbage Tomato Swiss Chard</td>
</tr>
<tr>
<td>6</td>
<td>Onion Cabbage Tomato Swiss Chard Beans, green Onion</td>
</tr>
</tbody>
</table>

Furthermore, the recommended crop rotation pattern in different agro-climatic zones:

- In wet and moist dega agro-climatic zones: Barley – horse beans/peas – wheat – short improved shallow with vetch, lupins or tree lucerne, then back to barley.
- In wet and moist weyna dega agro-climatic zones: Barley– chick pea or other food legume– wheat– improved fallow with sesbania sesban, vetch, alfalalfa, or tree lucerne,
- In kola and dryland: Sorghum + mung bean – teff – chick pea – maize + haricot bean.

Exercise 1:

Develop a crop rotation system for your specific area by taking into consideration the following facts:
(i) Consider major cereal crops, (ii) Identify major legume crops (iii) Include vegetables in the rotation cycle

3.2.2.3 Organic fertilizers and their application

- Organic fertilizers are fertilizers prepared from naturally existing organic materials;
- Organic fertilizer improve soil structure and soil aeration;
- Organic fertilizers primarily include:
  (i) Manures;
  (ii) Green manures and
  (iii) Compost.
Organic fertilizers increase the content of SOM and increases resistant of the soil from being detached and easily washed away by surface runoff and reduces soil erosion.

As it is explained above organic fertilizers, in addition to supplying of soil nutrients required by plants, they play a significant role in improving soil structures, which ultimately improves water holding capacity and soil aeration. Furthermore, organic fertilizers have the potential to increase the content of soil organic matter, which increases the resistant of the soil particles from being detached and easily washed away by surface runoff and consequently reduces soil erosion and regulating the soil temperature for plant growth.

In line with this the major sources of organic fertilizers are discussed in more detail hereunder.

1) **Manure preparation and its application**

- Farmyard manures (animal manures) are the most commonly used form of organic fertilizers;
- Manures are breaking down quickly, which makes them valuable as fertilizers for crops;
- Properly collected, stored and applied animal manures can maintain the soil fertility of the land.

**Limitations:**

- Farmyard manure is dried up and burned for cooking, or not recognized as a source of nutrients;
- Livestock management system is loose and kept in places where not appropriate for collecting;
- By drying or burning of farmyard manure, large quantities of organic matter and nutrients are lost;
- Nutrient content of manure varies, depending on the:
  - type of animal;
  - type and amount of bedding used;
  - moisture content of manure and
  - the kind of capture and handling system employed.

Compared to chemical fertilizers, animal manures are:

- Usually lower in nitrogen, phosphorous, and potash contents
- Manures replenish the soil's organic matter and improve the soil structure and
- Manures are also contributing in increasing the beneficial soil microbes.

The best way to determine manure’s nutrient content is to have manure samples tested at the time of use if possible. This can be done in a laboratory, which is experienced with the procedures of manure nutrient content testing. In many cases, however, this is not practical, particularly in the Ethiopian condition. However, tabular values for the nutrient concentration of manure or the results of previous testing of similar manures can be used to determine application rates for good crop production and water quality protection. Testing of manures by taking samples following the appropriate sampling procedures is possible through Regional Soil
Laboratories and even research centres. Table 4 provides a good estimate of nutrient content values of some manure that can be available for use.

**Table 4. Nutrient contents of manure from different sources**

<table>
<thead>
<tr>
<th>Manure Types</th>
<th>Nutrient content (%)</th>
<th>Water content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nitrogen</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>Cattle dung</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Chicken waste</td>
<td>3.03</td>
<td>2.63</td>
</tr>
<tr>
<td>Sheep and goat waste</td>
<td>3.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Human faeces</td>
<td>4.0</td>
<td>1.53</td>
</tr>
</tbody>
</table>

NB: na*- data not available


**Table 5. Approximate NPK values of various animal manures**

<table>
<thead>
<tr>
<th>Animal</th>
<th>% nitrogen</th>
<th>% phosphoric acid</th>
<th>% potash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy cow</td>
<td>0.57</td>
<td>0.23</td>
<td>0.62</td>
</tr>
<tr>
<td>Beef steer</td>
<td>0.73</td>
<td>0.48</td>
<td>0.55</td>
</tr>
<tr>
<td>Horse</td>
<td>0.70</td>
<td>0.25</td>
<td>0.77</td>
</tr>
<tr>
<td>Swine</td>
<td>0.49</td>
<td>0.34</td>
<td>0.47</td>
</tr>
<tr>
<td>Sheep/goat</td>
<td>1.44</td>
<td>0.50</td>
<td>1.21</td>
</tr>
<tr>
<td>Rabbit</td>
<td>2.40</td>
<td>1.40</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Source: Adapted from: George Kuepper. Manure for organic crop production. NCAT Agriculture Specialist, March 2003

**Preparation of farmyard manure**

- Farmyard manure should be collected & stored for a while so as to obtain a manure of high quality.
- The best result is achieved if the farmyard manure is composted.
- Manure stored under anaerobic conditions is of inferior quality and not recommended.
- Some manure may contain contaminants such as residual hormones, antibiotics, pesticides, disease organisms, and other undesirable substances.
- Use of fresh manures usually associated with increased weed problems and disease incidence.
- Harmful substances can be eliminated through high temperatures in an aerobic process.
- Bedding materials (straw, grass and crop residues) is recommended to absorb and hold the liquid.
- Usually, the manure is stored next to the stable, either in heaps or in pits.
- In any case, the farmyard manure should be protected from the sun, wind and rain.
- Storage site should be well-drained and impermeable underneath to avoid nutrient leaching.

Storing manure in pits is practically suitable for:
- Dry areas and during dry seasons, where there is scarcity of water for watering the pile;
Storage in pits reduces the risk of drying out and the need to water the pile;
- There is a greater risk of water logging and more effort is required to dig out the pit;
- For this method a 90 cm deep pit is dug with a slight slope at the bottom;
- The bottom is compressed and then first covered with straw.
- Pit is filled with about 30cm thick and each layer compressed & covered with a thin layer of earth;
- The pit is filled up until it stands about 30 cm above ground and then covered with 10 cm of soil
- The manure will stay in this condition for sometimes up until it is ready for use.

The following are important signs for the control and producing of quality manure:
- Appearing of white fungus indicates that the manure is too dry and dampened with water or urine;
- If a yellow- green colour and/or bad smell is coming up then these are signs that the manure is too wet and not sufficiently aerated;
- If the manure shows a brown to black colour throughout the heap, the conditions are ideal.

Application of farmyard manure
- It should be transported to the field and spread or it can be applied at spots on planting holes;
- Manure should be immediately incorporated into the soil in order to avoid nutrient losses;
- Spreading can be done manually and incorporated into the soil by ploughing or hand hoeing;
- In commercial farms this can be handled easily using manure spreading machines;
- Manure can add trace nutrients and organic matter to the soil to improve soil conditions.
- If fresh manure is used it should be applied to the land two months before planting;
- Recommended rates of manure application 10 to 15 t/ha (it can increase up to 15 to 25 t/ha);
- The most responsive crops for manure application are maize, and tuber crops.
- Crops like squash, sweet maize, peas, and beans do best when manure is applied prior to planting;
- Leafy greens, though only well-composted manure should be used. Cabbages, tomatoes, potatoes and root crops, on the other hand, tend to do better when the manure is applied the previous year.
Calculation procedures to determine manure application rates

The rates of manure application depend on: (i) Nutrient needs of the crop, (ii) Nutrients available from the manure, (iii) The amount of a priority nutrient to be supplied by the manure (N, P, K).

Based on the information provided above the amount of manure to be applied should be calculated in order to determine the right amount of manure to be used that would provide the required amount of nutrients by the crop. If the nutrient content from manure is not satisfying crop needs then a difference of the nutrients that need to be supplied from other sources need to be calculated and added from other sources.

Exercise 2:

Calculation procedures are illustrated using a given example to provide the nitrogen needs of a maize crop. Fertilizer recommendations from soil test results are given as 80 kg of nitrogen, 30 kg of phosphate, and 57 kg of potash. No pre-planting fertilizer is used in the example, but 5 t/ha of manure would have been applied. The amount of manure required to supply the priority nutrient needed by the crop.

Calculation worksheet

<table>
<thead>
<tr>
<th>Calculations</th>
<th>Example</th>
<th>Your Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Crop to be grown</td>
<td>Maize</td>
<td>__________</td>
</tr>
<tr>
<td>2. Fertilizer recommendation:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Nitrogen (N)</td>
<td>80</td>
<td>__________</td>
</tr>
<tr>
<td>b) Phosphorus (P₂O₅)</td>
<td>30</td>
<td>__________</td>
</tr>
<tr>
<td>c) Potassium (K₂O)</td>
<td>57</td>
<td>__________</td>
</tr>
</tbody>
</table>
### Calculations

<table>
<thead>
<tr>
<th>Calculations</th>
<th>Example</th>
<th>Your Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Preplant fertilizer application:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) N</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>b) P₂O₅</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>c) K₂O</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4. Applied nutrient – N from manure application (tons)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>5. Net nutrient need:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) N (2a – 3a)</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>b) P₂O₅ (2b – 3b)</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>c) K₂O (2c – 3 c)</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>6. Available nutrient from manure applied:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) N (Test result N x availability coefficient = 0.45)</td>
<td>55 x 0.45</td>
<td></td>
</tr>
<tr>
<td>b) P₂O₅ (Test result P₂O₅ x 0.80)</td>
<td>55 x 0.80</td>
<td></td>
</tr>
<tr>
<td>c) K₂O</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>7. Application rate to supply priority nutrient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Priority nutrient N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) Amount needed (5a, b, or c)</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>c) Manure needed (7b/6a, b, or c)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Nutrients supplied by 7c:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) N (7c x 6a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) P₂O₅ (7c x 6b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) K₂O (7c x 6c)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Additional nutrients needed:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) N (8a - 6a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) P₂O₅ (8c - 6b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) K₂O (8c - 6c)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2) **Green manures**

- Green manure crops are legumes grown and turned into the soil to improve soil fertility;
- Green manure crops supply nitrogen to the soil through atmospheric nitrogen-fixation;
- In addition, to supplying of nitrogen they also add to the soil organic matter;
- Green manure crops are usually sown during off-season and do not compete with the main crops;
- Green manure crops can effectively serve to reduce soil erosion by reducing impact of rain drops;
- Usually green manure crops are legumes such as vetch, chickpeas, alfalfa, clover, lupine, etc;
- Green manure crops supply nitrogen to the soil through atmospheric nitrogen-fixation;
- Deep rooting legumes can extract nutrients from deep layers & accumulate on the upper soil.
Green manure crops have additional advantages like other organic fertilizers:

- Reduce soil alkalinity;
- Reduce aluminium hazard;
- Improve availability of other soil nutrients;
- Improve water holding capacity of the soil;
- Improve the activities of soil micro-organisms.

3) Compost making and its application

- Compost is the process of decomposing organic materials of plant or animal origin into humus, which is rich in soil nutrients and applied to the soil for increasing nutrient availability to crop plants.
- Compost is an excellent source of plant nutrients.
- Chemical fertilizers are becoming extremely expensive and difficult for subsistence farmers.
- Compost making can be considered as a potential solution
- It can be used primarily in home gardens, since it is somewhat difficult to prepare large amounts.
- The use of compost is becoming a wide spread practices in the highlands of Ethiopia.

Composting materials can be:
- Dead plants and animal wastes,
- Good composting materials can be weeds but not parasitic and problematic species,
- Grasses, crop residues, straw, banana stalk, coffee pulp, and manures of different types,

Not recommended as composting materials are:
- Composting wastes, particularly from industrial areas need to be avoided, due to heavy metals;
- Non-organic materials such as glass, plastics and artificial fibres should also be removed;
- It is also important to avoid diseased plant materials in order to avoid the spread of diseases;
- Care should be taken in selecting composting materials for quality compost preparation.

Agents of composting process:
- Micro-organisms are responsible for breaking down into carbon dioxide, water and nutrients.
- Nutrients are released and can be taken up directly by plant roots.

The rate of humus production and mineralization in the soil depends on:
- In a hot climate organic materials will be broken down more rapidly than in a cold climate.
- the acidity of the soil, the composition of the organic matter, the humidity and the availability of oxygen strongly influence the rate of decomposition.
- Composting is a very labour intensive technique for adding up and regularly mixing of;
- plant residues, soil and water
- manures, soil and water

- Decomposition takes place over a period of 1-4 months and to be ready for application.

There are some limitations in using compost. These are:
- Compost mounds require a large quantity of plant material;
- Cannot be used in the lowlands, where severe weed infestation is a problem;
- Cannot be practiced on steep slopes;
- Labour is needed to harvest, prepare, transport the composted materials to the field to distribute,
- Composting materials in rural areas, particularly cow dung is used for household energy or as fuel.

THE COMPOSTING PROCESS
- The composting process happens, due to the activity of micro-organisms (bacteria) and other larger organisms like worms and insects.
- Microorganisms need certain conditions to live - moisture and air.
- To make the best possible compost, the micro-organisms must be able to work optimally.
This can be achieved if the following four factors are combined to the best advantage:

- type of organic material
- air
- moisture and
- temperature.

The composting process will be optimal when:

- various materials of different decomposition rates are combined;
- the different materials are well mixed;
- the heap size varies from 1.5 x 2 meters to 2 x 2.5 meters wide to make the temperature constant.
- The length depends on the organic material availability but it is better to make a shorter heap.

PHASES OF THE COMPOSTING PROCESS

In the process of composting three main phases can be distinguished:

- the heating phase,
- the cooling phase and
- the maturing phase.

The heating phase

- The first phase of composting starts within about 3 – 5 days of setting up the compost heap.
- The compost heap starts to heat up considerably and the temperature rises to 60 to 70 °C and usually stays at this level for 1–3 weeks, during this time most of the decomposition occurs.
- This effect is known as fermentation and is the result of the breaking down of the complex and tough fibrous material of the organic matter and fermentation is strongest in the centre of the heap.
- If the temperature is too high, the necessary microorganisms may die and decomposition to a halt.
- In this phase, it is mainly bacteria which are active. The high temperature is a result of energy released during conversion of easily decomposable materials by the bacteria.
- The warm temperature is a typical and important part of the composting process and it destroys diseases, pests, weed roots and seeds.
- During the first phase of the process the bacteria have a very high oxygen demand, due to the rapid development of their population.
- High temperature in the heap is a signal of an adequate oxygen supply for the bacteria.
- If there is not enough air in the heap, bacterial development will be hindered and the compost will develop an unpleasant odour.
- In addition, humidity is also essential to the composting process as bacteria require humid conditions for their work. The need for water is greatest during this phase because of high biological activity and strong evaporation during this heating phase.
- Further, as the heat increases, the pH of the compost heap rises (acidity ↓).
To accelerate the fermentation process and undergone effectively, a number of factors are important:

- the compost heap should be made of different organic materials,
- the right microorganisms have to be present, in this case the bacteria and
- it is very important that there is adequate oxygen and water in order to speed up microorganisms to multiply and change at rapid rate, which accelerates the heating up process.

The simplest way to see if fermentation has started is by testing the temperature. This can be done:

- Put a stick in the centre of the heap about 5 days after completing the compost heap or after the final turning over. Leave it there for about 5 to 10 minutes.
- Then taking out the stick and feel it immediately. It should be considerably warmer (60 - 70 °C) than the body temperature. It is possible to feel the warm at the hand. If not, then this is an indication that something is wrong, perhaps the material used or aeration is at fault.

The cooling phase

- Once the material, which is easily digested by the bacteria, the temperature in the compost heap declines slowly and will remain at 25–45 °C.
- The fermentation phase gradually changes into a cooling down phase.
- Decomposition occurs without much generation of heat and the temperature drops slowly.
- During this period new types of micro-organisms convert the organic components into humus.
- While temperature decreases fungi will settle and start the decomposition of straw, fibres and wooden material.
- As this decomposition process is slower, the temperature of the heap does not rise.
- As the temperature drops, the pH of the composting material declines (i.e. acidity increases).
- By regulating temperature, air and water supply, the process can be accelerated or slowed down.

The period of the cooling down stage depends on:

- the type of the heap;
- the material used,
- the overall management of the heap,
- the climate, etc.
The maturing phase

- The temperature drops to soil temperature, depending on the climate, 15 - 25 °C.
- At this stage in addition to micro-organisms, large soil fauna are active (red compost worms).
- In temperate regions, earthworms in particular, feed on the strongly decomposed organic material.
- During the maturing phase nutrients are mineralized and humic acids antibiotics are built up.

Compost is ready for use

- Compost is ready for use if it feels crumbly and looks like good brown/black organic soil.
- During longer storage it loses its quality, while its capacity to improve soil structure increases.
- In the maturing phase, the compost needs much less water than in the heating phase.

Therefore, well-decomposed compost is:

i) friable
   ii) does not stick in the hand
   iii) dark grey or blackish in colour
   iv) original material cannot be distinguished and
   v) odour, smells like fresh soil.

METHODS OF COMPOST PREPARATION

Usually, there are two methods of compost making:

(i) Heap method and
(ii) Pit method.

Selecting of the most appropriate method depends on various socio-economic and biophysical factors:

- In practice, the pit method is preferred in dry, windy and moisture deficit areas where the supply of water is a constraint,
- the heap method is more preferred in mid and highland areas where water supply is not a constraint; the agro-climatic condition is wet, warm and less windy areas.

Setting up the heap

- The heap of organic material has to be set up in order to better facilitate the composting process.
- Decomposition is easier if the material is cut into small pieces and if easily decomposable material is mixed with materials more difficult to decompose and this result in obtaining the best compost.
- Start the heap by a foundation of coarse plant material such as twigs or sugar cane stalks.
The outside air can easily flow in under the heap and any excess water flows away more quickly.

**Covering the heap**

- In an area of heavy rain the heap will have to be protected against excess water.
- Preferably it can be kept dry by putting a simple roof above the heap:
  - Covering with a layer of leaves, a cloth, jute or plastic, etc.
  - If plastic is used then only cover the top, so that the air can penetrate through the sides.
  - Trenches around the heap facilitate the run off of excess rainwater.
  - Covering the top with the materials mentioned can also be an advantage in dry areas.
  - It prevents excess evaporation of moisture from the heap and it dries out less quickly and at the same time reduces nutrient loss - nitrogen.

**Requirements for compost making**

- The requirements for making good quality compost include:
  - a suitable site, well drained location
  - availability of raw materials (organic wastes of plant and animal origin, industrial wastes)
  - water
  - labour and
  - air, the pile pit and its enclosure should be well ventilated.

The most easily available sources of raw material include:

- **Plant sources**: These include crop residues, green and dry plant materials from grasses, legumes, fodder trees, weeds, and dry leaves from trees and vegetable waste and leftover animal feeds.
- **Animal manure**: The composting material on the farm is made of cereals which have low nitrogen content and the cattle manure can be used to raise the nitrogen content of the composting materials.
- **Soil**: The soil provides food for micro-organisms to initiate decomposition process and absorbs nutrients thus, reducing loss of nutrients due to leaching.

(1) **Pit method**

The pit method of compost preparation is recommended in areas where there is:

- moisture deficit and
- hard to supply sufficient water,
- in very cold areas,
- in windy areas and
- in nursery sites.
The steps for compost making using pit method are as follows:

a) Select the appropriate site for compost making under a shelter;
b) Collect organic wastes, animal manures any source and ash (from kitchens);
c) Demarcate the area and dig out 2 pits with an average size of 2 m wide, 4 m long & 1.2-1.5m deep.
d) Prepare compost in the 1st pit by making layers of:
   ✦ Pile crop residues and other wastes of about 15 - 20 cm thick, which are difficult to decompose and then easily decomposable materials about 10 cm thick and add water.
   ✦ Sprinkling of ash over the layer of plant waste: 0.5 kg/ m\(^2\)/layer will be enough.
   ✦ Apply farmyard manure (FYM) about 2 cm thick or 3-5 full spade/m\(^2\)/layer.
   ✦ Soil should also be spread (2 - 3 cm) on top of each layer to transfer micro-organisms.
e) Pile another layer of materials in the same sequence and repeat until a height of about 1.5 m.
f) To improve aeration, bamboo/sticks should be placed standing in the middle of the pit at every 2 m.
g) Leave the pit for one month and check the moisture once in week and add water to keep moist.
h) After 2 to 3 weeks turn and mix the compost into the second pit.
i) Compost will be ready after 3-5 months and it should be kept under shade and covered.

![Figure 16 Dimensions of pit for compost preparation (Source: CBPWD Guideline, MoA, January 2005, Addis Ababa)]

- It is important that refilling of the first compost pit one month before the end of the composting process taking place in the second pit and repeat the same procedure.
- This will allow producing compost three times a year or more if the time of decomposition is faster.
The decomposition is complete if the plant material has changed into an unrecognizable crumbly, dark mass.

Twigs and thick stems do not decompose completely and can still be seen. Under favorable conditions, the decomposition process in the pit method takes 3 months, but under adverse conditions it may take longer than 5-6 months.

Advantages:

- Pit composting is quick, easy and cheap as it does not require investment in materials. It needs less water so it is useful for dry areas where water is scarce and difficult to apply on daily basis.

Disadvantage:

- It is more difficult to follow of the decomposition process than with an above ground heap.

(2) Heap method

- The heap method is not suitable in dry, windy or very cold areas.
- Nutrients can be leached if heap is not protected.
- Therefore, the heap needs to be protected from direct sunlight and rains in order to avoid nutrient losses either through leaching or volatilization processes.

Steps of heap method compost preparation:

- Follow steps “a” and “b” as mentioned for the pit method.
- Then first demarcate the boundaries of the heap using wooden pegs. The size of the heap depends from the amount of organic waste but it should not be wider than 2 m and 1.5 m high (see Figure-17), and as long as necessary. Then dig a shallow pit (30cm deep) for collection of leached nutrients and moisture.
- Then follow all the same steps from “d” up to “l” mentioned for the pit method. This sequence of layers is repeated until the heap has reached a final height of 1.5 to 2 meters. In this way the heap is composed of many layers. Building the heap should be done quickly, preferably within a week.
- The sides of the heap can be also covered or plastered with soil to some height to keep the heap warm and to avoid drying by wind.
During decomposition process the heap has to be turned over regularly, in order that it remains well aerated and all the material is converted into compost.

The heap should be turning after 2-3 weeks or a month later depending on the speed of decomposition.

The heap is broken down and built up again next to the old heap. The layers are mixed and the heap is, as it were, turned upside down and inside out.

Again, a foundation of coarse plant material is made first. Then the drier and outer, less decomposed part of the old heap is placed in the central part of the new heap.

The drier material will have to be watered before the heap can be built up further. This core is covered with the rest of the material. The original layered structure is lost.

The second turning is after 3 weeks and it may be necessary to turn over again for a third time.

Repeat the moisture test and the temperature test a few days after each turning over operation.

The advantages of this method are:
(i) the process can be kept under control and runs smoothly, because the heap is turned regularly; and (ii) compost is produced in a short time.

Disadvantages of this method are:
(i) it requires much water; and
(ii) it is very labour intensive.

APPLICATION OF COMPOST

- When the compost is ready for use, it has to be kept properly for a while until it can be put to use.
- Care should be taken in order not to lose its nutrients during storage.
- Compost should never be left uncovered in the rain or in the sun.
♦ The rain washes out the nutrients and the sun can cause burning.
♦ In order to reduce this loss the compost should be covered.
♦ Some useful covers are:
  ✓ banana leaves,
  ✓ intertwined palm leaves or a sheet of plastic.
♦ If the compost is left too long, it may also become a breeding place for unwanted insects, such as termites and the like.
♦ It is important to store compost in shady and protected areas both from the sun and rains.

♦ The composted materials can be applied for different purposes such as:
  ✓ fertilizing the garden soil;
  ✓ potting soil, nursery soil, planting trees;
  ✓ for erosion prevention and
  ✓ sometimes it can be used for fish feeding.
  ✓ However, the discussion here is given emphasis to apply compost primarily for home gardens and treated areas where soil and water conservation measures are applied.
♦ The advantage of using compost for fertilizing is to improve soil fertility in the long run, by improving the soil structure by adding organic matter to the soil.
♦ Organic matter is the key factor in improving soil structure.
♦ Organic matter contains a lot of micro-elements important for plant growth and it improves the water retention capacity of the soil.
♦ Another aspect is that compost releases the nutrients slowly, which means that the effect of compost is one in the long run.
♦ Adding artificial fertilizer alone is not sufficient to retain a sufficient level of soil fertility.
♦ Organic matter (OM) is needed to retain the water and nutrients.
♦ In a degraded soil, where there is no organic matter, yields will still decrease, even if artificial fertilizer is added. This means that whenever artificial fertilizers are being used, the farmer needs to take care of the organic matter content of the soil.
♦ Therefore, it essential to design an integrated approach, combining application of compost with artificial fertilizers is a good strategy to quickly satisfies nutrient needs of crops.
♦ If compost is to be used for direct fertilizing of a field crop on a large piece of land, a very big quantity will have to be applied, which is a constraint in most cases.
♦ Using compost in the vegetable garden or on small plots of land is very advisable.
♦ It is important to take care to apply the compost locally at the specific places where it is needed.
♦ When preparing a sowing bed the compost can be mixed superficially through the top soil.
♦ The fertile compost is then easily available for the seedlings.
It can also be applied in pits or trenches in which the crops are planted. This method is particularly useful in dry regions. The crop is planted in pure or compost mixed with top soil.

- Use of compost to prevent erosion is strongly linked with improving soil structure and soil fertility.
- A fertile soil is less susceptible to erosion, because the OM holds the soil particles together.
- In addition compost used as a ground cover counteracts splash erosion caused by rain.
- Compost is an excellent opportunity to support increased productivity of conserved areas.
- Therefore, compost can be strategically applied in cultivated fields treated with bunds.
- In the first year a significant amount of compost is applied along the first 2-3m of cultivated land above bunds.
- This will have maximum impact in creating a re-cycling zone where the soil is deeper and moisture is the highest and it is recommended to plant high value crops along the strips.
- During the next season, apply additional compost to the same area and expand the application of compost by 2-3m upwards every year.
- For annual crops such as wheat, maize, sorghum, sweet potato, vegetables and ornamental flowers, compost should be spread onto the field before tillage and incorporated with the soil immediately in order not to lose nutrients, particularly nitrogen.
- For perennial crops, such as fruit trees compost should be spread around the trunk of the tree and similarly worked out with the soil.
- The application rate of compost in Ethiopian condition is about 15–20 tons/ha or 10 kg per tree in the case of fruit trees but if sufficient amount is available in can be 20-25t/ha.

### 3.2.3 Cover crops

- Vegetation cover is important for the protection of the soil surface from the beating action of raindrops (rain splash) and erosion by surface runoff.
- Crops growing in the field to cover the bare soil primarily with the aim of reducing soil erosion and improve soil fertility are called cover crops.
- These cover crops in most cases can be leguminous plants that can serve different purposes or weeds with fast growing characteristics and can cover vast areas permanently and have a potential of giving large amount of biomass.
- Cover crops are basically living vegetation or mulches to the soil surface, in order to protect the soil from erosion, suppress weed establishment and reduce excess evapotranspiration or loss of water.
- The main objective of cover crops is to protect the soil from erosion, they can also play role to:
  - Replenish soil organic matter
  - Improve soil physical and chemical properties and
- Ultimately improve soil fertility through addition of decayed plant materials into the soil.
- As a result of increased soil fertility and weed control possibilities, cover crops reduce the need for fertilizers and herbicides application.
- Cover crops can be used as a source of food for human beings and forage for animals.

Cover crops have their own limitations:
1. May compete for soil moisture and nutrients;
2. Involves additional farm labour and inputs;
3. May sometimes compete with the main crops as weeds;
4. May serve as alternate hosts for crop pests;
5. Some cover crops may contain chemicals, which inhibit the subsequent crop growth;
6. Dense foliage crops serve as shelter for rats and the like.

In selecting cover crops the following characteristics need to be taken into consideration:
- Seeds must be cheap, easily available, easy to harvest, store and multiply;
- Fast growing characteristics and has the ability to quickly and fully cover the soil;
- Be resistant to insect pests and diseases;
- Produce large amounts of organic matter and dry materials;
- Tolerant to drought and a wide range of soil conditions;
- Have the potential to trap nitrogen and convert it to easily plant available forms;
- Have the ability to produce their own seeds;
- Fast decomposition of leaves;
- Easy to sow and to manage as a single crop or associated with other crops;
- Easy to control; some cover crops can be very aggressive and may be difficult to eliminate and
- The cover crop can be used as fodder and/or as grains for food.

### 3.2.4 Intercropping

**Definition:** Intercropping is a system of crop production, where two or more crops are grown together on the same field with the objective of increasing production and protect the soil from soil erosion.

Objectives of intercropping are:
- Efficient utilization of crop growth factor resources (such as water, light and nutrients);
- Better ground cover and efficiently protect the soil from erosion;
- Efficient utilization of growth factor resources leads to yield advantages over sole cropping.
- Gives an opportunity to grow various crops both annual and perennial crops;
- Intercropping is not only considered as an activity for increasing land productivity but it is also an effort to avoid crop failures, induced due to drought or other natural hazards.
Recommended crops for intercropping practice are: In weyna dega areas intercrop maize with pigeon peas, maize with cow peas, maize with mung bean and maize with haricot bean.

![Intercropped of maize crop with pulse crops such as haricot bean](image)

**Figure-18 Intercropped of maize crop with pulse crops such as haricot bean**

Advantages:
- The advantage of intercropping system from the soil conservation point of view is that some of the crop will grow fast and cover the soil quickly, while the other crop is growing slowly.
- Intercropping has also other advantages in growing legume crops in the system where it will give an opportunity to grow crops rich in protein content which is essential for human consumption.

Recommendations:
- Selection of proper plant crops and planting arrangement is highly beneficial.
- In the intercropping system, particularly pulses can play significant roles in increasing soil fertility.
- Inclusion of pulses in the intercropping system reduces the burden of purchasing artificial fertilizers.
- Intercropping is most practicable in low and medium altitude areas.
- In low rainfall areas need to be integrated with soil and moisture conservation practices.

To accomplish this, four things must be considered:
- spatial arrangement,
- plant density,
- maturity dates of the crops, and
- plant architecture or planting systems.
Intercropping can be arranged in a spatial arrangement:
- Planting in rows - growing of two or more crops at the same time in b/n rows one after the other.
- Strip cropping - growing two or more crops in wide strips to permit crop production activities,
- Mixed intercropping - growing two or more crops together in no distinct row arrangement and
- Relay intercropping or planting of a second crop into a standing crop at a time when the standing crop is at its reproductive stage but before harvesting.

### 3.2.5 Relay cropping

- Relay cropping is a practice of growing two or more crops during the same growing season with certain overlaps between planting of the second crop and harvesting of the first crop.
- The main purpose of relay cropping is just to take advantage of residual moisture and space between rows of the first crop in order to grow the second crop.
- Relay cropping has much in common with intercropping, but the distribution in time is different.
- For instance a crop maturing in four months is planted in April. The land will be cleared in August only, and too little time is left for another crop to plant and obtain reasonable yield.
- Therefore, to make space for another crop, a second planting is made around end of June.

<table>
<thead>
<tr>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
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*Figure-19 Schematic illustration, which shows the planting time of the second crop in relay cropping system.*

- In this planting arrangement the germinating and maturing crops will interfere little with each other, but the second crop is ready to cover the ground in August, and to utilize the rain.
- Two harvests are gained instead of one, and the land is covered all through the season.
- Relay cropping is being practiced in some parts of Wollo, Hararghe, and Shoa.
- In Hararghe it is common to use a high seeding rate of sorghum and to thin out through the season to secure fodder for their cattle.
However, this system could very possibly be modified into an intercropping / relay cropping system, where fast growing fodder crop is planted early and sorghum is interplanted at the normal time.

Crop mix, plant populations and spacing to use is recommended to be based on local conditions.

3.2.6 Double cropping

Double cropping is a cropping system, in which two or more crops are grown on the same field one after the other using the available soil moisture within the period of one production season. This system is entirely dependent on the rainfall, therefore, it is vital to select the crops carefully and arrange the planting time as to have an opportunity to get sufficient moisture for germination and establishment of the second crop. In principle, the second crop usually grows and matures using the residual moisture and use the late season rains as an opportunity to supplement its moisture demand. The advantage of double cropping is getting of double crops in a season, increasing land productivity and the second crop can also serve as a cover crop in protecting the soil from being directly hit by rain drops and reduce erosion.

This cropping system is being practiced in many parts of Ethiopia, particularly in the high and mid altitude areas, where late sown legumes such as chickpea, lentils, and fenugreek are commonly grown on residual moisture on vertisols right after barley or potato is harvested. However, this cropping system is difficult to be practiced in lowland areas, due to inadequate moisture availability.

Careful management is required in double cropping system for production of a profitable second crop. The second crop planting date is critical in determining productivity of the system. The time of harvest of the first crop will significantly affect the potential yield of the second. Therefore, it is strongly advised to plan to timely harvest the first crop and plant the second crop on-time, without any delay. Selecting an early-maturing of first crop variety can allow for early harvesting and timely planting of the second crop.

Soil moisture present at the time of the first crop harvest is the critical factor for determining the potential yield of the second crop. If soil is quite dry at the time of harvest, double-cropping should not be attempted, due to limited moisture availability that could affect the second crop germination. Selection of the proper crop variety for the second crop is also critical. In general, a variety with a mid-season maturity rate for the area is usually the best choice. It is important to note that double cropping need careful management.
3.2.7 Strip cropping

- Strip cropping is a soil conservation based crop production system, which grow two or more crops in alternate rows along the contour of same width for erosion control.
- Contour strip cropping divides a steep land into contour strips that cut across the path of overland flow and reduce its velocity.
- A soil-conserving crop is grown in a contour strip across the slope to absorb runoff, retard runoff velocity, and encourage sedimentation of entrained sediment.
- The practice of strip cropping is useful for controlling soil erosion in areas where cropping system is dominated by row crops (sparsely populated crops).
- Strip intercropping is the adaptation of intercropping system, in which the multiple crops are grown in narrow, adjacent strips that allow interaction between the different species, but also allow management with improved equipment.
- In general, net gains in crop yield and economic return are the main short-term indicators of success or failure of such a cropping system.
- Therefore, as with any other business, farm managers or growers will ultimately choose practices that maximize yield and increase economic return.

![Diagram of contour cultivation and planting](image)

*Figure-20 Alternate strips of erosion susceptible crop and soil conserving crop in stripe cropping practice*

- The direction of intercrop strips is ultimately determined by topography.
- Ideally, strips run perpendicular to the slope so that the small grain strips can trap eroded sediment and reduce runoff.
- Strips perpendicular to wind direction will maximize the windbreak effect of corn, influencing the microclimate experienced by other crops.
- Crop orientation may complement and improve the effect of strip direction, e.g., when strips have a north-south direction, planting soybeans on the east side of the corn strip benefits both crops.
Crop management practices need to be considered in designing the strip width and direction.

Various categories of strip cropping exist. These are:

- **Contour strip cropping**: Alternate strips are established on the contour. These contour strips facilitate the performance of all farm operations on the contour.
- **Buffer strip cropping**: Buffer strips are established on a rolling topography with complex slopes where not possible for contour strip. Buffer strips are generally planted to cover crops and trees.
- **Field strip cropping**: This practice involves establishing rectangular strips parallel to one side of a field. This type of strip cropping can be done only on gentle slopes with soils of low erodibility.
- **Barrier strips**: These strips involve a single or double row of closely growing grass or cereals established on the contour to provide protection against runoff such as vetiver hedges.
- **Border strips**: Property boundaries are often established with hedges of perennial vegetation. These strips also minimize the risks of erosion.

In addition to controlling erosion in cultivating land, alternate strips may gradually regenerate soil fertility, improve soil structure, and restore productivity of land. The biomass produced in buffer strips can be used as mulch, fodder, and for composting. Buffer strips are usually planted with quick-growing and easy-to-establish forage legumes. Some common forage legumes suitable for the soil and environment of the humid tropics are Centrosema pubescens, Desmodium buergeri, Medicago sativa, Phaseolus acontifolius, Stylosanthes guianensis and Trifolium species.

**3.2.8 Ley cropping**

Ley cropping is a cropping practice in which legume based pastures are rotated with food crops aimed at increasing the food and fodder production and to enhance soil fertility concurrently. In this system, grasses and/or legume based pastures are grown in rotation with annual crops on fallow lands for sometimes to improve soil fertility. Ley farming has an extra advantage of linking livestock with crop production where shortage of grazing land and feed is a constraint to livestock production. The practice is more feasible in the highlands where fallowing is being practiced with the objective of soil fertility improvement in areas where soil is highly degraded. During the fallowing period, there are actually three major ways through which soil fertility restoration takes place in the natural fallowing practice. These are through atmospheric nitrogen fixation by the native leguminous plants, recycling of nutrients from deeper soil profiles by deep-rooted natural vegetation and accumulated on the top soil layers ready to be used by
the crop plants and natural recycling of organic matter resulted from dead plants, leaves and other plant parts.

In ley cropping, vegetation, which provides good ground cover and stimulates biological activity in the soil is desirable. The establishment of dense, productive forage crops during fallowing period provides a thick ground cover to control erosion. The substantial biomass produced is either harvested for hay making or maintained on the ground and incorporated into the soil to improve soil fertility.

The recommended suitable trees/grass species in different agro-climatic zones are:

- In Wet-Moist Dega- *Trifolium spp.*, *Vicia dasycarpo* (vetch), *tree lucerne* and *medicago spp.*
- In Wet-Moist Weyna Dega- *Sesbania sesban*, *Vicia dasycarpo*, *Trifolium spp.*, and *medicago spp.*
- In Kolla and Dry Weyna Dega agro-climatic zones - pigeon peas, *Siratro* and *Stylos.*

### 3.2.9 Improved fallows

One of the traditional ways of improving land productivity is leaving the degraded land fallow without cultivating for one or more seasons. The fallow period actually depends on the size and availability of land owned by the households. The non-productive arable land can be reclaimed and restored within a shorter period by incorporating suitable tree species in the fallow system. Some examples are *Acacia* species, *Leucaena, Sesbania, Calliandra, Cajanus cajan*, etc.

Land for annual crop production must be secured to sustain a family, which might not be feasible where land is scarce.

**VEGETATIVE CONSERVATION MEASURES**

The main objective of vegetative conservation measures is actually establishing vegetation cover in all types of land use systems in order to reduce erosion and improve soil fertility. These include:

- Vegetation cover on physical structures,
- Vegetation for fencing and around farm boundaries,
- Vegetation under forestry and agro-forestry systems,
- Vegetation on grazing lands,
- Vegetation on crop lands for food production,
- Vegetation in water ways, gullies and
- Vegetation on degraded lands.
3.3  Grass Strips

A grass strip is a ribbon-like band of grass laid out on cultivated land along the contour. Usually, grass strips are about 1 meter wide and spaced at 1-2 m vertical intervals. They are mainly used to replace physical structures on soil with good infiltration (sandy, silty) on gentle slopes. Cattle interference must be excluded from the areas where these structures are put in place for about a year in order to provide for the grass strips to be well established and reach for sufficient length of grasses to slow runoff and retain soil sediment. Practically grass strips can be applied in areas from moist Kolla to wet and moist Wurch agro-climatic zones in slopes of more than 15% gradients and in all soil types.

Grass strips are recommended to be planted along the contour and along cut-off drains. Spacing with 1 m vertical interval means that on a 3% slope, grass strips will be 33m apart, and on a 15% slope, only 7m apart, still sufficient for ploughing between the strips. Grass strips help to reduce runoff and to filter out sediments carried out by runoff. These are especially suitable on soils with good infiltration and where the climate is not too dry for dense grass development. If grazing is totally prevented, the grasses from strips will build up into terraces and provide good fodder for cattle, which can be used by cut and carry system.

The recommended grass species suitable for grass stripes in different agro-climatic zones are:
- In Dega agro-climatic zone: Phalaris aquatica and local grass;
- In Weyna Dega areas: Phalaris aquatic, Setaria species, Panicum maximum and local grasses;
- In Kolla: Cenchrus ciliaris and local grasses
Planting of grass strips should be carried out at the onset of rainfall, when the soil is not too wet or too dry. Generally, recommended to plant grass strips early, as soon as the main rainy seasons started for better establishment. In areas receiving good belg rains, it is possible to plant with the onset of belg rains.

**Planting materials**

There are various forms of planting materials used for the establishment of vegetative barriers. The planting materials can be seed or vegetative forms (eg. Seedlings, root splits, stem cuttings, etc). Vegetative forms such as seedlings, root splits and stem cuttings are in growing process, and they have more viability for better establishment and survival in the field. However, when planned to cover a large area within a short period of time it is recommended to use seeds, instead of seedlings and other forms of planting materials.

**Seedbed preparation**

A one-meter wide strip of land is marked out along the contour. A one-meter vertical interval is used to layout the consecutive contour strips. After the strip is marked out along the contour, seedbed preparation is properly carried out to get fine seedbed. Seedbed for most grasses should be firm and fine.

**Planting techniques**

- For seeded grass species with small seed sizes is recommended to use broadcasting planting technique, while large seed sizes will allow using either broadcasting and/or row planting.
But the vegetative forms of planting materials limit to row planting.
In broadcasting seeds, the seeds of selected grass species are mixed up with seeds of legumes.
It is highly important to take care during uprooting from the nursery/from old pasture.
Root splits need to be cut at about 12 cm above the ground, and then clumps are carefully uprooted and transported to the permanent planting site in container under moistened condition.
At the time of planting each clump is split into pieces containing 2 to 3 tillers to ensure good establishment and care should be taken not to damage the roots and growing points.

![Diagram showing planting techniques of grass strips using root splits](image)

**Figure-22 Schematic illustration of planting techniques of grass strips using root splits**

### 3.4 Agroforestry Practices

#### 3.4.1 Definition and concept of agroforestry

Agroforestry is the most recently emerging science for an old set of land-use practices. The most widely acceptable definition to the term of agroforestry is the one, which was given by the World Agroforestry Centre, which defined agroforestry as "a collective name for land use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc) are deliberately used on the same land management units as
agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence". It is a land management system where agricultural production system is integrated with forestry on the same unit of land to allow farmers to produce food crops, fiber, fodder, and fuel simultaneously from the same unit of land on a sustainable basis.

Agroforestry is a dynamic, ecologically based, natural resources management system that through integration of trees on farms and agricultural landscapes, diversifies and sustains production for increased social, economic, and environmental benefits for land users. It is a sustainable multiple-production system where the outputs can be adjusted to local needs. Agroforestry has multifaceted roles to play in the agricultural production system, which include soil fertility maintenance through erosion control and biological nitrogen fixation (BNF), watershed protection, maintain ecological stability, conservation of bio-diversity and carbon sequestration for climate change mitigation.

Therefore, the main objective of introducing agroforestry systems in the farming practices is to enhance and enhance the positive interactions among trees/shrubs, ground cover, crops, livestock and water in order to increase and diversity the overall production from a given unit of land. In this regard, agroforestry practices are aimed at: (i) Long-term economic stability (ii) Harmonized production system (iii) Environmental protection and (iv) Better use of the available land resources, including marginal lands.

**3.4.2 Classification of agroforestry systems**

Agroforestry systems can be classified:

- **Agrosilvicultural systems**: This is an agroforestry system where agronomic crops are combined with shrubs/trees on the same unit of land for better-sustained production of all components.

- **Silvopastoral systems**: This is an agroforestry system where range of crops and/or animals and trees are combined for better production of grasses and fodder.

- **Agrosilvopastoral systems**: This is an agroforestry practice by which food, pasture, and tree/shrub crops are combined on the same unit of land for the production of grass and browse feed, biomass for fuel wood and green manure, and food for human consumption.

**3.4.3 Traditional agroforestry practices in Ethiopia**

Agroforestry is an age-old practice in the Ethiopian farming systems. Trees are planted in agricultural or silvopastoral systems to provide shade, windbreak, medicines, or to meet household energy and construction needs. Traditional agro-forestry system takes
the form of trees scattered on crop fields, woodlots, homestead multipurpose tree planting and multi-storey home garden.

The Gedeo agro-forestry system has been practiced since the time land users inhabited the area and it has gradually developed through experiences gained and being adapting to other parts of the country. Varying agro-forestry systems have at the same time been practiced in Sidama, Guji, Wollaita, Kembata and Tembaro, Hadiya and Keffa zones (SLM Technologies and Approaches in Ethiopia, former MoARD, 2001, Addis Ababa). The crops grown largely depend on the agro-climatic and socio-cultural conditions of the area. Various agroforestry systems are being practiced in various agro-ecological zones of Ethiopia, which range from multi-storey systems to scattered trees kept in the crop lands such as growing of Acacia albida as a permanent tree crop on farmlands with cereals, vegetables and coffee in the Harrarghe highlands.

3.4.4 Agroforestry practices in different land use systems

3.4.4.1 Definition and concept of agroforestry

Agroforestry is the most recently emerging science for an old set of land-use practices. The most widely acceptable definition to the term of agroforestry is the one, which was given by the World Agroforestry Centre, which defined agroforestry as "a collective name for land use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc) are deliberately used on the same land management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence". It is a land management system, where agricultural production system is integrated with forestry on the same unit of land to allow farmers to produce food crops, fiber, fodder, and fuel simultaneously from the same unit of land on a sustainable basis.

Agroforestry is a dynamic, ecologically based, natural resources management system that, through integration of trees on farms and agricultural landscapes, diversifies and sustains production for increased social, economic, and environmental benefits for land users. It is a sustainable multiple-production system where the outputs can be adjusted to local needs. Agroforestry has multifaceted roles to play in the agricultural production system, which include soil fertility maintenance through erosion control and biological nitrogen fixation (BNF), watershed protection, maintain ecological stability, conservation of bio-diversity and carbon sequestration to climate change mitigation.

Agroforestry refers to combinations of trees, crops and livestock that are intentionally designed and managed as a whole within the same production unit. Therefore, the main objective of introducing agroforestry systems in the farming practices is to enhance and magnify the positive interactions among trees/shrubs, ground cover, crops, livestock and water in order to increase the overall production and diversify the overall production from a given unit of land.
3.4.4.2 Classification of agroforestry systems

In order to get clear and complete understanding and evaluate the different agroforestry systems existing and to develop action plans for their improvement, it is necessary to classify them according to some common criteria. However, it must be clear that the main purpose of classification should be to provide a practical framework for the synthesis and analysis of information about the existing systems and further development of new and promising ones. Depending on the focus and emphasis of strategies for development of improved systems, the nature of a given framework will vary.

Any classification scheme should therefore, include: (i) a logical way of grouping the major factors on which the production system will depend; (ii) indicate how the system is managed (pointing out possibilities for management interventions to improve the system's efficiency); (iii) offer flexibility in regrouping the information; and (iv) be easily understood and readily handled (practical).

The most obvious and easy-to-use criteria for classifying agroforestry systems are the spatial and temporal arrangements of the components, the production aims or outputs from the system, and the social and economic features. They correspond to the systems structure, function (output), socio-economic nature, or ecological (environmental) spread. These characteristics represent the main purpose of classification and the first logical step in classifying it should be based on the nature of the components of the system.

The most common set of criteria used to classify agroforestry systems and practices are therefore:

- **Structural basis:** refers to the composition and arrangement of components—spatial and temporal.
- **Functional basis:** refers to the main function or role of the components especially the woody components as for soil conservation and soil fertility improvement.
- **Socioeconomic basis:** refers to the intensity or scale of management and goals of the system.
- **Ecological basis:** refers to the environmental and ecological suitability of systems. There can be separate sets of agroforestry systems for arid and semi-arid lands or humid and sub-humid tropics.

A. Structural classification

a. On the nature of the composition

Using the structural classification based on the nature of the three basic components, agroforestry systems can also be classified for all practical purposes according to their component composition:
Agrosilvicultural systems

This is an agroforestry system where agronomic crops are combined with shrubs/trees on the same unit of land, which aimed at improving and sustaining of production systems of annual crops, fodder, and wood. Agrosilvicultural system further refers to use the land for the production of agricultural crops and forest trees, either simultaneously or alternatively, e.g., intercropping of a forest plantation with agricultural crops, growing agricultural fruit trees with forest trees.

This type of agroforestry practice is a common phenomenon in the traditional farming system of Ethiopia in the form of scattered trees on farm lands, fruit trees on homestead and farmlands, which is a common practice in Benshangul-Gumuz region around Assosa and its surroundings, e.g., mango trees. The rural communities are maintaining trees on his farmlands to satisfy his different needs such as the grains of annual crops are being used both for home consumption and marketing of the surplus, the fruit trees are being used food, shading for humans and livestock during high temperatures and of course, the trees are being used for construction, poles, farm tools and fuel.

Silvopastoral system

Silvopasture is a form of agroforestry where deliberately integrate trees, forages and livestock to take advantage of their beneficial interactions. Silvopasture systems support greater biological and economic diversity and provide environmental benefits as well. The main focus of this type of agroforestry system is basically for producing of grasses and fodder for animals, while producing as trees to serve different purposes. This combination can be arranged as a pure stand with fodder trees/shrubs planted as a protein bank, which can be utilized by cut-and-carry fodder production system, and/or mixed in different configurations such as living fences of fodder trees and hedges. The trees and shrubs and grass components are arranged in such a way that their healthy coexistence is not disrupted. The acacia-dominant system in the arid parts of Ethiopia is a good example for such type of system.

Silvopasture concepts and practices are not new, but their research and use in Ethiopia is limited, particularly with hardwood trees. This clearly indicates the need of research support in order to promote the system and enable the rural communities to get the required benefits, particularly in pastoral areas where livestock rearing predominates throughout.

This system can be practiced on both range and forest lands for the production of both feed and woody materials. This system could also be practiced on sloping ground by
growing grasses and trees/shrubs together for soil conservation purposes. The main objective of this practice is to supply feed for livestock during the dry season with high quality tree leaves and pods. This will substantially increase the productive capacity of poor and scarce pasture lands common on the Highlands of Ethiopia and fuel wood and construction poles can also be produced with this system.

Selection of trees for silvopastures is one of the key considerations that need to be taken into account in order to effectively establish the system to get the required benefit. Desirable characteristics in this regard, include: (i) high value marketable timber; (ii) high-quality wood; (iii) rapid growth; (iv) deep-rooted morphology; (v) drought-tolerance; (vi) potential of trees to be used for livestock feed source; and (vii) provision of environmental conservation services; (viii) role of trees for nitrogen fixation and moisture conservation; (ix) effect on reducing micro-climate temperature to be used for shading of both humans and livestock during high temperature events and (x) trees with no allelopathic effects for forage species.

It is important that tree growth patterns and morphology should complement production of the understory forage crops. Species that produce leaves in the dry season, with sparse and open canopies are more preferable as they allow penetration of sufficient light to support forage growth and development in order to give optimum yields. In addition, trees with rapid leaf decomposition characteristics are also desirable.

**Agrosilvopastoral system**

This is an agroforestry practice by which food, pasture, and tree/shrub crops are combined on the same unit of land for the production of grass and browse feed, biomass for fuelwood and green manure, and food for human consumption. This system is practiced when the farmer needs all the benefits that would be obtained from silvipasture and agrisilviculture systems from a unit of land. Usually, such a system is practiced on cultivated land. Alternative rows of hedges, grass strips and/or crops would form such a system, a form of alley cropping can be considered as part of this system.

Agrosilvopasture is also practiced when the cropland is constrained by slope and threatened by erosion. These are very common problems of land use in most of the Ethiopian Highlands; therefore, this system has the potential for use in various regions of the country.

**b. Classification based on dominance of components**

On the basis of dominance components, the agroforestry system is further classified into the following categories:

i. **Silvoagricultural**: Here silviculture is the primary aim of land use. Trees constitute the major component while agricultural crops are integrated with them, e.g., shifting cultivation and taungya cultivation.
ii. **Agrosilviculture**: Agriculture is the primary (major) component and the trees are secondary, e.g., multipurpose trees on farm lands, hedgerows or alley cropping, intercropping of trees, homegardens.

iii. **Silvopasture**: Trees are the primary (major) components land use with pastures as secondary, e.g., most grazing lands in forests.

iv. **Pastoral silviculture**: Pasture is a primary component while the tree is secondary, e.g., grazing lands.

v. **Agrosilvopasture**: It is a combination of crops, trees and pastures. Both crops land and trees are dominant over pasture.

vi. **Slivoagropasture**: It is a combination of trees, crops and pastures, e.g., trees are dominant over other components.

c. **Based on the arrangement of the components**

Arrangement of components can involve the dimensions of space and time. Based on the arrangements of the components agroforestry systems can be classified as:

- In space or spatial arrangements
- In time or temporal sequence
- Vertical stratification of components

i. **Classification of agroforestry systems on the basis of in space or spatial arrangements**:
   - **Mixed dense**: different components are arranged together in a high density, e.g., home garden.
   - **Mixed sparse**: different components are arranged together in a low density, e.g., most systems of trees in pastures, scattered trees on agricultural lands.
   - **Strip plantation**: Width of strip to be more than one tree, e.g., Alley cropping, boundary plantations: trees on edges of plots/fields.

ii. **Classification of agroforestry systems on the basis of in time or temporal sequence**:
   - **Coincident**: It occurs when different crops occupy the land together, e.g., Tea/coffee under trees, pastures under trees.
   - **Concomitant**: When different components stay together for certain period, e.g., Taungya system.
   - **Intermittent**: When annual crops are grown with the perennial ones, e.g., seasonal grazing of cattle in pastures under trees.
   - **Interpolated**: When different components occupy the space during different times, e.g., homegardens.
   - **Separate**: When different components occupy space at different times, e.g., improved fallows species in shifting cultivation.
iii. **Classification based on stratification:**

a. **On the basis of vertical stratification:**
   - Single layered: The major components usually grow in one layer or story, e.g., tree garden.
   - Double layered: The components are grown in two layers, e.g., tea/coffee under shade trees.
   - Multilayered: Different components are grown in different layers, e.g., homestead agroforestry.

![Figure-23 A multilayered agroforestry system (Source: Abera, May 2009, Wondo Genet)](image)

b. **On the basis of spacing**
   - Dense: The plant population is high per unit area, e.g., monoculture plantation forest, boundary plantation.
   - Scattered: The components are grown sparsely or scattered, e.g., agrosilviculture.
   - Mixed intercropping: Different components are grown together, e.g., growing of annual crops and horticultural crops in dryland forest.

B. **Functional classification**

On the basis of various functions agroforestry systems classified into the following categories:

a. **Productive agroforestry system:** This system refers to the production of essential components that required to meet the basic needs of the society. It includes intercropping of trees, home gardens, plantation of trees in and around crop fields and production of animals. Productive functions are as follows:
   1. Food crops
   2. Fodder
   3. Fuel wood
   4. Other products

b. **Protective agroforestry system:** This system refers to protect the land, to improve climate, to reduce wind and erosion, improve soil fertility, provide shelter, and other benefits, e.g., windbreaks. Protective functions are as follows:
i) Windbreak   ii) Shelterbelt  iii) Soil conservation  iv) Moisture conservation  
v) Soil improvement  vi) Shade (for crop, animal and human being)

c. **Multipurpose agroforestry system:** It ensures multipurpose production through optimizing both productive and protective functions, e.g., hedgerow, intercropping, home garden.

D. **Ecological classification**

The agroforestry system is related to the various agro-ecological factors. Agroforestry can be classified on the basis of important agroecological parameters (climatic, edaphic and physiographic factors). Therefore, on the basis of agro-ecological parameters, it can be classified:

a) **Tropical:** Vegetation in extreme climate such as high temperature, low humidity and scarcity of water, e.g. silvopasture.

b) **Sub-tropical:** Vegetation in suitable climatic condition, e.g., agroforestry practice in woina dega agroecological zone.

c) **Temperate:** Vegetation in low temperature, e.g., silvopasture or pastoral silviculture in temperate regions.

d) **Sub-alpine:** Vegetation in low and medium mountainous regions, e.g., natural or artificial forest.

e) **Alpine:** Vegetation in high mountainous regions, e.g., natural forest in high altitudes.

E. **Socioeconomic classification**

On the basis of socio-economic considerations, agroforestry system classified as follows:

a) **Subsistence agroforestry system:** It aims at meeting the basic needs of small family having less holding and very limited capacity for an investment, e.g., shifting cultivation, scattered trees in the farm, homestead agroforestry.

b) **Commercial agroforestry system:** It refers to larger scale production on commercial basis. The main consideration is to sale the products, e.g., coffee/tea production under tree shade.

c) **Intermediate agroforestry system:** It is an intermaidte between commercial and subsistence agroforestry systems It is often practiced in medium sized farms. The system aims at meeting the needs of the family and selling of the surplus.

The socio-economic classification of agroforestry system may further be classified on the basis of management: (i) intensively and (ii) extensively managed systems. Furthermore, it can be classified based the technology used: (i) low, (ii) high and (iii) intermediate technology system.
3.4.4.3 Traditional agroforestry practices in Ethiopia

Agroforestry is an old-age practice in the Ethiopian farming systems. Trees are planted in agricultural or silvopastoral systems to provide shade, windbreak, medicines, or to meet household energy and construction needs. Traditional agro-forestry system takes the form of trees scattered on crop fields, woodlots, homestead multipurpose tree planting and multi-storey home garden.

The Gedeo agro-forestry system has been practiced since the time land users inhabited the area and it has gradually developed through experiences gained and being adapting to other parts of the country. Varying agro-forestry systems have at the same time been practiced in Sidama, Guji, Wollaita, Kembata and Tembaro, Hadiya and Keffa zones (SLM Technologies and Approaches in Ethiopia, 2010, former MoARD). Crops grown largely depend on specific agro-climatic and socio-cultural conditions of the area. There are various agroforestry systems are being practiced in various agro-ecological zones of Ethiopia, which range from multi-story systems to scattered trees kept in farm lands such as growing of *Acacia albida* as a permanent tree with cereals, vegetables and coffee in the Hararghe highlands (Badege Bishaw, 2003).

The type and composition of crops and vegetations varies depending on slope, soils, amount of rainfall and socio-cultural conditions of the area. Some of the commonly practiced agroforestry systems in different parts of the country include: cereals-trees, coffee-trees, enset-trees, enset-cereals, fruit trees-root crops and the like. The most suitable combination of trees and coffee plants according to Jimma Agricultural Research Centre (SLM Technologies and Approaches in Ethiopia, MoARD, 2001) are: Delinox–coffee, Milletia-coffee, Albizia-coffee, Acacia-coffee, Sesbania-coffee or the mix of the two or more of these trees with coffee. Similarly, the most suitable combination of trees and enset plants are Cordia (Cordia Africana), Hagenia, Vernonialina (Vernonia, Amygdalina), Erythrina (Erythrina brucei) and Croton.

3.4.4.4 Agroforestry practices in different land use systems

*Scattered trees on crop lands*

Scattered trees on crop lands is one of the most widely practiced agroforestry systems in Ethiopia. The trees are usually permanent and full size and they may be dispersed either singly or in clumps. Dispersed trees grown in farmlands characterize a large part of the Ethiopian agricultural landscape. In most cases, farmers plant trees or maintain them in their croplands for different purposes. The system has much potential for supplying fodder, poles, farm equipment, fuel wood, and agricultural improvements, which farmers are believed that growing of selective tree species in their croplands can increase production of annual crops and improve the soil and water conditions for crop growth and development. Traditionally, trees would be grown in a scattered form over a
crop field and usually the number of trees varies between 1–20 trees per hectare to minimize impact on the companion crop.

Some good examples include growing of Cordia africana intercropping with maize in Bako in western Oromia; Acacia albida-based agroforestry system in the Hararghe Highlands and Debrezeit area (Hoekstra et al. 1990). It was indicated that *Acacia albida* is particularly a well-suited tree species for its unique property that it drops (sheds) its leaves during the rainy season and the leaves do not re-emerge until the dry season is completely on. Therefore, cereal crops will have the opportunities to grow well under the leafless trees without any effect of shading. In addition, the pods and leaves of *Acacia albida* can provide a delicious source of food for livestock. The trees can be lopped or pollarded and the leaves, twigs and branches are used for improving soil fertility, fodder, fuel, farm tools. The most commonly maintained trees in South Central Highlands of Ethiopia areas are *Acacia* spp, *Juniperus procera*, Cordia africana, Croton macrostachys, Sasbania sesban, Grevillea robusta and Olea africana.

- **Management and maintenance**

In places where such practices are not introduced yet, selected tree seedlings suitable for the agro-ecology under consideration can be planted haphazardly in the farmland at the rate of 50 seedlings/ha. For the first few years the seedlings planted must be kept free from livestock interference as the seedling could be trampled and damaged by animals. This is the great challenge in the Ethiopian context, where open grazing is widely practiced on croplands after harvest. On the other hand, weeding and mulching is important to protect them from the invasion of weeds and reduce competition for nutrients and soil moisture and evaporation rate. In addition, construction of micro-basins around newly planted seedlings and mulching with leaf litters are essential to conserve water for better survival of seedlings in dry areas.

The spacing actually depends on different factors for example; the recommended spacing for *Acacia albida* on farmlands when planted in a systematic manner is 10mx10m and the trees showed good performance.
Home gardens can be found commonly in southern and southwestern parts of Ethiopia. Crops such as coffee, enset, pepper, and numerous kinds of vegetables are dominant components of the Ethiopian home gardens. Trees like *Cordia Africana*, *Milletia fruginea*, *Albezzia gummifera*, *Ficus* species, and *Acacia* species are among the species that form the upper storey. In some areas fruit trees such as avocado and mango can be found in the system. The middle story containing enset, coffee, and maize, while vegetables, spices, herbs cover the lower canopies. The structural complexity in the Ethiopian home gardens is varied and ranges from complex and diverse forms containing numerous species and strata, as the one in Sidama, to the less complex forms, with one or two crop/tree mixtures as in Gurage enset home gardens.
Alley cropping

Alley cropping is an agroforestry system in which fast growing nitrogen fixing trees/shrubs are planted as hedgerows at wide spacing, creating alleyways within which agricultural crops are produced and the system is suited to humid and sub-humid tropics (kola and Woina Dega areas) and contributing to improve soil fertility. Alley cropping is an important step in meeting the fodder, fuel and food requirements of the farmer. The primary purpose of alley cropping is to maintain or increase crop yields by improving the soil fertility and micro-climate. This system is most suitable for marginal and sub-marginal lands, on flat lands and sloping lands. This form of agroforestry is practiced in many parts of Ethiopia.

The sorghum/maize and chat (Catha edulis) hedgerow intercropping in the Hararghe Highlands of eastern Ethiopia is one such example of alley cropping. The shrub chat is a stimulant cash crop that generates cash for the farmer while the sorghum provides food grains. Although the soil regenerative properties of the system are not obvious, studies indicated that the chat undoubtedly played a role in soil conservation in the hilly landscapes like that of the Hararghe area, (Bishaw & Abdelkadir 1989).

Design and recommended species for alley cropping

Alley cropping is distinct from other agroforestry practices because with alley cropping the focus is on soil improvement but mulching between the hedgerows. Contour vegetation strips, by contrast, are designed to reduce the length of slopes and the speed and the amount of water flowing across the soil surface. In designing alley cropping it will be important to select trees that do not compete with crops for nutrients, soil moisture and light. In alley cropping system trees to be selected in addition to soil fertility improvement need to provide products such as fuel wood, fodder and/or food.
There are actually some design considerations that need to be taken into account in designing of alley cropping systems. These are: (i) hedge species (ii) within-row plant spacing, (iii) width of hedgerows, (iv) spacing between hedgerows (or width of cropped alleys), and (v) management of pruning.

Planting space depends mostly on plant species, climate, slope, soil condition and space required for people and animal farming to move freely. In humid and moist sub-humid climates, direct sowing of seed has been successful, following which, seedlings can be thinned to a spacing of the order of 10cm. The recommended spacing is usually ranges from 4 to 8m between rows and 25 cm to 2m between trees within rows. The closer spacing is used in humid areas and wider spacing in sub-humid and semi-arid regions.

The recommended species for alley cropping usually includes leguminous trees to improve soil fertility through nitrogen fixation, which have the following characteristics: (i) trees with sparse, small crown to permit sunlight (ii) with fast re-sprouting capacity after pruning, coppicing, pollarding and lopping (iii) have deep-tap rooting system with few lateral branched roots near the surface.

Recommended species suitable for dry areas are Giliricida sepium, Cacia siamea, Cajanus cajan, Calliandra calothyrsus and Sesbania sesban. Leucaena leucocephela is reported for its effect on high yielding and nutrient recycling potential but it is not recommended, due to the fact that it highly attracts animals and insect pests. But for Dega agro-climatic zones the recommended species are tree lucerne, Erythrina bruce and Acacia decurrense, Korthc, Grevillia robusta; whereas for Weyna Dega agro-climatic zone recommended to use Sesbania sesban, Calliandra calothyrsus, Leucaena leucocephela and Croton.

Management

The important aspect that should be taken into account is that during establishment hedgerows need protection from browsing animals, trampling or pests. Weeding, fertilizing and other management practices done for the crop would be beneficial to be used as well for the hedgerows. Alley cropping can be combined with fodder crops such as Acacia albida, fruit trees such as Persica Americana (avocado) and Carica papaya or trees intended for pole production or combined with contour vegetation strips, other structural measures and composting. The woody plants are pruned periodically and leaves and twigs are used as mulch on the cropped alleys in order to reduce evaporation from the bare soil surface, suppress weeds that compete with the annual crops for nutrients, water and light.
Figure-26 Showing alley cropping practice

Figure-27 Alley Cropping of Sesbania and Barley
**Agroforestry on pastures and rangelands (Silvipasture)**

The production of livestock can be increased and sustainably used if fodder trees are incorporated in pastures development. This is increasingly important in arid and semi-arid areas for as shrubs and trees are the most important nutrition source for livestock during the dry season. Branches, fruits, leaves and twigs are consumed by animals and provide a good deal of protein. The other advantage is that grass production is higher under the shade of fodder trees and remains green longer than those growing in open fields. Silvipasture involves the selective protection and management of naturally occurring trees and shrubs of particular values for animal fodder. Tree may also be deliberately planted with existing grasses, either dispersed as individuals, in clumps or in rare cases in lines or blocks. Grasses or any other fodder shrubs can be planted in selected naturally occurring trees compatible to the forage species under the consideration and this can be managed by thinning out the natural plantation in order to allow sufficient light penetration for normal growth and development of fodder species.

Species that can be promoted on pastures and rangelands include:

- In the semi-arid and sub-humid areas: *F. albida, A. seyal, A. tortilis, A. sieberiana, A. abyssinica, A. etbaica, A. bussei, B. aegyptiaca and Z. spina-christi*.
- In the arid areas there is the *Acacia - Commiphora* woodland vegetation with *Acacia misera, A. socotrana, and A. spirocarpa* species; and near wadis *Tamarix nilotica, Ziziphus mauritiana, Z. mucronata, Phoenix reclinata, Leptadenia spartium* and *Conocarpus lancifolius*.

**Agroforestry in farm boundaries and border spaces**

Multipurpose trees can be planted for living fences to protect people and their dwellings, crops, animals and delineate individual farm fields and plots. Plants may form the entire fence structure, or living trees may be used as fence posts and serve as sources for fuel wood, fodder, construction purpose. Farm boundary spaces provide a convenient site for planting productive trees and shrubs that do not fit with the other land use systems, elsewhere. In practice, in farm boundaries and border spaces available a few large trees of particular species may be planted in lines or in dense hedges. These multipurpose trees normally do not occupy too much spaces or they do not have significant shading effects on annual crops since the trees are grown on farm boundaries or open spaces and do not interfere with the regular farming operations. *Grevillea robusta, Mangifera indica, Calatropis procera, Euphorbia abyssinica, Commipora erythraea* and *Acacia* species are among the recommended tree species for farm boundary planting.

However, it is important to note that the selected trees for farm boundary planting must have deep rooting system and compatible with the farming system in order to
avoid the negative effects of trees on annual crops grown. In most cases, there is a
tendency of planting Eucalyptus species in farm boundaries, which have negative effects
on the crops grown nearby. In the first place Eucalyptus has a high water consumption
pattern and competes for water with other crops and secondly, it is believed that
Eucalyptus has a characteristic of releasing some exudates through its roots to its
surrounding, which might have a growth restriction nature on the other plant species
grown around.

Live fences however, are different from that of border line planting, where trees or
shrubs for live fences planted in a more densely spaced manner in order to avoid easily
penetration of animals and people to access the resources. Many species adapt to the
use of live fences. *Euphorbia* species, *Acacia machrostachya*, *Acacia nilotica*, *Balanites
aegipatica*, *Calatropis procera*, *Commiphora africana*, *Parkinsonia acculeata*, *Erythrina
abyssinica* and *Ziziphus* are among the recommended species for live fencing.

**Wind breaks**

Multipurpose trees can be planted in farm boundaries for windbreaks to protect crop
fields, pastures and soil and water resources from being damaged by wind. Windbreaks
are strips of trees and other vegetation intended to reduce the speed of wind, thereby
contributing to minimize the negative impact of wind erosion, evaporation, and wind
damage to crops. Sometimes windbreaks are referred to as shelterbelts although this
term is used for wider strips of vegetation with more rows of trees and shrubs than
windbreaks. Windbreaks have high the potential for cereal crops such as millet and
sorghum. The windbreak trees can also provide significant quantities of fuel wood and
poles without affecting their primary function.

The density of vegetation determines the effectiveness of a windbreak. A vegetation
density of 60-80 percent seems to work best in arid areas. But if the vegetation is too
dense that blocks the wind completely, it causes turbulence close to the ground
loosening the soil particles which is then will be easy to be picked up by the wind. Wind
that carries soil particles causes damages to crops through the scratching effect of the
sediment load on plant tissues. Therefore, in areas where open spaces are significant
and exposed for strong wind movement, it is recommended to establish plantings to
serve as windbreaks and reduce the likely impact of strong winds on crop fields and
consequently reduce crop yields.
**Agroforestry on communal lands**

Agroforestry practices can be implemented in communal lands such as in schools, clinics, or in places of worships and road side plantings resemble other form of plantings in public places. In all cases, the planting of trees may include planting of ornamental and shade trees or trees that provide useful products for local consumption such as for food or its medicinal values. Schools, clinics, worship places may be excellent sites to demonstrate new agroforestry practices or species to the local community. The use of woody plants in public spaces may range from planting of a single large tree of religious or cultural significance to trees, which could provide shade, fruits or fodder or planted for construction purpose.

Road side planting, particularly well suited to demonstrate combinations of grasses and trees or fully developed agroforestry production systems. Planting trees along the roads or walking paths is also common in many parts of Ethiopia and this needs further encouragement in order to increase areas under tree cover. The principal objective of road side planting is that road side soils can be protected from erosion and trees can
serve for shading. In addition, road side planting can be used for fuel wood and construction purpose. Species like *Eucalyptus* and *Grevillea robusta* can be cut back and pollarded respectively, almost every three to five years, yielding considerable amount of fuel wood and poles for construction. Trees must be planted on major roads with the recommended spacing and in such a way not to affect the traffic movement. In this regard, it is recommended to manage road side planting at least 2m to 4m far from the main road with the planting spacing of 6m on average and not closely planted and additional space must be kept around curves to enable good visibility for safe traffic movement.

![Figure-29 Road side planting](image)

**Protection and rehabilitation of waterways and gullies**

Multipurpose trees, shrubs and grasses may be planted to help stabilize rock or wooden structures established for erosion control on waterways and gullies. These trees may also be planted in lines to form living structures across the lower reaches of shallow channels or to help stabilize the areas behind conservation structures once these are filled with soil and debris. Multipurpose trees and tree crops may also be established with grasses on sloping bank of streams, gullies, or channels and in such sites, they serve to protect the soil on the slopes, to shade water courses and to provide fuel wood, fodder, fruit, etc.

Permanent vegetation, particularly trees and shrubs, can play a major role in stabilizing artificial waterways and gullies, as well as natural stream banks. If properly located in the channel sections, woody vegetation helps decrease water velocity along the channel edges and protects exposed soil, gravel or rocks from the erosive forces of flowing water. Woody plants once established can completely stabilize small washouts and gullies and can complement physical erosion control structures. In such sites; trees,
shrubs and herbaceous plants may also provide fuel wood, producing of small poles, fodder, fruit and medicine. Furthermore, well established woody vegetation in gullies can also serve for bee forage, oil seeds or fibers.

In most cases, there are three types of channels that need stabilization:

- Naturally existing ones such as stream courses,
- Gullies caused by poor management practices,
- Artificial waterways, cut-off drains and diversion ditches

**Priority setting in gully treatment**

The treatment of gullies is an expensive operation and it would therefore, be necessary to set priority for treatment because resources and finances are always limited. Consider the following, in setting priority:

- Discontinuous gullies should be given first priority for treatment, because they have greater potential for rapid growth than continuous gullies and younger gullies are easier and economical.
- The potential for vegetation growth and development in the watershed must be carefully studied. If quick revegetation of the gully can be ensured, a combination of minor structures and vegetation measures can minimize the number of gullies requiring intensive treatment.
- Gullies that have more or less reached the stage of metastable equilibrium through natural vegetation, should best be left to nature, for recovery through vegetation and excluding of livestock.

Strategies that need to be followed for effective gully control are:

- Apply preventive measures, including proper land use, soil management & conservation practices.
- Runoff control is the first, foremost and effective control method of gully control. This can be done through conservation of the water in the catchment of the gully, diversion of the water from flowing into the gully and conveyance of the water through the gully.
- Watershed rehabilitation; retention of water on the watershed through mechanical and vegetative measures. This can be achieved through construction of micro-basins, level terraces and plantations, which are considered as viable techniques for gully treatment.

**Gully stabilization**

The conservation measures for gully stabilization include:

- Biological /vegetative/agronomic conservation measures,
- Physical/engineering/mechanical/structural

A gully will revegetate naturally if the water causing erosion is conserved or diverted before it reaches the gully and if livestock are kept away. But this process is slow and in
in order to speed up the recovery rate and for an effective gully control programme, vegetative and structural conservation measures should be combined. Structural measures are just an aid to vegetative measures. However, in dry areas where conditions are harsh for vegetative measures, then structural measures are necessary.

Figure-30 Stabilization of water ways and gullies

**Exercise 3:**

Describe the traditional agroforestry based land management system in your locality and come up with the proposed ideas how to improve the system? Select the more appropriate and representative agro-ecologies in your working areas and discuss in brief your conclusion to training participants.

**3.4.4.5 Some considerations in designing and establishing agroforestry system**

Agroforestry is a system of practice that involves a close association of trees and shrubs with food crops and animals and/or pasture development. Existing traditional land-use
practices involving combined production of trees and agricultural crops and managing of livestock within the same unit of land in many parts of the world and Africa, including Ethiopia. Therefore, agroforestry was recognized as a land-use system which is capable of yielding both wood and food, conserving and rehabilitating the ecosystem.

Agroforestry system could be identified and implemented as one of the potential interventions that could be captured in an integrated community-based watershed development programme. Agroforestry needs to be seen not as an independent component but as integrated part of watershed components, which can be implemented in a more integrated manner with other natural resources management activities.

Factors that necessitate implementation of agroforestry as a land management system are:

- Multipurpose effects of agroforestry in conserving the ecosystem & improving soil productivity,
- Increased interest of the scientific world in intercropping farming system gave rise to agroforestry,
- Increased rate of deforestation and ecological degradation, due to increased demand for energy, construction materials, expansion of land for cropping and grazing,
- Energy crises of 1970s and consequent price escalation and shortages of fertilizers,
- Establishment of supportive research institutions worldwide to support expansion of agroforestry.

The main objective of introducing agroforestry systems in the farming practices is to enhance and maximize the positive interactions among trees/shrubs, ground cover, crops, livestock and water in order to increase the overall production and diversity from a given unit of land. Overall, agroforestry practices are aimed at achieving the following major goals: (i) Long-term economic stability (ii) Harmonized production system (iii) Environmental protection and (iv) Better use of the available land resources, including marginal lands.

In designing the agroforestry based land management systems it is vital to take into consideration the following characteristic features: (i) Compatibility of the proposed components of agroforestry to the existing land use system suitable to the various agro-climatic zones, (ii) Social acceptance- this means the recommended agroforestry system should be widely accepted by the local communities and (iii) Economic return from adopting the new agroforestry system- multiple uses such as firewood, timber, green manure, fodder and raw materials for local industry in addition to producing of food crops. These products are very valuable and provide more income to farmers as compared to the income obtained from rainfed farming and (iv) in the designing aspect the traditional knowledge base and local level experiences need to be considered. In this
regard, the preference of the communities and/or individual farmers needs to be taken into account in order to convince them to adopt the recommended options.

### 3.5 Area closure

In the Central and Eastern highlands, Northern and North Western parts of the country, areas with steep slopes (over 70%) have now been either cultivated or grazed due to the increasing demand for land significantly contributing to increased rate of land degradation. These severely degraded areas demand conservation efforts in order to reclaim and improve their productivity.

Area closure is therefore, one of the components of biological conservation measures and it is practiced in all land use types where soil erosion becomes serious and the land has lost its productive potential. When land is severely degraded, due to erosion, it would be impossible to produce sufficient biomass. Hillsides are more susceptible for erosion and these areas are the most prominent sites for carrying out area closure. Area closure is a simple conservation system carried out to improve severely degraded hillsides primarily through regeneration of natural vegetation. However, to some extent limited interventions are also recommended to be carried out to enhance the rehabilitation processes such as enrichment planting, water harvesting structures, fencing and the like.

Area enclosure meant for natural resources conservation is being carried out in different parts of the country. Substantially vast areas of severely degraded areas have been rehabilitated with area enclosures, particularly in Northern and Central Highlands of Ethiopia. In particular, the efforts and best experiences observed in mass mobilization in Tigray region and the corresponding achievements recorded in area closure and in other soil and water conservation activities can demonstrate the effectiveness of the approach if properly implemented. In closed areas, regeneration of the environment is observed, ground water discharge increased and the downstream users are protected from erosion.

Protecting of hillside plantations from interference is entirely different from that of area enclosures. Hillside plantations are undertaken in lands, which are not seriously degraded, and techniques such as micro-basins, trenches and hillside terraces are used wherever necessary to ensure the survival of the seedlings planted. Area enclosure is a practice implemented in areas with severely degraded lands that are closed from the interference of livestock or human activities and left for nature to take care of the regeneration processes.
Major activities being undertaken under area closure

- Carry out close consultation and actively involve the communities in the decision process for area delineation and closure,
- Agree with the communities for how long the area needs to be closed based on the specific conditions of the area,
- Close off the entire area from human and livestock interference until it is completely recovered and ready to be reused,
- Clearly set out the roles and responsibilities of stakeholders including communities for effective management and protection of area closure,
- Plan and implement for what purpose the area be used after it has recovered,
- Identify key interventions to enhance the natural rehabilitation process of area closures
- Identify appropriate species and prepare quality planting materials,
- Conduct regular field inspection and control unwanted and uneconomical plant species,
- Carry out soil improvement activities such as application of organic manures,
- Apply appropriate management practices, which include weeding, removal of unwanted plants, pruning of trees, and protection from livestock,
- Design appropriate strategies to effectively utilize the available resources after the natural recovery such as introduction of cut and carry system, introducing of beekeeping activities.

Experiences showed that area closures planned and executed by the community including hillside plantations by individual land users have shown promising results (experiences in Wello and Tigray). Similarly, promising results are coming up in other parts of the country such as in Oromia and SNNPR regions, of which area enclosures established by Self help International, Ireland in the dry lands of the Rift Valley of South Shoa can be cited. Wherever area enclosures were established, the impact on regeneration has been substantial. The enclosures were established with the consent and involvement of the local community. However, it is important to indicate as well that there are different research needs, which include testing of the effectiveness of enclosures by the communities, adoption and scaling up, socio-economic studies, species selection, effective duration for natural regeneration depending on the specific situation of the area and enrichment planting studies.

In some areas it is witnessed that area enclosures are kept for long period without being used, which is contradicting with the principles of conservation. It should also be understood that after sometimes area under closure could in the future be used for cultivation, grass production or tree production whichever land use system suits the
specific situation of the area. It is also advisable to ensure the equitable utilization of the available resources between community members from the rehabilitated area based on the agreed principles and procedures to avoid conflicts.

Figure-31 Area Closure (Note the abundant grass and tree growth)

3.6  
**Nursery Management and Afforestation Program**

3.6.1  
**Seed Collection and Nursery Management**

3.6.1.1  
**Seed Collection, Processing and Storage**

- Trees are naturally propagated either vegetatively or through seedlings produced from seeds.
- Sometimes seedlings can be collected from natural regeneration.
- Healthy seedlings are artificially produced in the nursery with great care and intensive management, which ensures their better survival rates, ease establishment at the permanent planting sites and confer their subsequent normal development of seedlings into mature trees that can provide the required ecological, social and environmental services.
- In seed collection, processing, handling and storing activities the following are the major activities that are necessary to be undertaken for raising the required quantity and quality of seedlings:
  - Proper species and provenance selection,
  - Determine the required quantity and quality of seeds to be collected,
  - Ensure proper seed collection (period of collection, tree species and collecting of seeds),
Proper seed processing, handling and storing,

- Acquiring quality of seeds to grow seedlings in a nursery is an extremely important step in the regeneration process of forest species.
- The quality of seedlings produced depends on the proper seed source (provenance) and the correct processing, storage treatment and sowing of seeds.

### 3.6.1.2 Species and provenance selection

In tree nursery establishment the first most important issue to be resolved is where to get the required amount and quality of seeds to raise the amount of seedlings sufficient for the intended planting areas. In addition, the type of tree seedlings to be produced depends on site specific situation and other factors.

Provenance means the place in which a stand of trees is growing and it refers to the area where seeds are collected or the location of mother trees. Seedling raising and growing of trees depends on: (i) Maintaining of the right kind of seed source (provenance), (ii) Good quality of seeds collected, (iii) The amount of seeds collected, which should be sufficient for the intended planting areas, and (iv) Availability at the right time.

Seed trees should not be selected at random or on the basis of proximity or convenience to the seed collectors. The genetic quality of the parent tree is an important consideration in seed collection process because characteristics such as fast growth, tree form, and resistance to diseases and insects can be passed on from generation to generation. Therefore, selection of mother trees for seed collection is very important and seeds should be collected from matured and healthy mother trees.

The following points should be considered during seed collection:

- Collect seeds only from healthy and vigorous trees of reasonably in good form.
- Collect seeds from middle aged to mature trees and avoid young or over-mature trees.
- Collect seeds preferably from middle branches since these will be more viable and healthy.
- Avoid collecting seeds from crooked, deformed, abnormal growth, diseased and infested trees.
- Don't collect seeds from isolated trees, due to self-pollinate and seedlings are weak or malformed.
- Seeds should be collected from natural vegetation, which naturally cross-pollinated and dominant.
### 3.6.1.3 Seed collection

#### Period of seed collection

Seeds must be collected when they are ripe and ready for collection. Seed maturity can be detected easily for fruits and cones by their colour. Most fruits turn yellow, red, brownish, etc. (depending on their nature) when they are ripe enough and these indicate the right time for seed collection. Other methods like moisture content, specific gravity can also be taken as a good indicator to determine the time of seed collection. But in the field, change in the colour of fruits and its readiness to fall are important methods for deciding the period of seed collection. Fully ripened fruits are picked directly from the trees or collected as they fall but collecting of ripened fruits directly from the tree is more preferred to maintain quality seeds.

Seed bearing of trees/shrubs may not be regular in every season. Therefore, it is wise to make advantage of seed collection during good season as much seed as possible and use them during bad seed seasons. However, tree species like *Tectona grandis*, *Gmelina arborea*, *Acacia nilotica*, *Jacaranda mimosaefolia*, *Delonix regia*, *Acacia mearnsii*, *Eucalyptus* hybrid and the like are seeding almost in every season. For such species this will give an opportunity to collect the required quantity of seeds in every season.

#### Seed collection and handling

Seeds and fruits can be collected from a standing tree by hand and the collector picks the seeds/fruits while standing on the ground. On the other hand, the branches that bear the seeds or fruits can be cut down with the help of long pruning saw and collect the seeds. Collection of seeds and fruits can be done by climbing up the tree. Shaking trees to collect seeds by laying canvas on the ground is another means of cheap seed collection method. In seed collection, labelling of the right tree species (provenance), the period of collection and the amount of seeds collected are important issues to be considered during seed collection.

### 3.6.1.4 Seed quantity

The amount of seed required depends on the number of seedlings needed for planting of the intended area and the capacity of the seeds to germinate and grow into healthy seedlings. The number of seedlings will depend on the recommended spacing of tree species, the number of seeds obtained from one kg seeds, which in most cases, will depend on the size and weight of the seeds.

Therefore, seed requirement can be calculated using the following formula:

\[
\text{Seed amount required} = 125 \times \frac{N}{pW} (1 + \frac{E}{100})
\]

where \(N\) = Number of seedlings required for planting; \(p\) = germination rate; \(W\) = No. of seeds per kg; \(125\) = correction factor to add a 25% reserve and \(E\) = an extra quantity required if some of the seeds are not good.
Exercise 4: Example of calculation of seed requirement:

Given:
- Species A targeted to plant 30 ha with a planting density of 2,500 seedlings/ha (number of plants required, \( N = 30 \times 2,500 = 75,000 \) seedlings),
- Germination rate (\( p \)) = 20%,
- No. of seeds per kg (\( W \)) = 70,000
- 10% will get damaged during storage (\( E \)) = 10%

Calculate the amount of seed required to plant 30 ha of land, including 25% reserve:

\[
\text{Amount of seed required, kg} = 125 \times \frac{N}{(1 + E/100) \frac{pW}{30 \times 70,000}} = 125 \times \frac{75,000}{75,000} = 125 \times 0.03571 = 4.464
\]

\[
30 \times 70,000 = 2,100,000
\]

\[
= 4.464 + 0.464 = 4.928 \text{ kg, which is approx } \approx 5 \text{ kg}
\]

3.6.1.5 Purity

In some cases the seed supplied to the nursery includes impurities. Purity test is therefore, essential in order to determine the amount of seeds required for a given size of nursery. Therefore, purity test is obtained by separating trashes or impurities from a given sample of seed lot. In performing a purity test a given sample is weighed, the trash and other impurities are separated and both separated portions are weighed again. If the weight of the original sample and the total of the separated components differ by more than 1%, then it is recommended to draw another sample.

Purity is computed by the formula:

\[
Purity \% = \frac{\text{Weight of pure seed} \times 100}{\text{Total weight of original sample}}
\]

Exercise 5:

Given:
If the total weight of original sample is 500 g and the weight of the pure seed is 450 g then calculate the purity of the given sample.

Calculation procedure:

\[
Purity \% = \frac{\text{Weight of pure seed} \times 100}{\text{Total weight of original sample}} = 450 \times 100 = 90\%
\]

\[
\text{Total weight of original sample} = 500
\]
3.6.1.6 Germination Percentage

Germination is actually the process of transformation of a seed or an embryo into a seedling. In order to determine the number of seedlings to be obtained from the amount of seeds collected, it is necessary to know the germination percentage. Germination percentage is expressed as the total number of seeds that germinate from a given number of seeds or from a given weighed seeds. For example out of 100 seeds if 20 have germinated, the germination percentage would be 20%. The germination percentage can easily be obtained for many of the species in few weeks time. Using such information will enable to determine how much seed would be required for the intended number of seedlings to be raised by adding the losses as a result of germination capacity.

Germination percentage is determined using the following formula:

\[
\text{Germination} \% = \frac{\text{Number of germinated seeds} \times 100}{\text{Total number of seeds sown}}
\]

Germination test is carried out usually in four replicates, which is composed of 100 seed. Each replicate is placed in a plastic box on a sterile medium. The medium may be sterile sand, perlite or crepe paper. Tree seeds need light for maximum germination, so the containers should not be stacked or covered. Tree seed are basically moisture tolerant. Most species will germinate on substrate moistures ranging from 30 to 70 percent of the water-holding capacity. Temperature is also important factor for tree seed germination. As temperatures increase, the speed of germination increases but not always total germination. In carrying out germination test, germination should be recorded starting from the seventh day of sowing and at least three counts must be made. Usually, germination might start on the fourth day after sowing but for most species the peak is from 7 to 14 days and it will continue up to 28 days. Thus, the most informative counts could be carried out from the tenth to twentieth days. For seeds with long dormancy period seed stratification is required in order to encourage maximum germination.

The other factor that needs to be known is to know for how long the seeds collected from different tree species can be stored before it loses its viability. In addition, during tree seeds collection it is important to remember the fact that some tree species may produce good yields of seed only in every second or third year. The approximate seeds storage period for some tree species is provided in Table 6 below.
Table 6. Seed characteristics of some selected tree species

<table>
<thead>
<tr>
<th>Species</th>
<th>Seed/kg (000)</th>
<th>Germination</th>
<th>Storage time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia cynophylla</td>
<td>66-77</td>
<td>Good in 10 days</td>
<td>3 years</td>
</tr>
<tr>
<td>A. decurrens</td>
<td>50-70</td>
<td>Very good in 7 days</td>
<td>2 years</td>
</tr>
<tr>
<td>A. lebbeck</td>
<td>6.6-8.8</td>
<td>50-90% in 10-30 days</td>
<td>4-5 years</td>
</tr>
<tr>
<td>Azadirachta indica</td>
<td>4-4.4</td>
<td>75% in 10 days</td>
<td>4-6 weeks</td>
</tr>
<tr>
<td>C. equistifolia</td>
<td>660-1,200</td>
<td>Fair in 1-2 weeks</td>
<td>4 months</td>
</tr>
<tr>
<td>Cuperssus lustanica</td>
<td>140-200</td>
<td>20% in 2-3 weeks</td>
<td>1 year</td>
</tr>
<tr>
<td>E. camaldulensis</td>
<td>200-1,000</td>
<td>Good in 7-10 days</td>
<td>3 years</td>
</tr>
<tr>
<td>E. globules</td>
<td>99-110</td>
<td>40% in 7-12 days</td>
<td>2 years</td>
</tr>
<tr>
<td>Grevillia robusta</td>
<td>65-100</td>
<td>Good in 2-3 weeks</td>
<td>3 months</td>
</tr>
<tr>
<td>Juniperus procera</td>
<td>40-45</td>
<td>20-40% in 2-8 weeks</td>
<td>1 year</td>
</tr>
</tbody>
</table>

Exercise 6: Calculating seed requirement

Given:
- Acacia decurrens has purity percentage of 90
- In 1 kg of seed A. decurrens has a maximum of 70,000 seeds
- Germination percentage is equal to 80%

Then calculate the seed requirement of Acacia decurrens, for producing 100,000 seedlings.

Calculation procedure:
- Calculate the amount of pure seeds with the purity of 90: Pure seeds = 70,000 x 90/100 = 63000;
- Calculate the required pure seeds with 80% germination: Pure seeds = 63000 x 80/100 = 50400
- Then calculate the actual seeds required: Required seeds, kg = 100,000/50,400 = 1.98 kg

3.6.1.7 Seed processing

The collected seeds need to be dried prior to storage. The seed of most species can be extracted by sun-drying. The collected fruits are spread in thin layers on canvas, trays or using other materials and exposed to sun. In order to fairly dry the seeds regularly stirring is essential until they are completely dried up and cones, pods or capsules are open and release the seed easily. For species with fleshy fruit, the pulp has to be removed first with knife, wash of the rest under water and then sow the seeds immediately. Chaff and seeds can be separated by winnowing or by submersion in water. Good seed will usually sink to the bottom, while dull seeds, chaff and other impurities float. After separation, good seeds are thoroughly dried in the sun. Wet or fleshy seeds and fruits should not be stored.
After the seeds are well sorted, they should be packed in sacks or bags and stored in a dry place.

3.6.1.8 Storage of seed

For most tree seeds, cool and dry storage in a dark place is recommended. Some species can be stored for several years without significantly losing their viability while others may lose their viability within a few months. Seeds of leguminous species (those having pods like beans) can be stored for many years even at normal temperature. In general, for any seed, storage temperature should be kept as constant as possible even though cool storage facilities cannot be provided. In addition, seed store needs to be free from moisture, well ventilated, having raised bed structures, and be free from insect and rodents.
3.6.2 Nursery Operations

The easiest and cheapest method of regeneration of trees is to sow seeds directly in the field and letting them grow by excluding human and livestock interference. Direct sowing is successful for most species of Acacia. But this is not always easy to achieve, and raising seedlings in the nursery is needed for producing dependable and vigorous seedlings.

Nursery operations include nursery site selection, land preparation, determining of the nursery size, design and layout of nursery, determining of management system such deciding potted or bare roots, determining of soil mixture, sowing and nursery management practices, which include mulching, shading, watering, transplanting, root pruning, cultivation and weeding, hardening-up, size and quality of seedlings, culling.

3.6.2.1 Nursery site selection criteria

Selecting a site for a permanent forest tree nursery is the most important step in the production of tree seedlings. Failure to select appropriate nursery site will result in unsatisfactory seedling production with low survival rates.

The following procedures need to be applied in order to select an appropriate site for tree nursery:

1. Determine the ultimate production capacity of the proposed nursery
2. Decide the geographical area
3. Topography of the area
4. Permanent water supply
5. Suitable soil type for nursery
6. Land availability and cost
7. Access and labour availability

3.6.2.2 Nursery capacity /size

The size of the nursery area depends on:

- The number of seedlings required for planting in a given area of land,
- The time it takes to produce seedlings of the desired size and species in the nursery,
- The size of the containers (if seedlings are planned to be produced in containers).
Therefore, the nursery area can be calculated depending on the specific situation as outlined above and also by taking into consideration the size of the potting materials being used.

**Geographic area /location**

The present and anticipated future capacity of the nursery will dictate the physiographic and land-use area where a nursery can be located. It might be sometimes difficult to establish nursery sites wherever required. Therefore, the nursery site should be located in a more representative geographic area and easily accessed by the communities and the concerned institutions for providing effective and efficient technical backstopping service. In addition, the nursery area requirements need to be determined based on the species and quantity of seedlings anticipated.

**Water availability**

A guaranteed water supply all year round is absolutely essential. Water is needed most when least available. On an average 10 – 20 litres of water per m² of productive area are needed depending on prevailing temperature. The construction of a small channel diverting water into or close to the nursery can greatly reduce time and cost of watering. However, water with high salinity content, which may occur in dry areas, should be avoided.

**Soil**

The soil of the nursery site is highly important, particularly for bare-root seedling production. But for potted plants, suitable potting soil should be available close to the nursery. The soil type to be selected for nursery establishment should not be too sandy because otherwise it falls out of the pots, nor contain too much clay because extreme swelling and shrinking damages seedlings roots. The best soil types have the characteristics of optimal proportions of air and water in soil pores after natural drainage, adequate drainage of excess water, adequate infiltration rate, high resistant to compaction and soils, which are not highly susceptible to erosion. Therefore, sandy loams or loamy sands whose silt and clay contents are 10 to 20% and have adequate amount of organic matter, which improves soil structure and drainage are considered best for nursery establishment. Shallow and stony soils with hard pans at certain depth are not suitable. The optimum pH for most tree species is between 5.0 and 6.0.
Topography

The nursery site should not be exposed to desiccating winds such as those prevailing on hilltops, nor to flooding or severe frost, as may occur in valley bottoms. Relatively flat land is most suitable, ideally 1-2% slope because this permits the water to runoff. Standing water, no matter how little it is, causes complete destruction of nursery stocks. If flat land is not available, in areas with slopes more 2% terraces have to be constructed in order to reduce runoff and minimize the impact of erosion.

7.1.1.1 Materials and equipment required for nursery management

The following are some of the materials required for nursery management: (i) Sand or fine gravel and humus or forest soils need to be available close to the nursery, (ii) Poles and sticks should also be available for fencing, shading, building etc., and (iii) different types of nursery tools (for details see annex I).

7.1.1.2 Basic nursery facilities

There are actually two types of nurseries, i.e., permanent and temporary nursery. In general, a tree nursery would have the following major facilities:

A) Access roads and paths - to facilitate the need for transport of materials and seedlings,

B) Fencing – to protect seedlings against browsing and trampling animals,

C) A shelter for keeping tools, materials and workers,

D) A soil dump - this is to store soils, sand and humus for the production of potted seedlings,

E) Seedbeds - the seedbeds should be 1 m wide with 60 cm path between seedbeds.

F) Potbeds - usually it is recommended to use beds 1 m wide and 5 – 10 m long,

G) Shading and shelter for plants to protect them from frost, hail and heavy rains.

7.1.1.3 Design and layout of nurseries

The production of high quality forest tree seedlings requires a skilfully designed nursery with adequate facilities. In this regard, care must be taken to plan and layout seedbeds, roads, drainage and other nursery facilities when the nursery is established. Proper designing and layout of the nursery is therefore, an essential step in order to make nursery management easy and make optimal use of the available area.
7.1.1.4 Area needed for nursery

The area needed for a nursery depends not only on the number of seedlings to be produced, but also on how much of the nursery stock is raised as potted plants, bare-root seedlings and cuttings. The diameter of the pots or the spacing between bare-root seedlings or cuttings will affect the area needed.

Table 7. Estimation of nursery size for potted seedlings

<table>
<thead>
<tr>
<th>No. of seedlings to be produced</th>
<th>Total area of beds (m²)</th>
<th>Total area for production (m²) a/</th>
<th>Area including fence &amp; windbreak (m²) b/</th>
<th>Area including roads (m²) c/</th>
</tr>
</thead>
<tbody>
<tr>
<td>100,000</td>
<td>250</td>
<td>450</td>
<td>500</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>360</td>
<td>650</td>
<td>720</td>
<td>1,080</td>
</tr>
<tr>
<td></td>
<td>490</td>
<td>880</td>
<td>980</td>
<td>1,470</td>
</tr>
<tr>
<td></td>
<td>640</td>
<td>1,150</td>
<td>1,280</td>
<td>1,920</td>
</tr>
<tr>
<td>500,000</td>
<td>1,250</td>
<td>2,250</td>
<td>2,480</td>
<td>3,750</td>
</tr>
<tr>
<td></td>
<td>1,800</td>
<td>3,240</td>
<td>3,560</td>
<td>5,400</td>
</tr>
<tr>
<td></td>
<td>2,450</td>
<td>4,410</td>
<td>4,900</td>
<td>7,350</td>
</tr>
<tr>
<td></td>
<td>3,200</td>
<td>5,760</td>
<td>6,340</td>
<td>9,600</td>
</tr>
<tr>
<td>1,000,000</td>
<td>2,500</td>
<td>4,500</td>
<td>4,950</td>
<td>7,500</td>
</tr>
<tr>
<td></td>
<td>3,600</td>
<td>6,480</td>
<td>7,130</td>
<td>10,800</td>
</tr>
<tr>
<td></td>
<td>4,900</td>
<td>8,820</td>
<td>9,800</td>
<td>14,700</td>
</tr>
<tr>
<td></td>
<td>6,400</td>
<td>11,520</td>
<td>12,670</td>
<td>19,200</td>
</tr>
</tbody>
</table>

Note: a/ Ratio b/n Total area for production and Total area of beds is approximately 1.8:1  
    b/ Ratio b/n Total area including fence and windbreak and Total area of beds is approximately 2 : 1  
    c/ Ratio b/n Total area including roads and Total area of beds is approximately 3 : 1
**Exercise 7:** Calculating the nursery area required to raise the given quantity of seedlings

What is the nursery area required to produce 900,000 seedlings/year? Plastic pots can be supplied only to the limited extent of approximately 450,000/yr. Due to a shortage of fencing materials, loading and unloading of vehicles will take place outside the nursery and consequently no inside roads are needed. The diameter of the pots is 5cm and the spacing for the bare-root seedling is 5 x 20 cm.

**Calculation:**

1) The nursery area required for bare rooted beds = 450,000 x 0.05m x 0.20m = 4500m²
   
   Area required for bare-rooted seedlings production = 4500m² x 1.8 = 8100m²

2) Nursery area required for potted beds = 450000 x 0.05m x 0.05m = 1125m²
   
   Area required for potted seedlings production = 1125m² x 2.0 = 2250m²

**Table 8. Estimation of nursery size for bare-rooted seedlings**

<table>
<thead>
<tr>
<th>No. of seedlings to be produced</th>
<th>Spacing b/n seedlings (cm)</th>
<th>Total area of beds (m²)</th>
<th>Total area for production (m²)</th>
<th>Area including fence &amp; windbreak (m²) a/</th>
<th>Area including roads (m²) c/</th>
</tr>
</thead>
<tbody>
<tr>
<td>100,000</td>
<td>5 x 20</td>
<td>1,000</td>
<td>1,600</td>
<td>1,800</td>
<td>2,600</td>
</tr>
<tr>
<td>500,000</td>
<td>5 x 20</td>
<td>5,000</td>
<td>8,000</td>
<td>9,000</td>
<td>13,000</td>
</tr>
<tr>
<td>1,000,000</td>
<td>5 x 20</td>
<td>10,000</td>
<td>16,000</td>
<td>18,000</td>
<td>26,000</td>
</tr>
</tbody>
</table>

**Note:**

- a/ Ratio b/n total area for production (bed for bare-root seedlings, pathways, irrigation system, soil dump and store) and Total area of beds is approximately 1.6:1
- b/ Ratio b/n total area including fence and windbreak and total area of beds is approximately 1.8 : 1
- c/ Ratio b/n total area including roads (as well as fence and windbreaks) and total area of beds is approximately 2.6 : 1

**7.1.1.5 Soil mixture**

The correct soil mixture for germination beds, bare-root beds and pots is characterized by good but not excessive drainage. The nutrient content is also an important aspect. Cattle manure, compost or forest soil rich in humus can be used; this not only increases the nutrient content, but also improves the physical structure of the soil. Up to 1-3 m³/ha cattle manure, green manure, compost or forest soil can be added to the beds depending on the quality of the local nursery soil. The proper soil composition for the pots is something between 1/5-1/3 of well decomposed cattle manure, compost or forest soil mixed with the local nursery soil. If the soil is too heavy, sand can also be added to the mixture.
Some species are better suited for growth in pots and some are more conveniently grown as bare-root seedlings. Therefore, for species that can be raised by either system, the advantage and disadvantages of both systems must be considered. The most important factors that need to be considered among others are: (i) Tree species, (ii) availability of the required materials, (iii) cost of production (iv) labour availability.

Bare-rooted seedlings

Bare-root seedling raising system is growing of seedlings from seed in an open bed from which seedlings are transferred bare to planting site. This is actually an old age practice and is still common in Ethiopia in small-scale nurseries.

Advantages

- They are less complicated to grow in the nursery
- Easy to transport
- Cheaper
- Recommended to use in areas with adequate rainfall
Disadvantages

- They need a bit more time in the nursery to grow to the required size for planting
- The roots are sensitive to air exposure during lifting, transporting and planting
- Difficult to store at the planting site if, for some reasons, not planted immediately.
- The survival rate is often low.

**Potted seedling raising**

Potted seedling raising is a system of growing seedlings in containers either singly or in multi-cavity trays, which are taken to the planting site and the seedlings planted with the ball or plug of soil around the roots.

Advantages

- The time in the nursery can, to some extent, be shortened
- The main roots are not damaged upon lifting, transporting and planting
- They usually have a higher survival rate than bare-root when planted on difficult sites

Disadvantages

- Relatively expensive and requires intensive management
- Regular root pruning may be required in the nursery,
- Plants with pots are bulky to transport.

**Seed handling/seed treatment prior to sowing**

Seed dormancy refers to a state in which viable seeds fail to germinate when provided with conditions normally favorable to germination, i.e., water, temperature and light. The advantage of dormancy is that it prevents seeds from germinating during storage and normal handling. On the other hand, where dormancy is complex and seeds need a specific pre-treatment, failure to overcome these problems may result in poor germination. Treatment of seeds for some of the tree species prior to sowing is sometimes necessary to stimulate and compensate in time for these natural mechanisms in order to accelerate and ensure uniform germination. In deciding which type of treatment is the most suitable depends on the type and combination of dormancy but also on the nursery's facilities.
Raising potted seedlings

Growing seedlings in containers is the standard method being used in Ethiopia, particularly in government owned nurseries. The main operations for growing seedlings in containers include:

(i) **Obtain potting soil:** The soil in the pots has to facilitate germination and root development and to supply the seedling with water and nutrients. It should therefore, be light and rich in nutrients.

(ii) **Prepare suitable soil mixture:** The agricultural soil can be mixed with humus rich soil and sand. There recommended mixture is with 3:1:1 ratio of agricultural soil, humus rich soil and sand.

(iii) **Fill pots:** Soils, sand, manure or compost are sieved and mixed thoroughly. The mixture is then moistened to become humid but not wet. The pots are filled with the help of a funnel.

(iv) **Place pots in beds:** Pots are placed in the beds in an upright position without being squeezed and maintain their normal round shape and space should be left for rain and excess water to drain out.

Sowing

In principle sowing consists of four steps: (i) decide on the sowing method either in pot or seedbed, (ii) procure seeds in the required quantity and quality (discussed in detail under seed collection), (iii) pre-treatment of seeds (discussed in more detail under 5.2.7.3 seed treatment prior to sowing (iv) sowing.

Direct seeding into pots is more convenient for species which germination percentage is high and more or less germinate at the same time, transplanting would cause damage, germination period is short, or if the species develops long and sensitive tap root system. Leguminous species such as Acacia and Eucalyptus can be sown directly into pots.

Sowing into pots saves time for transplanting, avoids shock and death of some seedlings during the operation. Seeds must be placed at the middle of the pot, pressed down gently and covered with the soil at a thickness of the seed.

Mulching

After sowing, mulching of the seedbed is necessary to protect the seeds from being washed away during watering. Therefore, grass mulch or locally available materials shall be used as a blanket for the germinating seeds. In addition, mulching materials serves to reduce evaporation and conserve moisture.

Shading

Seedlings in the early stage of their development, particularly from sowing to immediately after picking out are sensitive to full sunlight, high temperatures, heavy rains and strong winds. Therefore, they should be protected by shading, which is constructed from local materials i.e. branches, grasses, etc. When seedlings are more
resistant, shading is reduced gradually from all day to around midday, and later to none at all. Shades could be constructed in removable forms for ease of management.

![Diagram of pot bed shading](image)

**Figure-35 Removable shades constructed on frames built from branchwood**

However, during the last month in nursery, seedlings should be exposed to full sunlight in order to harden the seedlings and reduce the likely shocks after transplanting to the site.

**Watering**

Watering is a more or less continuous activity in the nursery from the preparation of beds and seedlings to lifting of the seedlings when it is time for planting. So many factors influence the water requirement. As a rule of thumb, the water needed on the bare-root beds or on the pots each day should correspond to a sheet of water of 2 centimetres depth. Though water is always needed, there are periods when it is most critical. These periods are:

- After seeding, to get good germination
- After transplanting to enable the seedlings to recover as soon as possible
- After root pruning to stimulate the development of fibrous root system
- After thinning and replanting in the bare-root bed to help plants become better established
- During hardening-off to prepare the plants for conditions at the planting site
- Just before lifting

Therefore, it is important to consider the following points for adequate watering:

- Water twice a day for the first weeks after germination because the roots do not reach deeply,
- Water only once in a day but thoroughly later and make sure water soaks the pots to the bottom,
Before watering, some pots in beds, if the soil is still sufficiently moist, do not water,

Advisable to water in the evening so less water will be lost through evaporation,

Use watering cans or sprinklers with fine nozzles so as not to wash the soil out of the pots,

Take care that all parts of a bed are watered evenly,

**Pricking out /transplanting**

Sowing in seedbeds requires transfer of the germinated plants into pots after sometimes. This operation is known as pricking out or transplanting of seedlings. It is very important that the seedlings are pricked out when they have reached the right size. In most case, this is when the seedlings have its first true leaves. These are the leaves which appear after the germination leaves. Pricking out or transplanting is a sensitive stage in the life of a plant as it usually causes shock to the seedlings even if carefully done. Carelessly handling of this operation could completely kill the seedlings. If transplanted earlier, the seedlings are too delicate. Later, their roots get too long or the seedlings stop growing because they are too close together.

Before transplanting seedlings, we must make sure that the pots/beds are not too wet or too dry but moist enough. Seedlings can then be lifted from the seedbed using a pointed wooden stick of a pencil size or a small shovel. The seedlings are collected in a small tin filled with a mixture of soil and water. Seedlings should be handled on the leaves but not the roots or the stems, as they can be easily damaged.

The seedlings dry out extremely quickly. Therefore, it is strongly recommended to work under the shade, preferably late in the afternoon or when the sky is cloudy. For ease of the operation it is important to erect a shade above the seedbed. Then make a small dibble hole with the stick into the centre of the pot deep and wide enough to accommodate the roots. The roots of the seedlings are placed carefully in the hole without bending and pointing upwards. The hole is closed by gently pressing the soil around the plant with the fingers to ensure that there is no air pocket left. The surface of the pot is then levelled to avoid depression round the roots, which may cause damping-off. Water the plants and shade them.

**Care and tending**

Care and tending of seedlings comprise of five major activities: (i) Watering (ii) Shading (iii) Weeding (iv) Protection of pests and diseases, and (v) Root pruning.

**Preparation of seedlings for planting out**

Before the seedlings can be delivered for planting in the field, some activities need to be undertaken. These activities include: (i) Hardening-off, (ii) Grading and (iii) Packing.
- **Hardening-off**

Seedlings should get the necessary management under ideal conditions in a nursery. This makes them very often succulent that they do not withstand harsh conditions. Therefore, before the seedlings are planted out, they must gradually exercise to survive in harsher situations in the nursery.

- **Size and quality of seedlings**

The size of seedlings ready for planting is important with respect to weed competition in the field. The usual size ranges from about 25 to 40 cm. However, size should not be taken as the only indicator of good seedling. It is important to separate seedlings into at least two classes based on their quality and as a strategy plant the best seedlings in areas where least accessible, far and difficult sites and plant the lower quality seedlings in areas where sites are more favourable and nearby sites where replacement planting is not as costly.

- **Culling**

Culling is the rejection of seedlings because of poor size or quality. About 20 to 25% additional seedlings must be raised to compensate culled out or dead seedlings. Normally culling is done in line with lifting seedlings from the seedbed for transportation to planting sites.

Generally, seedlings that don’t meet the following criteria should be rejected.

- Minimum 15 cm in length
- Shoot/root ratio less than 2:1
- Woody, strong stem
- Healthy and no deformation

**Packing and transporting**

Potted seedlings should be carried holding only the bags. They should never be pulled by the shoots. Preferably, use boxes for transporting of seedlings. If the seedlings are loaded to carts, pick-ups or trucks, load densely and upright. Never lay the seedlings down.

**3.7. Field planting and management (tending operations)**

**3.7.1. Site preparation**

The planting site must be well prepared and be ready for planting in order to ensure that planting can take place timely. Site preparation includes removal of existing vegetation and preparation of the soil to enable the seedlings to utilize the existing soil moisture as effectively as possible.

Compacted soil is not good for tree growth as it may cause poor root development of planted seedlings. It also causes poor infiltration of water leading to retarded growth of
the trees and excessive runoff. Therefore, the planting site if possible should be ploughed or tilled to improve water infiltration, root development and aeration. The ploughing/tilling should be done along the contour to avoid soil erosion if the area is sloppy as this is the reality in most places of the Ethiopian context.

Site preparation for woodlots and big plantations include the removal of bushes and shrubs. In agroforestry systems, however, removal of all shrubs and bushes may not be necessary since the objective is incorporation of valuable trees into the existing farming practice or pasture. Hence, during site preparation, provided that the existing trees/shrubs are not harmful to the new plantation, they shall be maintained.

On sloppy grounds and moisture deficit areas, construction of physical soil conservation structures and moisture harvesting trenches around planting spots are recommended. High value trees such as fruit trees may need watering at planting, particularly if the day is sunny and there is risk for wilting up and rain is not expecting at the later hours after planting.

### 3.7.2. Pit size

Use of big holes may be of advantageous to the planted seedlings at the initial stages. But the effect disappears as seedlings are growing in the subsequent years. In specific cases, sizes of the hole would depend on site condition and seedling container size. A pit size of 30 cm x 30 cm is adequate for most of the tree species. In arid areas and in hard soil surface, use of larger pit size up to 50 x 50 cm is recommended to improve water infiltration.

In general, the pit size should depend on growing media or soil depth, rainfall amount but care must be taken to that none of the roots of the seedlings should turn upwards. This is the most common planting mistake that leads to eventual death of seedlings, which will force replacing of dead seedlings. Actual spacing to be applied varies with species, site and the purpose of plantation. Therefore, it is vital to consider site specific situations and tree species under consideration in deciding the right pit size.

### 3.7.3. Spacing

By observing trees growing under natural conditions it can be found that in low rainfall areas trees grow wider apart. In higher rainfall areas they can grow more closely together and form a forest. It is obvious that moisture availability is a critical factor for successful tree plantation, which has direct influence on the tree population and it is directly proportional to the tree stand in a plantation. In line with this in high rainfall areas trees are planted relatively in narrow spaces and the trees are more densely populated, while in dry areas with limited moisture availability it is necessary to plant trees widely apart and remove all competing ground vegetation around the newly planted seedlings, which increases infiltration of rain water and decreasing evapotranspiration from the soil and the surrounding vegetation cover.
A common spacing, recommended for woodlots in the highlands is, 2x2m or equivalent to 2,500 trees/ha. For planting on poor sites, where moisture availability and mortality is a problem, a spacing of 3x3m is recommended. For other forms of planting (around homesteads, along paths and roads, etc) there are no specific recommendations. So that it will be vital to use common professional judgement.

3.7.4. Water harvesting structures for tree planting

In the dry areas, it is important to harvest limited run offs for tree use, which can be harvested at any time of the season. Therefore, construction of water harvesting structures in plantation sites is important as they enhance water infiltration and improve the moisture availability to the planted trees. In addition, the water harvesting structures do protect the soil from erosion as well. There are several types that include micro basins, trenches, eyebrows, herringbones, and various physical soil and water conservation structures. In integration with the construction of water harvesting structures, due attention should be given in establishing trees on different structures mentioned above, which will enforce physical structures and at the same time decrease run-off, which ultimately decrease soil erosion and increase water infiltration.

Figure-36 Planting pits can be used to conserve moisture for fruit trees in dry areas (CBPWD Guideline, Jan. 2005, MoARD, A.A).

3.7.5. Seedling transport

One of the principal reasons for poor survival rate is that seedlings are mishandled during transporting, loading and unloading operations. One must not expect a high survival rate from seedlings that are broken/ damaged mechanically during
transportation, loading and unloading process. In many places seedlings have been treated like any other commodity especially while being transported and unloaded by dump trucks. Maximum care must be taken for the seedlings when they are transported from nursery to permanent planting sites. The best quality seedlings could be damaged if they are handled carelessly.

On the other hand it is also common to transport seedlings on donkey back or carried by people. Since people cannot afford carrying many seedlings with pots; because of the weight of the soil, they remove the plastic pots with the soil in order to carry as many seedlings as they can, which is not advisable in any case. This can tremendously affect the survival rate of seedlings. Therefore, proper care must be taken during transporting the seedlings as safe as possible to the planting site.

Potted plants can be transported safe if they are stacked on the floor of trucks or other vehicles strictly in an upright position. This consumes a lot of space and requires quite frequent travel to and from the planting site. Instead, the seedlings can be laid one on top of the other, the shoots of two rows facing each other. In this manner the seedlings can be transported when the distance is reasonably short but should be unloaded and stacked in an upright position and the planting needs to start soon. Bare-rooted seedlings can be laid down on wet banana or enset leaves, sacks or other materials with the roots puddle with soil and water. The bundles of seedlings can be stacked upright on the vehicle floor. Transported seedlings to the planting site should be immediately planted or should be put in shaded places.

### 3.7.6. Seedling planting

Planting of trees should start when the rainfall amount has accumulated to about 100mm and spread over a consistent number of days or in simple terms, when the soil particles form a muddy wet bond when squeezed. Generally, tree planting should start as soon as the rainy season begins properly and the soil is sufficiently moist below the rooting depth of the plants. This is to make sure that there is a supply of sufficient moisture to the newly planted seedlings for their better survival.

#### (1) Notching

Notching is used only for bare-rooted seedlings. It is simply cutting of an opening (slit) in the ground with a spade or conical planting hoes. The slit has to be opened wide enough to insert the roots of the plant without distorting the roots. After planting the slit is closed by gently pressing or compacting the soil with feet and/or by hands. Care must be taken especially with the bare-rooted seedlings that none of the roots should turn upward. However, this kind of planting is uncommon and not recommended in dry areas but rather recommended to be used in high rainfall areas.
(2) Pit planting

This is the usual planting method both for bare-rooted and potted seedlings or plants. In most cases the planting hole is dug slightly larger than the soil cylinder of the potted plant. The planting hole is usually dug out ahead of time before planting and left open for sometimes. The process of planting usually starts by removing the plastic pot and maintaining the soil intact; place the seedling at the middle of the pit about the root collar level. Cover the surrounding preferably with wet topsoil. Do not mix with dry soil or grasses. Gently compact the soil around the seedlings with hands or feet to increase contact between the roots and the soil in order to avoid air-pockets that might be created. The soil around the plant should be left level as a depression around the stem easily creates waterlogged conditions that damage the plant.

It is recommended to plant seedlings on a dull cloudy day or during the cool hours of the day in order to enhance the survival of seedlings. Avoid planting of seedlings in dry, sunny and windy days since these conditions will significantly reduce their survival rates. It is important as well to pay special attention and remember always to select healthy and strong seedlings for planting, which are about 25-40 cm of height. In addition, try to avoid transporting of excess seedlings than the capacity of the available labour force to plant effectively all the transported seedlings. This minimizes wastage, due to unplanted seedlings.

Bare-rooted plants are put similarly in the pit so that their roots are spread in natural position. Care must be taken not to turn the roots upward. Unnecessarily too long roots should be pruned back before it is planted. It is essential to assign supervisors to go around and supervise the planting activities, while planting is being carried on, particularly if planting is carried out involving non-experienced personnel.

4. Physical Soil and Water Conservation

4.1. Developing Appropriate Soil and Water Conservation Strategy

Developing appropriate SWC strategy is about involving farmers in identifying, prioritizing, analyzing problems, and devising solutions. It involves encouraging group work and strengthening local institutions, recognizing the role of women in development, encouraging co-operation between government and NGO's, building on traditional practices, local knowledge and experience as far as possible and promoting measures that are replicable. Catchment approach is one element towards this better conservation strategy.

4.2. Purposes / functions of physical soil and water conservation

The main purposes / functions of physical soil and water conservation structures are:

a) To safely dispose off excess water/runoff
b) To modify landscape (slope)
c) To conserve moisture
d) To ease cultivation operation
e) To reduce erosion

For designing of physical SWC measures the following parameters are important:

- Peak discharge in cubic meter per second
- Maximum permissible flow velocity in meter per second
- Dimension of structures (i.e. width, depth, freeboard, cross-sectional area)
- Channel gradient, channel lining, shape, length
- Spacing (vertical interval and horizontal interval)

In the following section physical soil and water conservation structures will be discussed. As stated above the main purpose for these structures is to safely dispose off the excess rainfall or runoff. Therefore, the suitability of each structure depends up on the rainfall characteristics, soil condition, land use pattern, the topographic feature and other erosion related factors. Though agroecology has some effect on these erosion determinant factors, it is neither the only nor the major factor in determining which structure is more suited to an area.

4.3. Runoff estimation

The size of any runoff disposal system is calculated based on the basis of maximum expected runoff from the catchment area, which is to be handled by the structures. Generally, a peak of 10 years recurrence interval is considered to calculate the maximum expected runoff.

4.3.1. Catchment Characteristics Method

Before designing physical SWC measures estimation of runoff is essential. Runoff is part of the rainfall that does not infiltrate into the soil but flows down the slope to join streams, rivers and lakes. The runoff generating characteristics for any catchment can be represented by an area-weighted score based on its vegetation cover, soil type and slope (Table 9).

Table 9. Values of Catchment Characteristics for Runoff Estimation

<table>
<thead>
<tr>
<th>Catchment Cover</th>
<th>Soil type and drainage</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy grass or forest</td>
<td>Deep, well drained soils, sands</td>
<td>10, Very flat to gentle (0-30)</td>
</tr>
<tr>
<td>Scrub or medium grass</td>
<td>Deep, moderately pervious soil, silts</td>
<td>20, Moderate (3-60)</td>
</tr>
<tr>
<td>Cultivated lands</td>
<td>Soils of fair permeability and depth, loams</td>
<td>25, Rolling (6-90)</td>
</tr>
<tr>
<td>Bare or eroded</td>
<td>Shallow soils with impeded drainage</td>
<td>30, Hilly or steep</td>
</tr>
</tbody>
</table>

1 Select the most appropriate factors from each of these three tables and add them together.
Example: If a catchment of 50ha has A, B, and C sections, having 10ha, 15ha and 25ha, respectively, with the indicated cover, soil and slope conditions then catchment characteristics (cc) is calculated as follows:

<table>
<thead>
<tr>
<th>Region</th>
<th>Cover Factor Values</th>
<th>Soil</th>
<th>Slope</th>
<th>Percentage area weighted</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>25</td>
<td>40</td>
<td>20</td>
<td>0.20</td>
<td>17.0</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>25</td>
<td>10</td>
<td>0.30</td>
<td>18.0</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>40</td>
<td>5</td>
<td>0.50</td>
<td>27.5</td>
</tr>
<tr>
<td>Catchment Characteristic (CC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>62.5</td>
</tr>
</tbody>
</table>

Example:
From Table 10 below, read peak runoff with a ten-year return period for area (A) - 50 and CC - 62.5 Interpolating gives peak runoff = 9.25 cubic meter per second.

Table 10. Area and catchment characteristics for estimating peak discharge

<table>
<thead>
<tr>
<th>A/CC</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
<th>65</th>
<th>70</th>
<th>75</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>1.1</td>
<td>1.3</td>
<td>1.5</td>
<td>1.7</td>
<td>1.9</td>
<td>2.1</td>
</tr>
<tr>
<td>10</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>1.1</td>
<td>1.4</td>
<td>1.7</td>
<td>2.0</td>
<td>2.4</td>
<td>2.8</td>
<td>3.2</td>
<td>3.7</td>
</tr>
<tr>
<td>15</td>
<td>0.5</td>
<td>0.8</td>
<td>1.1</td>
<td>1.4</td>
<td>1.7</td>
<td>2.0</td>
<td>2.4</td>
<td>2.9</td>
<td>3.4</td>
<td>4.0</td>
<td>4.6</td>
<td>5.2</td>
</tr>
<tr>
<td>20</td>
<td>0.6</td>
<td>1.0</td>
<td>1.4</td>
<td>1.8</td>
<td>2.2</td>
<td>2.7</td>
<td>3.2</td>
<td>3.8</td>
<td>4.4</td>
<td>5.1</td>
<td>5.8</td>
<td>6.5</td>
</tr>
<tr>
<td>30</td>
<td>0.8</td>
<td>1.3</td>
<td>1.8</td>
<td>2.3</td>
<td>2.9</td>
<td>3.6</td>
<td>4.4</td>
<td>5.3</td>
<td>6.3</td>
<td>7.3</td>
<td>8.4</td>
<td>9.5</td>
</tr>
<tr>
<td>40</td>
<td>1.1</td>
<td>1.5</td>
<td>2.1</td>
<td>2.8</td>
<td>3.5</td>
<td>4.5</td>
<td>5.5</td>
<td>6.6</td>
<td>7.8</td>
<td>9.1</td>
<td>10.5</td>
<td>12.3</td>
</tr>
<tr>
<td>50</td>
<td>1.2</td>
<td>1.8</td>
<td>2.5</td>
<td>3.5</td>
<td>4.6</td>
<td>5.8</td>
<td>7.1</td>
<td>8.5</td>
<td>10.0</td>
<td>11.6</td>
<td>13.3</td>
<td>15.1</td>
</tr>
<tr>
<td>75</td>
<td>1.6</td>
<td>2.4</td>
<td>3.6</td>
<td>4.9</td>
<td>6.3</td>
<td>8.0</td>
<td>9.9</td>
<td>11.9</td>
<td>14.1</td>
<td>16.4</td>
<td>18.9</td>
<td>21.7</td>
</tr>
<tr>
<td>100</td>
<td>1.8</td>
<td>3.2</td>
<td>4.7</td>
<td>6.4</td>
<td>8.3</td>
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<td>12.7</td>
<td>15.4</td>
<td>18.2</td>
<td>21.2</td>
<td>24.5</td>
<td>28.0</td>
</tr>
<tr>
<td>150</td>
<td>2.1</td>
<td>4.1</td>
<td>6.3</td>
<td>8.8</td>
<td>11.6</td>
<td>14.7</td>
<td>18.2</td>
<td>21.8</td>
<td>25.6</td>
<td>29.9</td>
<td>35.0</td>
<td>40.6</td>
</tr>
<tr>
<td>200</td>
<td>2.8</td>
<td>5.5</td>
<td>8.4</td>
<td>11.7</td>
<td>15.3</td>
<td>19.1</td>
<td>23.3</td>
<td>28.0</td>
<td>33.1</td>
<td>38.5</td>
<td>45.0</td>
<td>52.5</td>
</tr>
<tr>
<td>250</td>
<td>3.5</td>
<td>6.5</td>
<td>9.7</td>
<td>13.2</td>
<td>17.2</td>
<td>21.7</td>
<td>27.0</td>
<td>32.9</td>
<td>39.6</td>
<td>46.9</td>
<td>55.0</td>
<td>63.7</td>
</tr>
<tr>
<td>300</td>
<td>4.2</td>
<td>7.0</td>
<td>10.5</td>
<td>14.7</td>
<td>19.6</td>
<td>25.2</td>
<td>31.5</td>
<td>38.5</td>
<td>46.2</td>
<td>54.6</td>
<td>63.7</td>
<td>73.5</td>
</tr>
<tr>
<td>350</td>
<td>4.9</td>
<td>8.4</td>
<td>12.6</td>
<td>17.2</td>
<td>23.2</td>
<td>30.2</td>
<td>37.8</td>
<td>46.3</td>
<td>53.8</td>
<td>62.5</td>
<td>71.5</td>
<td>81.0</td>
</tr>
<tr>
<td>400</td>
<td>5.6</td>
<td>10.0</td>
<td>14.4</td>
<td>19.4</td>
<td>25.6</td>
<td>33.6</td>
<td>42.2</td>
<td>51.0</td>
<td>60.0</td>
<td>69.3</td>
<td>79.5</td>
<td>90.0</td>
</tr>
<tr>
<td>450</td>
<td>6.3</td>
<td>10.5</td>
<td>15.5</td>
<td>21.5</td>
<td>28.5</td>
<td>36.5</td>
<td>45.5</td>
<td>55.5</td>
<td>65.5</td>
<td>76.0</td>
<td>86.5</td>
<td>97.5</td>
</tr>
<tr>
<td>500</td>
<td>7.1</td>
<td>11.0</td>
<td>17.3</td>
<td>23.5</td>
<td>31.0</td>
<td>40.5</td>
<td>51.0</td>
<td>62.0</td>
<td>73.0</td>
<td>84.0</td>
<td>95.0</td>
<td>106.5</td>
</tr>
</tbody>
</table>

On Table 10 above, A is the area of the catchment in hectares, CC is the catchment characteristics and the runoff (in cubic meters per second) is for a 10-year frequency. Depending on catchment shape adjustment factor is presented in Table 11.
Table 11. Adjustment factors to runoff values for rainfall intensity, catchment shape and return period under table:

<table>
<thead>
<tr>
<th>Rainfall intensity:</th>
<th>Tropical (high)</th>
<th>multiply by 1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperate (low)</td>
<td>multiply by 0.75</td>
</tr>
<tr>
<td>Catchment shape:</td>
<td>Long, narrow</td>
<td>multiply by 0.8</td>
</tr>
<tr>
<td></td>
<td>Square/circular</td>
<td>multiply by 1.0</td>
</tr>
<tr>
<td></td>
<td>Broad, short</td>
<td>multiply by 1.25</td>
</tr>
<tr>
<td>Return period:</td>
<td>2 years</td>
<td>multiply by 0.90</td>
</tr>
<tr>
<td></td>
<td>5 years</td>
<td>multiply by 0.95</td>
</tr>
<tr>
<td></td>
<td>10 years</td>
<td>multiply by 1.0</td>
</tr>
<tr>
<td></td>
<td>25 years</td>
<td>multiply by 1.25</td>
</tr>
<tr>
<td></td>
<td>50 years</td>
<td>multiply by 1.5</td>
</tr>
</tbody>
</table>

4.3.2. The Rational Formula Method

Follow the following steps:
Step 1. Determine the peak runoff rate, generated from the area which is needed to drain through the structure. The peak runoff rate \( Q \) is estimated using the Rational formula (which is applicable for watersheds 5 km\(^2\) or less) given below:

\[
Q = \frac{CIA}{360}
\]

Where, \( Q = \) Design peak flow rate, m\(^3\)/s; \( C = \) Runoff coefficient, (Table 12); \( I = \) Rainfall intensity (mm/hr); and \( A = \) Area of catchment (ha)

The runoff coefficient, \( C \) is the portion of the total rainfall that is expected to become runoff during the design storm.

Table 12. Runoff coefficient values for use with the rational formula.

<table>
<thead>
<tr>
<th>Topography and vegetation</th>
<th>Soil texture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sandy loam</td>
</tr>
<tr>
<td>Woodland</td>
<td>Flat (&lt;5% slope)</td>
</tr>
<tr>
<td></td>
<td>Rolling (5-10% slope)</td>
</tr>
<tr>
<td></td>
<td>Hilly (10-30% slope)</td>
</tr>
<tr>
<td>Pasture</td>
<td>Flat (&lt;5% slope)</td>
</tr>
<tr>
<td></td>
<td>Rolling (5-10% slope)</td>
</tr>
<tr>
<td></td>
<td>Hilly (10-30% slope)</td>
</tr>
<tr>
<td>Cultivated</td>
<td>Flat (&lt;5% slope)</td>
</tr>
<tr>
<td></td>
<td>Rolling (5-10% slope)</td>
</tr>
<tr>
<td></td>
<td>Hilly (10-30% slope)</td>
</tr>
<tr>
<td>Urban areas</td>
<td>30% of area impervious</td>
</tr>
<tr>
<td></td>
<td>50% of area impervious</td>
</tr>
<tr>
<td></td>
<td>70% of area impervious</td>
</tr>
</tbody>
</table>
Step 2. Calculate Time of concentration

To estimate the rainfall intensity knowledge of the time of concentration is required (Kirpich formula). The volume of the rainfall intensity for use in the Rational formula is the highest that can be expected in a 10 year return period for a time equal to the time of concentration of runoff at outlet of the catchment. The time of concentration is time taken for water storm to reach by surface flow, the outlet from the furthest parts of the catchment. At this time all parts of the catchment are assumed to be contributing to the runoff at the outlet simultaneously. Time of concentration is dependent on various factors such as the size of the catchment, the shape of the catchment, the steepness of the catchment, the density of the drainage network and the ground cover.

\[ T = 0.02 \left( L^{0.77} \ast S^{-0.385} \right) \] - Kirpich formula

Where, \( T \) = Time of concentration (min); \( L \) = Maximum length of flow (m); and \( S \) = Average gradient (m/m)

For small watersheds, the time of concentration is less than 1-hour and the 1-hour storm can be considered as the design rainfall intensity. Often, it would be difficult to get 1-hour storm data. Under such conditions, 50% of the daily (24-hours) rainfall can be considered as the design rainfall intensity (I).

Step 3. Find out the value of permissible flow velocity.

If runoff is to be discharged through graded structure (bund, cut-off drains, waterways) it is essential that the velocity of water is controlled so that it does not cause erosion. The ability of water to cause scouring and erosion varies with lining material (earth, grass, stone or concrete), for each of these is a maximum permissible velocity above which scouring can occur (Table 13).

<table>
<thead>
<tr>
<th>Material</th>
<th>Max. velocity on cover expected after two seasons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bare</td>
</tr>
<tr>
<td>Very light silt sand</td>
<td>0.30</td>
</tr>
<tr>
<td>Light loose sand</td>
<td>0.50</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>0.75</td>
</tr>
<tr>
<td>Sandy soil</td>
<td>0.75</td>
</tr>
<tr>
<td>Firm clay loam</td>
<td>1.00</td>
</tr>
<tr>
<td>Stiff, clay or stiff gravel soil</td>
<td>1.50</td>
</tr>
<tr>
<td>Coarse gravel</td>
<td>1.50</td>
</tr>
<tr>
<td>Shale, hardpan, soft rock, etc.</td>
<td>1.80</td>
</tr>
<tr>
<td>Hard cemented conglomerates</td>
<td>2.50</td>
</tr>
</tbody>
</table>
The velocity of water in a channel can be reduced either by reducing gradient (bed slope) or by increasing the width so that the water spreads over a wider area and depth of flow is reduced. The amount of runoff should be reduced as far as possible by good land husbandry and the amount of land taken out of cultivation must be kept to a minimum. Although it is possible to design a channel to carry water at a velocity that is below the maximum permissible, this is not usually done because it would encourage sedimentation and the channel would have to be wider. More labor would be needed for digging and more land would go out of production.

**Step 4.** Compute the cross-sectional area of the channel.

The cross-sectional area should suit the value of peak runoff rate (Q) and permissible flow velocity (V). It is computed by the following equation:

\[ Q = A \times V \Rightarrow A = \frac{Q}{V} \]

Where, \( Q \) = Peak discharge \((m^3/s)\); \( V \) = Maximum permissible velocity \((m^3/s)\); \( A \) = Cross-sectional area of the channel \((m^2)\)

**Step 5.** Compute the various dimensions to suit the area of cross-section obtained using Step 4 (Figure 37).

**Step 6.** Calculate the hydrologic radius (R) from the value of cross-sectional area (A) and wetted perimeter (P) of the channel, given as Figure 37.
Step 7. Compute the grade (S) of the channel using Manning’s formula, given as:

\[ V = \frac{S^{1/2} R^{2/3}}{n} \Rightarrow S = \sqrt{V \cdot S \cdot R^{-2/3}} \]

Where, \( Q \) = flow rate in m\(^3\)/s; \( V \) = mean velocity in m/s; \( A \) = area of flow in m\(^2\);
\( R \) = hydraulic radius in m; \( S \) = bed slope in m/m; \( n \) = Manning’s roughness coefficient.
This value is often assumed to range between 0.03 to 0.04. In this equation, except \( n \) (Mannings’s roughness coefficient) all parameters are known.

Step 8. The channel’s grade obtained in Step 7 can be rounded off for convenience of layout.

Step 9. Using rounded value of channel’s grade, again compute the flow velocity at the section taken into consideration. If it is the same to the value of velocity obtained in Step 3, then design is assumed to be correct. Otherwise, the cross-sectional area of the channel is again required to be adjusted.

4.4. Waterways

A waterway receives water from cut off drains, terraces or small creeks and conveys it safely to a bigger channel (Figure 38). Diversion ditches and graded channel terraces should not be constructed if there is no proper waterway to collect and safely dispose-off the runoff. Ideally it is constructed one or more years before other graded structures. Before designing and constructing a waterway runoff need to be estimated.

Some points to note while choosing/designing waterways:

i. Whenever possible use the existing natural water ways as being located in depressions, surface runoff and sometimes sub-surface seepage collect in them naturally and the slope in natural drainage lines usually approaches the required design slope, and the construction expenses are less than in artificially excavated channels.

ii. Link to waterways (natural/artificial) to safely divert run-off.

iii. Construct scour checks in a cut-off drain (Figure 39 and 40) with stones and grasses every 50 cm for 10-20 meters before the outlet to a waterway.

iv. As required construct strong drop structures to minimise the effect of water dropping into the waterway or gully, thus avoid the risk of creating additional erosion at the outlet level.

The success of artificial waterways depends upon:

- The correctness of the location
- The adequacy of the capacity
- The establishment of suitable linings and drop structures whenever necessary
- The proper routine maintenance
The following aspects have to be considered when designing waterways

![Diagram of a cut-off drain and a waterway connected with a drop structure](image)

*Figure-38 Meeting point of a cut-off drain and a waterway connected with a drop structure*

a) Slope and Size

- Waterway is designed to convey the peak runoff rate from a storm within a ten-year return period. Grassed waterways are recommended for slopes up to 14° (25%). For steeper slopes the channel should be lined with stones, masonry or reinforced concrete. The slope of a waterway is normally the slope of the land at right angles to the contour. Waterways running diagonally across a slope are not recommended because if they break or overtop the damage can be serious. Table below can be used to find suitable dimensions.

b) Design Width and Depth

- The design width (t) and top width (T), after freeboard is added, are determined using equations in Figure 2. The design depth (d) for a parabolic section can be approximated from the hydraulic radius (R) as; \(d = 1.5R\).

c) Freeboard

- A safety margin or freeboard is added by increasing the design depth by 25% for grass waterways and 10% for stone lined waterways.

d) Channel Roughness

- The rougher the surface over which water flows, the greater the resistance to flow. The velocity of water in a channel can be reduced by making it wider and shallower (i.e. lowering the hydraulic radius) or by making the surface rougher. Growing a grass will provide more resistance.
A. VEGETATIVE WATERWAYS (VW)

Most criteria set for the design of cut-off drains are valid for waterway design.  
**Slope:** < 10%  
**Size:** Small waterways preferred (1-5 ha drainage area).  
**Shape:** Choose parabolic cross section as this tends to resemble natural waterway.  

**Design steps:**  
1. Determine the *Drainage Area*.  
2. Determine the *Width* in meters of waterway from (Table 14) having measured slope of the waterway.  
3. From the table showing relationship between depth and width (Table 15), determine *Depth* in meters.  
4. *Checks-drop-aprons (CDAs)*: place stone or brushwood CDAs every 20m (slope <5%), 10 m (slope 5-10%) and 5 m (slopes 10-25%) (See Figure 39).  
5. *Excavation*: soil piled and compacted on one or both sides of waterway (see Figure-39).  
6. *Stabilization*: local grass - sods - dry straws lines dug into the ground during first year.  

B. STONE PAVED WATERWAYS (SPW)  
**Slope:** < 20-25% slope  
**Size:** Small waterways preferred (1-5 ha drainage area)  
**Shape:** Choose parabolic cross section as this tends to resemble natural waterway.  

**Design steps:** same as VW (see Figures 39 and 40)  

*Excavation and stone paving*: place flat heavy stones at the bottom - fill with smaller stone the space between large ones  

*Stone checks-drop-aprons (CDAs)*: at 1 meter vertical interval. The apron length = to height of drop. To build use stones or wooden pegs + stones. Height of CDAs is 0.3-0.5m.  

<table>
<thead>
<tr>
<th>Runoff Area (Ha)</th>
<th>Width of the waterway (m)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slope (0-5%)</td>
<td>Slope (6-12%)</td>
<td>Slope (13-25%)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td>2</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>3</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>3.5</td>
<td>8</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>4.5</td>
<td>12</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>
Table 15. Relationship between depth (m) of waterway and width (m)

<table>
<thead>
<tr>
<th>Width in meters</th>
<th>Depth in meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3</td>
<td>0.3</td>
</tr>
<tr>
<td>4.0 – 6.0</td>
<td>0.4</td>
</tr>
<tr>
<td>More than 6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

C. Having decided the peak runoff using Cook’s method or the rational formula, another method for dimensions of grassed waterways Table 16 can be used.

Table 16. Grass waterway design minimum dimensions for different situations

<table>
<thead>
<tr>
<th>Ground slope</th>
<th>5%</th>
<th>10%</th>
<th>15%</th>
<th>20%</th>
<th>30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lining</td>
<td>Close grass</td>
<td>Close grass</td>
<td>Close grass</td>
<td>Grass/stone</td>
<td>Grass/stone</td>
</tr>
<tr>
<td>Design velocity</td>
<td>2 m/s</td>
<td>2 m/s</td>
<td>2 m/s</td>
<td>3 m/s</td>
<td>3 m/s</td>
</tr>
<tr>
<td>Discharge: 0.25 m³/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth m</td>
<td>0.4</td>
<td>0.24</td>
<td>0.18</td>
<td>0.26</td>
<td>0.19</td>
</tr>
<tr>
<td>Width m</td>
<td>0.65</td>
<td>1.1</td>
<td>2.3</td>
<td>0.67</td>
<td>0.91</td>
</tr>
<tr>
<td>Area m²</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>0.50 m³/s: Depth m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width m</td>
<td>1.3</td>
<td>2.2</td>
<td>4.43</td>
<td>1.34</td>
<td>1.82</td>
</tr>
<tr>
<td>Area m²</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>0.75 m³/s: Depth m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width m</td>
<td>1.96</td>
<td>3.3</td>
<td>6.73</td>
<td>2.01</td>
<td>2.73</td>
</tr>
<tr>
<td>Area m²</td>
<td>0.38</td>
<td>0.38</td>
<td>0.38</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>1.00 m³/s: Depth m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width m</td>
<td>2.61</td>
<td>4.39</td>
<td>8.86</td>
<td>2.68</td>
<td>3.63</td>
</tr>
<tr>
<td>Area m²</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.33</td>
<td>0.33</td>
</tr>
<tr>
<td>1.25 m³/s: Depth m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width m</td>
<td>3.27</td>
<td>5.49</td>
<td>11.16</td>
<td>3.35</td>
<td>4.54</td>
</tr>
<tr>
<td>Area m²</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
<td>0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>1.50 m³/s: Depth m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width m</td>
<td>3.92</td>
<td>6.59</td>
<td>13.28</td>
<td>4.02</td>
<td>5.45</td>
</tr>
<tr>
<td>Area m²</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>1.75 m³/s: Depth m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width m</td>
<td>4.57</td>
<td>7.69</td>
<td>15.58</td>
<td>4.69</td>
<td>6.36</td>
</tr>
<tr>
<td>Area m²</td>
<td>0.88</td>
<td>0.88</td>
<td>0.66</td>
<td>0.58</td>
<td>0.58</td>
</tr>
<tr>
<td>2.00 m³/s: Depth m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width m</td>
<td>5.23</td>
<td>8.79</td>
<td>17.71</td>
<td>5.36</td>
<td>7.27</td>
</tr>
<tr>
<td>Area m²</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.67</td>
<td>0.67</td>
</tr>
</tbody>
</table>
Figure-39 Various views of stone and/or grass paved waterways with wooden posts for fixing the grass sod and stone paving
Figure -40 Different views of grassed and stone paved waterways

D. Design of a waterway using the permissible velocity approach

Design procedures are based on the principles of open channel hydraulics. For SWC work, a channel is normally designed to convey the peak runoff with a 10-year return period without scour or fill.

Example: Design a parabolic grassed waterway to convey 6m³/sec on a 1 percent slope over an erodible sandy soil with Bermuda grass vegetation in a good stand cut to 6cm. Design using maximum permissible velocity approach.

**Design using maximum permissible velocity approach**

i) Discharge (Q) is given = 6m³/s

ii) Slope (s) is given = 0.01

iii) From Table 12 select a maximum permissible velocity (v), e.g. v = 1.5m/s

iv) From Table 13 select a suitable value for the Manning roughness coefficient, e.g. n = 0.034

v) From the Manning equation, calculate the hydraulic radius (r):

\[ r = \left( \frac{vn}{s^{0.5}} \right)^{1.5} \]

\[ r = (1.5*0.034/0.01^{0.5})^{1.5} \]

\[ r = 0.364 \text{m} \]

vi) Calculate the required cross-sectional area (A) of the channel

\[ A = \frac{Q}{v} = \frac{6}{1.5} = 4 \text{m}^2 \]

vii) For a parabolic section, take the design depth (d) = 1.5r

\[ d = 1.5*0.364 \]

\[ d = 0.55 \text{m} \]
viii) For a parabolic section, the design top width (W) = A/0.67d
    \[ W = \frac{4}{0.67 \times 0.55} \]
    \[ W = 10.86m \]

ix) Design criteria are: depth = 0.55m; width = 10.86m.

x) Check that capacity of channel is adequate:

xi) For a parabolic section, \[ Q = A v = 0.67 \times W \times d \times v \]
    \[ = 0.67 \times 10.86 \times 0.55 \times 1.5 \]
    \[ = 6m^3/s \text{ which is adequate.} \]

xii) Final design criteria are:
    depth = design depth + 20% freeboard = 0.55 + 0.11 = 0.66m
    top width = 10.86m

---

**Table 17. Maximum safe velocities in channels**

<table>
<thead>
<tr>
<th>Material</th>
<th>Bare</th>
<th>Medium grass cover</th>
<th>Very good grass cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very light silty sand</td>
<td>0.3</td>
<td>0.75</td>
<td>1.5</td>
</tr>
<tr>
<td>Slight loose sand</td>
<td>0.5</td>
<td>0.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>0.75</td>
<td>1.25</td>
<td>1.7</td>
</tr>
<tr>
<td>Sandy soil</td>
<td>0.75</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Firm clay loam</td>
<td>1.0</td>
<td>1.7</td>
<td>2.3</td>
</tr>
<tr>
<td>Stiff clay or stiff gravelly soil</td>
<td>1.5</td>
<td>1.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Coarse gravel</td>
<td>1.5</td>
<td>1.8</td>
<td>Unlikely to form very good grass cover</td>
</tr>
<tr>
<td>Shale, hard pan, soft rock, etc.</td>
<td>1.8</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Hard cement conglomerates</td>
<td>2.5</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

---

**Table 18. Manning’s roughness coefficient**

<table>
<thead>
<tr>
<th>A</th>
<th>Channels free from vegetation</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uniform cross-section, regular alignment free from pebbles and vegetation, in fine sedimentary soils</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td>Uniform cross-section, regular alignment free from pebbles and vegetation, in stiff clay soils or hard pans</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td>Uniform cross-section, regular alignment few pebbles, little vegetation in clay loam</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td>Small vegetations in cross-section, fairly regular alignment, few stones, thin grass at edges, in sandy and clay soils, also newly cleaned, ploughed and harrowed channels</td>
<td>0.0225</td>
</tr>
<tr>
<td></td>
<td>Irregular alignment, ripples on bottom, in gravelly soil or shale, with jagged banks or vegetation</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td>Irregular section and alignments, scattered rocks and loose</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Channels free from vegetation</td>
<td>n</td>
</tr>
<tr>
<td>---</td>
<td>-------------------------------</td>
<td>----</td>
</tr>
<tr>
<td></td>
<td>gravel on bottom, or considerable weeds on sloping banks, or in gravelly material up to 150mm diameter</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>Eroded irregular channels, channels blasted in rock</td>
<td>0.03</td>
</tr>
<tr>
<td>B</td>
<td>Vegetated channels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Short grass (50-150mm)</td>
<td>0.03-0.060</td>
</tr>
<tr>
<td></td>
<td>Medium grass (150-250mm)</td>
<td>0.030-0.085</td>
</tr>
<tr>
<td></td>
<td>Long grass (250-600mm)</td>
<td>0.04-0.150</td>
</tr>
<tr>
<td>C</td>
<td>Natural stream channel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clean and straight</td>
<td>0.025-0.030</td>
</tr>
<tr>
<td></td>
<td>Widening with pools and shoals</td>
<td>0.033-0.040</td>
</tr>
<tr>
<td></td>
<td>Very weedy, widening and overgrown</td>
<td>0.075-0.150</td>
</tr>
</tbody>
</table>

### 4.5. Cut-off drains

Cut-off drain is a diversion ditch constructed across a slope to intercept surface runoff and convey it safely to an outlet such as a waterway (Figures 41 and 42). It is a graded channel constructed to intercept and divert the surface runoff from higher ground/slopes and protect downstream cultivated land or village. It diverts the runoff to a waterway or river, etc. Cut-off drains are used to protect, cultivated land, compounds, roads from uncontrolled runoff and to divert waterway from active gully heads. The shape of cut-off drain is deeper and narrower while waterway is wider and shallower. The reason is compared to waterways it is expected to carry less water. Cut-off-drain is the first line of defence and vital to the total conservation system in the cultivated land below, because all the conservation structures lower down will be designed on the assumptions that the cut-off-drain will effectively control all the runoff from above the arable land. If it fails to do its job, the water released from the cut-off-drain will almost certainly break the conservation works lower down. It is named variously: a storm water channel, diversion terrace, diversion ditch, storm drain, interception ditch or other combinations of these words. For example a cut-off drain is known as “Trass Boy” in Amharic and “Booyii Booraattii” in Oromiffa. Since the practice is very common in the wet highlands of the country other regions could also have their corresponding naming as well. It is traditionally well known in the tradition of Ethiopian farming. In the dry lands, cut-off drains may be used mainly for the following purposes:

- Divert additional water to cultivated plots;
- Divert additional water to SS dams and cropped areas
- inside gullies;
- Divert additional water into reservoirs for irrigation and/or domestic use.

A cut-off drain is:

- Usually it is shaped trapezoidal and with larger capacities than channel terraces.
• The location of cut-off drain is determined after checking the outlet conditions, topography, land use, soil type and slope length.
• If it is intended to protect cropland against runoff from adjoining non-arable land, it should be constructed at the boundary between the two.
• When needed to divert runoff from a gully head, it should be far enough above the gully head so that stable slopes will exist.

The following procedure shows how to design cut-off drain:

a) Runoff discharge capacity
• The first step in the design is to estimate the peak rate of runoff from contributing catchment area using Cooks method or Rational Formula (Tables 15, 16 and 17 for Cooks method and Table 18 for the Rational Formula, above).
• The cross sectional area of the ditch can then be found from the following equation:

\[ Q = V \times A \quad \text{or} \quad A = \frac{Q}{V} \]

Where, \( Q \) = Peak discharge, m\(^3\)/sec
\( V \) = Maximum permissible / allowable velocity, m/sec (Table 19).
\( A \) = Cross sectional area of ditch, m\(^2\) (Table 19).

b) Channel Gradient
c) Channel Lining and Stability
d) Channel Shape and Dimensions
e) Channel Length

The first step is to estimate a probable maximum rate of surface run-off.

**Step 1**: For a given area, compute the peak discharge rate \( Q \) (m\(^3\)/sec) using the Cooks or Rational Formula method.

**Step 2**: Compute the required flow cross sectional area \( (A) \) using the corresponding maximum permissible velocity \( (V) \).

\[ A = \frac{Q}{V} \]

**Step 3** : Decide the shape of the channel. Trapezoidal or Parabolic is recommended.

**Step 4**: Use Depth from Table 15 using \( V \) and Channel gradient. Gradient: 1-10ha =0.8-1%; 10-30ha = 0.5%; 30-50ha= 0.25%

**Step 5**: Find the channel discharge per unit of depth using Table 20.

**Step 6**: Find top width of the cut-off drain. For trapezoidal and parabolic cross-section: runoff from the catchment divided by Discharge from the cut-off drain.
Example: Find the size of a channel (cut-off drain) to be constructed at the foot on hilly grassland with 20% slope. Soils of the catchment are clay. The runoff area is 6 ha. The grassland has medium cover. Use rainfall intensity of 150mm/hr.

Step 1: Find the corresponding run-off using rational method (table 1): \( Q = K \frac{IA}{360}, \) where \( Q \) = the peak run-off rate (m³/sec); \( K \) = the run-off coefficient; \( I \) = the rainfall.
intensity (150mm/hour); A = the runoff producing area. Thus, K = 0.82 (from Table 18), I = 150mm/hr, A= 6 ha, then Q = 0.82 x 150 x 6 ha/360 = 2.05m3/sec.

**Step 2:** Find the maximum allowable velocity using table 14. In this case, Velocity = 1.8 m/sec for clay surface.

**Step 3:** Determine the gradient and depth of channel. For a catchment of 6 ha, a 1% slope selected. Following this determine channel depth from table 14 against 1.8 velocity and 1% slope, which is = 0.4 m.

**Step 4:** Find channel discharge rate per unit width from Table 20. Accordingly, for gradient of 1% and depth 0.4, the discharge is 0.9m3/sec (Table 20).

**Step 5:** Find the top width of the cut-off drain by dividing the catchment run-off by the channel discharge rate per unit width = 2.05/0.9 = 2.3 m.

**Table 19. Depth of a channel in meters**

<table>
<thead>
<tr>
<th>Channel gradient %</th>
<th>Maximum allowable / permissible velocity (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Table 20. Discharge in m3/sec/meter width**

<table>
<thead>
<tr>
<th>Depth of channel</th>
<th>Slope (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8-1</td>
<td>0.5</td>
</tr>
<tr>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td>0.4</td>
<td>0.9</td>
</tr>
<tr>
<td>0.5</td>
<td>1.3</td>
</tr>
<tr>
<td>0.6</td>
<td>1.8</td>
</tr>
<tr>
<td>0.7</td>
<td>2.25</td>
</tr>
<tr>
<td>0.8</td>
<td>2.8</td>
</tr>
<tr>
<td>0.9</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Once the dimensions of the cut-off drain are known then Table 21 (below) can be checked whether the runoff is well accommodated or not.

**Laying out a cut-off drain**

Laying out can be made with a line level. It begins from the outlet end and stakes are placed at 5 - 10 m intervals. The soil from the ditch should be placed on the downward side to form the embankment (Figure 42).
Table 21. Cut-off drains dimensions and gradient (Earth lining and 1:1 side slope)

<table>
<thead>
<tr>
<th>Channel Dimensions</th>
<th>Gradient of Channel Vs Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1%/ (m³/s)</td>
</tr>
<tr>
<td>Bottom width (m)</td>
<td>Depth (m)</td>
</tr>
<tr>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>1.2</td>
<td>0.6</td>
</tr>
<tr>
<td>1.4</td>
<td>0.7</td>
</tr>
</tbody>
</table>

N.B. For the work norms see National Guideline (CBPWD, 2005), Annex, Page 49.

4.6. Level and Graded Channel farmland Terraces

Farmland terraces can also be named as soil bunds (Figure 43), stone bunds or stone faced soil bunds, depending on the availability of construction material.

Technical design of soil bunds
- Height: 60-70cm up to 100 cm (lower side).
- Total Base width: (height/2) + (0.3-0.5 m).
- Top width: 30-40 cm.
- Foundation: 0.3 m width x 0.3 m depth.
- Grade of stone faces downside: 1 horiz: 3 vert.
- Grade of stone faces upper side: 1 horiz: 4 vert.
- Grade of soil bank (seal) on upper side: 1 Horiz: 1.5-2 vert.
- Bunds need to be spaced staggered for animals to cross.
- Max bund length 60-80 meters.

Work norms: 150 PDs/Km includes the following activities
Layout and Vertical Interval (VI) specifications

<table>
<thead>
<tr>
<th>Ground slope %</th>
<th>Height of bund (m)</th>
<th>Vertical Interval (M)</th>
<th>Horizontal Interval (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.5</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>0.5</td>
<td>1.5</td>
<td>15</td>
</tr>
<tr>
<td>15</td>
<td>0.75</td>
<td>2.2</td>
<td>12</td>
</tr>
<tr>
<td>20</td>
<td>0.75</td>
<td>2.4</td>
<td>10</td>
</tr>
<tr>
<td>25</td>
<td>1</td>
<td>2.5</td>
<td>8</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
<td>2.6</td>
<td>8</td>
</tr>
<tr>
<td>35</td>
<td>1</td>
<td>2.8</td>
<td>6</td>
</tr>
<tr>
<td>40</td>
<td>1</td>
<td>2.8</td>
<td>5</td>
</tr>
<tr>
<td>50</td>
<td>1.15</td>
<td>2.8</td>
<td>4</td>
</tr>
</tbody>
</table>

- **Caution:** although the table above shows the possibility to build stone bunds up to 50% slope they should not be constructed above 35% slope. Spacing should be discussed with farmers and in case of lateral slopes try to maintain lines as straight as possible by applying reinforcements on depression points to avoid excess curving or cutting of the plough line.

![Schematic view and standard cross section of the channel and bund / embankment for conventional soil bund on stable soil](image)

*Figure-43 Schematic view and standard cross section of the channel and bund / embankment for conventional soil bund on stable soil*

Where,

<table>
<thead>
<tr>
<th>T</th>
<th>t</th>
<th>d</th>
<th>E</th>
<th>B</th>
<th>m</th>
<th>W</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top width of burrow trench (80 cm)</td>
<td>Bottom width (40 cm)</td>
<td>Depth of burrow trench (50 cm)</td>
<td>Embankment gradient 1 (horiz.): 2 (vert.)</td>
<td>Width of bund at base (90 cm)</td>
<td>Berm (10 cm)</td>
<td>Overall width (180 cm)</td>
<td>Top width (30 cm)</td>
</tr>
<tr>
<td>Height after compaction (50 cm)</td>
<td>Height before compaction (60 cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The artificial or natural waterway should be constructed one year before the graded bund. The channel is graded up to a maximum of 1% (10cm for every 10 meter lay out of the line level).

Height: min. 60 cm after compaction.

Base width: 1-1.2m in stable soils (1 horiz: 2 vertical) and 1.2-1.5m in unstable soils (1 horiz: 1 vertical). Top width: 30 cm (stable soil) - 50 cm (unstable soil). Channel: shape, depth and width vary with soil, climate and farming system.

Channel cross section increases towards the end because of more water concentration e.g. from 25cm depth and 50cm width to 50 and 100cm, respectively. Ties (if appropriate): tie width with dimension as required, placed every 3-6 m interval along the channel.

*Figure-44 Design of soil bunds for different soil types*

The advantages of channel soil bunds (Figure 44) are that during first year the bunds can accommodate more sediments and water than Fanya Juu – thus less prone to breakages due to layout or construction problems. During 2nd and following years good deposited soil is not taken from upper level for upgrading. Rather for rapid benching maintaining FJ principle is preferred. Cropping close to the embankment is also facilitated (less space
out of crop production). Depending on the rainfall intensity and nature of the soil FJ bunds can be level or graded. For more detail the reader is advised to refer infotechs or other specific manuals.

**Upgrading soil bund using Fanya Juu principle**

Problem with Fanya Juu is that they overtop easily and break. So in difficult slopes with traverse/lateral gradients it is better to implement soil bunds and stone bunds/stone faced bunds than Fanya Juu. After the 1st or 2nd year upgrade the terrace by using the FJ principle (Figure 45) for rapid benching + apply compost to improve infiltration near embankment/raiser. This form of upgrading + conditioning can be applied at very large scale on existing conserved areas.

![Figure-45 Maintaining soil bund according to Fanya Juu principle (in the second year)](image)

**4.7. Fanya Juu**

Fanya Juu is a “Swahili” language word which means “Throw UP” (Figure 46). That is the conventional soil bund is inverted in the sense that the channel is dug and the soil for embankment is thrown up slope. Compared to conventional soil bunds it is constructed in gentler slopes. The advantages of FJ over the ordinary soil bunds are that benching is achieved faster, less land taken by the structure and also difficult to be crossed by livestock. Depending on the rainfall intensity and nature of the soil FJ bunds can be level or graded.
Stone bunds can be constructed on farmlands. On farmlands, compared to soil/FJ bunds, stone bunds take less space (Figure 47). This is due to that bunds with stones can be kept more vertical and the need for channel is less required since the stone is impervious and excess water can make its way though. On farmlands for most of the cases stone bunds are laid out and constructed level. If draining of excess water is needed then stone-faced-soil-bunds are essential. The other reason why we construct stone-faced soil bunds is dependent on the amount stones available for construction.

**Procedure to construct stone bund**

- Work out the gradient of the slope using line level;
- Decide the spacing of the stone bunds based on the slope;
- Excavate of the foundation, place and build stone walls (larger stone for foundation);
- Continue to build the wall with stones until you reach the desired height;
- Fill voids between walls with smaller stones;
- Sealing of the upper side with soil as required;
- Reinforcement of depression points;
- Move down to the next bund and repeat the steps;
- Repeat the same in the next bund;
- Stabilization and application of compost;
- Plant the bunds with grasses, fodder legumes & tree to stabilize and make it productive.
**BW** = Base width \\
= \( h + 30-50 \text{cm (minimum)} \) \( \frac{1}{2} \)

*Figure-47 Different sections of a stone bund on cultivated fields*
4.9. Stone Faced Soil Bunds

Definition: stone faced soil bunds are where one or both sides of the embankment are reinforced with a stone wall or riser. In some instances, the reinforcement may take place only along the depression points to compensate for layout problems and to protect the entire length of the bund. Strengthening of soil bunds with stones throughout their entire length is recommended wherever farmers tend to increase the spacing between structures and stones are available.

Technical specifications

Slope range: the slope range may increase up to 35-40% slope compared to soil bunds alone. However, on such extreme slope range, the spacing apart bunds should be guided by standard technical recommendations (relationships between slope, vertical interval and soil depth). Besides, above 30% slope the stone riser of the downstream embankment should have a deep foundation (30cm). Generally, spillways may be required below 8% slope if water logging problems are likely to occur.

Stone faced soil bunds can be constructed in all types of soils, excluding sandy soils. For soil depth and texture same as for soil bunds. Stones should be available from the field itself or from adjacent areas. Spacing may be slightly wider than for soil bunds, particularly up to 15% slope, add 10% on the spacing of soil bund. The dimensions of the stone faced soil bunds are identical to the ones already explained in previous section. The difference is on the stone walls placed on one or both sides of the soil bund (See Figure 48 & 49). Therefore, the bund is larger and stronger. In terms of layout bunds should be level and wing up laterally in order to evacuate excess water. As mentioned for the layout of soil bunds, farmers may want to cross small depression points straight instead of curving up and down hill continuously. In this case the entire bund should be reinforced on both sides, including a stone key.

Types of stone reinforced soil bunds

a) Single faced protection wall+/- collection trench

Stones are placed on the downstream side, well inclined to offer maximum resistance (1:2 – 1:3 vert.). A collection trench is dug on the upper stream side of the bund (Figure 48). They are provided with spillways if necessary (spacing, type of soils and type of crops). Stone keys are also applied in depression points if any.
b) Double faced stone/soil bunds +/- collection trench

Both sides are reinforced with stones. This type of bund is rather resistant against excess runoff. Stone keys along depression points within the earthen part of bund should also be applied as required (Figure 49).

Figure-49 Stone faced soil bunds (double faced)
c) **Double faced stone/soil bunds without collection trench**

Are suitable for gentle and uniform slopes (<8%). The soil embankment is obtained by scratching a wider and shallow layer of top soil. Small ties can be placed at regular intervals along the upper side of the bund.

d) **“Corner” or lateral stone/soil bunds**

This type of corner or lateral bunds differs from those for soil bunds because they are stone faced on both sides and through their entire length (Figure 48). In some instances, if the bend is on one side only these bunds are also called “Walking Stick bunds”. They are used for moisture retention. They are suitable for lateral field boundaries with gentle slopes (<5%) where farmers want to extend their bunds without following a precise contour line. The bunds should then be raised at those corners and strongly reinforced on both sides with stones (Figure 50). The tips of the bunds winging upwards, whilst remaining level, are of decreasing height towards the slope. They may also evacuate excess water through their tips if their top level decreases inwards. The bunds can also be provided with spillways.

![Figure-50 Laterally bending bund](image)

**Construction phases for all stone faced bunds**

- Some suggested standards are as follows:
  - Grade of lower stone face: 1 horiz. To 3 vertical;
  - Grade of upper stone face: based on soil embankment grade;
  - Grade of soil: 1 horiz. to 1.5 vertical on stable soils and 1 horiz. to 2 vertical on unstable soil;
  - Lower stone face riser foundation: 0.3 depth x 0.2 – 0.3 width;
  - Upper stone face riser foundation: 0.2 x 0.2 m;
  - Stone size: 20 cm x 20 cm stones (small and round shape stones not suitable);
  - Top width: 0.4 - 0.5 m;
  - Height: min 0.7 and max 1 m (lower stone face); and Ties required at 3- 6 m;

Stone faced bunds can be constructed by digging a foundation for stone blanket. Large stones are then placed in the ditch with the right inclination. Soil then dug from a trench on the upper side and, together with smaller stones is recommended. The rest technical specifications are identical to soil bund. Provision of spill ways or excess water disposal
devices can be placed at the end, in the middle or in whatever convenient position with its apron at the outlet.

**Work norm:** 250 PD/km (includes from stone collection up to ending of construction)

As for integration and input requirement it is same as for soil bunds except demanding more labour. For management and maintenance, well constructed bunds require little maintenance, upgrading bund height and controlled grazing. Farmers need to get enough training and supervision particularly in shaping and positioning of bunds.

### 4.10. Bench Terraces

Bench terrace is mainly done to reduce erosion and conserve moisture by letting the rainfall to infiltrate into the soil layer; therefore, it is more suited to areas with low rainfall or the soil has steep slope and poor water holding capacity. Definition: bench terraces are level or nearly level steps constructed on the contour and separated by embankments known as risers (Figure 52 & 53). There are about four types of bench terraces, namely; level, inward sloping, outward sloping and stone faced (Figure 51).

Terraces can also be known as “radical” or “progressive” depending on their speed of terracing. If a bench terrace is constructed at one go using the four diagrammatic steps followed before it called radical terrace. This is to mean the terrace is developed quickly. If the terrace is left to be developed through gradual maintenance i.e. erosion, cultivation operation and deposition then the terrace is known as progressive.

![Figure-51 Types of bench terraces](image-url)
• Level and reverse sloping bench terraces are very effective in controlling erosion on slopes of $30^0$ (55%) provided that the soils are deep enough and stable enough.

• In areas of unstable soils, the increases in infiltration can cause high water pressure in the soil pores and collapse terrace embankments. In such areas it would not be advisable to make bench terraces on slopes over 150 (30%).

• Bench terracing is always a major reclamation job, whether carried out on steep cultivated and eroding slopes or uncultivated land.

• Excavated bench terraces are extremely costly to build and maintain and is recommended for high value or cash crop grown area.

The following points should be considered during site selection for construction of excavated bench terraces:

• Good soil texture with sufficient depth; Very sandy soils should be avoided. The minimum depth on the cut section should not be less than 40-50 cm (after the cut) for deeper soil than annual crops.

• Topographic features and crop adaptation; Areas with very broken topography should be excluded. Annual crops should be planted on terraces up to 25% slope and orchards should be planted on higher slopes with very narrow bench strips.

• Excavated bench terraces should have slight back-slopes; otherwise, runoff down the riser would cause severe erosion. Risers can be constructed from soil or stones if available. When they are made of soil materials, they should be at slope and sodded/seeded with well-adapted grasses or legumes.

• A small drain, about 10 cm deep, should also be constructed at the bottom of each rise to take care of the runoff from the rises.

• Topsoil should be first removed and later on spread back after the terrace is constructed.

• On shallow soils (soils with less than 0.5 m depth), developed bench terraces are recommendable. This is done by leaving the grass strips with permanent vegetation along the contour or by constructing bunds. As the soil moves down, the grass strips or walls of the bunds will stop it. This process will ultimately form a bench terrace, which is called developed bench terrace.
Designing Bench Terrace: the design of bench terraces considers the following aspects:

a) Terrace Spacing

• Spacing is usually expressed in terms of the VI at which they are constructed. VI of 1.8 m is common on steep slopes over 20% and on less steep slopes VI of 1.2-1.5 m is recommended.

• The total width can vary from 2-10 m depending on ground slope, depth of soil, depth of cut and mode of formation. The recommended VI in Ethiopia for constructing bench terraces on slopes of up to 15% is 1 m and on slopes greater than 15% is two and half times the depth of workable soil.

b) Terrace Gradient

• Bench terraces, which are level or reverse sloping from front to rear, may also be graded laterally. Reverse slope bench terraces have a reverse gradient of 1% but they are not common, as they require higher embankments, deeper soil, and more work of construction than level bench terraces.

c) Risers

• Bench terrace risers usually have a uniform slope, which varies with the height of the riser, the soil type and the method of stabilization, whether grass or stones.

• Risers of 1 m in very stable clay loams can be nearly vertical but if they are 2 m high an angle of 70° - 80° would be advisable.

• With less stable soils an angle of 50° - 60° is safer. These angles can be adjusted depending on soil stability and methods of stabilizing risers.

Laying out Bench Terrace

• Bench terraces can be laid out with a line level. The lay out has to be in sequence starting from the top. Small adjustments can be made in spacing and alignment to meet the farmer's need. The first step is to throw the topsoil to the centre line between terraces. The subsoil is then excavated and levelled. The terrace risers or embankment should be compacted by beating and stabilized with grass or stone (see Figure 54).
Figure-52 & 53 Radical Bench Terrace in Wolaita zone, Soddo Zuria Woreda, on the foot hill of Damot Mountain; Note the wood used to hold the risers during construction
4.11. Hillside Terraces

Definition: a hillside terrace is a structure along the contour where a strip of land, about 1 meter wide, is levelled for tree planting. A vertical interval of 2-5 meters can be used for constructing hillside terraces (Figure 55, 56 & 57). Hillside terraces are recommended for low rainfall areas, because they help to retain runoff and sediment on steep slope land. When it is applied in moist areas, a slight inclination or slope to one side to safely drain excess runoff and a proper waterway should also be established at the end. Generally, hillside terrace is very costly. Hence, it should be used only if there is a strong justification for its construction.
Design of hillside terraces

- Height or stone riser = 0.5 m - 0.75 m
- Width of terrace = 1.5 m - 2 m
- Foundation = 0.3 m depth x 0.3 m width
- Grade of stone riser = 1:3
- In lower rainfall areas hillside terrace needs to have 5-10% gradient back slope. Integration with micro basins in between terraces is recommended.
Technical standards for hillside terracing with trenches

- Stone riser height: 0.75-1 m from ground level;
- Stone riser foundation: 0.3-0.4 mD x 0.3 mW;
- Top width: 0.5 m (0.25 m stone riser and 0.25 m soil);
- Grade of stone riser: 1 horiz: 3-4 vertical;
- Grade of soil bank: 1 horiz: 1.5 (unstable soils) to 2 vertical (stable soil);
- Base width: based upon slope;
- Size/place of trench: 50W x 50cm D x terrace length - placed 0.75-1m above stone wall;
- Size/place of ties: within trenches ties are placed at 2-3m intervals based upon plantation requirements and half way the depth of the trench (0.25 m) with 0.6m horiz. length x 0.5 cm width for planting seedlings;
A 30x30x30 cm plantation pit is placed in the middle of the tie or in front of the trench (between berm and embankment) with lateral spacing depending on tree and shrubs planted (1-3 metres);

Max length of HTTs: 50-80m. HTTs should wing up laterally, before depression points.

Figure-57 Hillside terracing for tree plantation and steep slope stabilization

4.12.  **Eye Brow Basins**

Like other water harvesting structures eye brow basins are suited to moisture deficit areas and where the soil’s water holding capacity is poor.

**Definition and use:** Eyebrows are larger circular and stone faced (occasionally sodded) structures for tree and other species planting (Figure 58). Based upon experience they are effective in low rainfall areas to grow trees and harvest moisture. Can be constructed in slopes above 50% for spot planting. Controls runoff and contribute to recharge of water tables. For the eyebrow if laid out and constructed in staggered arrangement significant reduction in runoff can be achieved. Community acceptance and closure or fencing is important.

**Design considerations**
- Size: 2.2-2.5 m diameter
Stone riser (or stabilized by brushwood or life fence): with 0.2 m depth of the foundation and a height of 0.4-0.6 m;
Stone riser sealed with soil excavated from water collection area;
Water collection area: dug behind the plantation pit: 1 m width x 1 m length x 20-25 cm depth (lower side);
Plantation pit(s) of 50cm depth x 40cm diameter dug between riser and water collection area;
Water collection ditch can be placed sideways or in front of plantation pits depending on soil type;
Two planting pits per eyebrow basin can be arranged;
Eyebrow can also be constructed between widely spaced hillside terraces.
4.13. Trenches

Definition and use: Trenches are large and deep pits constructed along the contours with the main purpose of collecting and storing rainfall water to support the growth of trees, shrubs, cash crops and grass or various combinations of those species in moisture stressed areas (350-900 mm rainfall). Trenches can have FLEXIBLE DESIGN, to accommodate the requirements of different species. Therefore, they can suit what the farmer want to grow. Trenches collect and store considerable amount of runoff water, thus vegetation grows faster and vigorous. They protect cultivated fields located downstream from flood and erosion. Part of the water captured by the trenches reaches the underground aquifer. Therefore, water tables are recharged and supply springs and wells with good quality water and for a long period of time (Figure 59).

Technical specifications

A) Site selection
- On hillsides where soil at least 50 cm deep and not too rocky (from 5-50% slopes);
- On abandoned lands that you wish to restore for growing tree/shrubs or other crops;
- On portions of forest land or closures that should be enriched;
- On homesteads for growing high value trees or other crops.

B) Layout and design
- Start from the top of the hill or field;
- Using an A-frame (or other level) the same size of the trench (2,5-3 m long) level the two tips of the frame and then mark the shape of the trench;
- Continue marking more trenches with the A-frame adjacently and below the first one;
- The spacing between two trenches laterally is 25-50 cm;
- Catchment Area/Trench Area ratio CA/TA is 3-5:1 (based on rainfall and tree water requirements) – normally 2-3 meters distance between lines of trenches;
- They are constructed in a staggered position one from another (triangle);
- If an A-frame is not available use another level (water level, etc).

C) Type of trenches

Trench for the growth of trees and grass
It can be constructed to grow 1 or up to 3 trees in each trench. The designs of the trench depend from the type of soil, rainfall, and the type and position of trees.

a) Standard design
- After layout dig soil to reach 20-25cm depth x 50cm width x 2.5-3m length (1).
- Keep some of the good topsoil aside for filling planting pit (s);
• Then dig a 50 x 50 cm wide x 40cm deep pit in the middle of the trench (2);
• Bottom of the pit should be 10-15 cm deeper than bottom of trench;
• Side ditches may slope towards ties for maximum utilization of light rain showers;
• Demarcate the tie around the pit (10cm from pit border on both sides) and proceed to deepen the collection ditch around the ties up to the required depth of 50cm (3);
• The embankment is to be shaped level and well compacted;
• Construction sequence – see Page 149 CBPWD National Guideline, 2005);
• No of trenches/ha from 800-1200.

b) Modified design for planting two to three trees
Take advantage of the water harvesting effect of the trench by planting 1 fast growing tree and 1 or 2 additional slow growing trees (which require less water).
B1) Trench with two trees planted on pits dug in two ties
B2) Trench with 1 tree planted in a tie and 2 trees on pits dug in front of trench
B3) Trench with 2 trees planted in two ties and 1 tree planted in front of the trench
N.B. For further detail see Page 149, CBPWD National Guideline, 2005.

Figure-59 Trenches in Lemmo Woreda, SNPP
5. Gully Treatment/Control Measures

5.1 Stone/Rock Check-dams

Definition and objective: A stone check-dam is an obstruction wall across the bottom of a gully or a small stream, for the purpose of reducing the velocity of runoff and prevents the deepening and widening of a gully channel. So check dams reduce velocity of flow, reduce erosion, increase deposition and provide soil for planting vegetation. Sediments behind a check-dam may be planted with crops or trees/shrubs and grasses for providing additional income to farmers. A spill way is provided to let excess run-off to the next/downstream check-dam. Check-dams also serve to recharge ground water and give rise to springs at downstream sites. Series of check-dams can be cascaded in a gully (Figure 60).

Check-dams are constructed across the floor of the gully to reduce the channel gradient and then to slow runoff and to trap sediment. They are mainly used to facilitate the establishment of vegetation in the gully, which will eventually stabilize and protect it from further erosion. If properly used and the runoff flowing to the gully is diverted, check-dams can also be used to gradually build up the floor of the gully to its original ground level, or to rehabilitate the gully.

The following criteria should be considered in the design of check-dams.

- Properly keyed across its base and up the abutments, to the crest elevation;
- Adequate spillway should be provided for safe disposal of water;
- An apron of non-erodible material should be provided at base, to dissipate the energy of water falling through the spillway. The apron should have a length of 1.5 times the height of the check-dam. For gullies with slope more than 15% the apron length should be 1.8 times the height of the dam. At the end of the apron a sill of about 15 cm height should be provided to reduce the speed of the water and keep some water on the apron that serve as a blanket;
- Proper spacing between the successive dams should be ensured;
- The height of the dam should be properly planned;
- Construction material should be of good quality;
- Size of catchment area and peak flow. Flow more than 1m$^3$/s will require posted stone check-dam;
- Stage of erosion: active gullies with steep gradient require stronger and durable check-dams;
- Availability of materials. Wherever possible locally available materials should be used;
- Costs: gully control is expensive and therefore cost effective measures should be used;
• Purpose of treatment. Gully control activities and type of measures to be taken for treatment should depend on the future intended use;
• Durability of structure. Structures for gully control should last until the required vegetation cover attained;
• Construction should start at the upper end to reduce the risk of failure if the water enters the gully before all check-dam have been constructed;
• Reshaping the head and sides of the gully to a slope ratio of 1:1 and plant with grasses, shrubs and trees.

**Minimum Technical Specifications**
Check-dams can be constructed in a wide range of conditions, such as

a) In small gullies serving a larger one;
b) As stone outlets for traditional or newly constructed bunds or terraces unable to accommodate all run-off;
c) As a silt trap for water ponds

![Figure-60 Check-dams Perspective View](image)

**Guidelines on rock quality**

- Large
- Broken and angular (smooth and round tend to shift)
- Size 25% in 10-14 cm diameter range
- Should not be easily disintegrating
S = 1.2H/G
Where; S is checkdams spacing; H is checkdam height; and G is gully bed slope

a) Determination of checkdams spacing

b) Well shaped stone walls

c) Frontal view

Figure 61 Spacing between two check-dams is calculated as

\[ S = \text{Height (m)} \times 1.2 \times \frac{1.2}{G} \text{ Gully bed slope (in decimal)} \]

Example: if effective height of stone check-dam is 1m. And slope of the gully is measured to be 4% on average. How far apart should the check-dams be?

\[ D = 1.2 \times H = 1.2 \times 1 = 30 \text{ m} \]
\[ G = 0.04 \]

Therefore, the check-dams should be 30m apart.

The spacing of the check-dams will depend on the gradient and dam crest height of the gully (Table 22 & Figure 61). The dam should have a spillway whose depth will depend on the expected flow. The check-dam should have a properly constructed apron on the downstream side to protect the dam from undercutting. The apron should have a length of 1.5 times the height of the check-dam. For gullies with slopes more than 15% the apron length should be 1.8 times the height of the dam.
Table 22. Spacing of check-dams estimated for bed slope and height of dam under various construction materials

<table>
<thead>
<tr>
<th>Height of dam crest above gully floor</th>
<th>Gradient of floor %</th>
<th>0.3m</th>
<th>0.3m</th>
<th>0.3m</th>
<th>0.6m</th>
<th>0.6m</th>
<th>0.6m</th>
<th>0.9m</th>
<th>0.9m</th>
<th>0.9m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wood &amp; gabion</td>
<td>Post-brush/stone wall with 1:1 slope</td>
<td>Wood &amp; gabion</td>
<td>Post-brush/stone wall with 1:1 slope</td>
<td>Wood and gabion</td>
<td>Post-brush/stone wall with 1:1 slope</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>30</td>
<td>45</td>
<td>15</td>
<td>23</td>
<td>15</td>
<td>15</td>
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<td></td>
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<tr>
<td>6</td>
<td>7.5</td>
<td>15</td>
<td>23</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
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<td></td>
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<tr>
<td>8</td>
<td>5.2</td>
<td>10</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>7.7</td>
<td>12</td>
<td>12</td>
<td>12</td>
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<td>12</td>
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<td>12</td>
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<tr>
<td>12</td>
<td>5.2</td>
<td>6.3</td>
<td>9.3</td>
<td>9.3</td>
<td>9.3</td>
<td>9.3</td>
<td>9.3</td>
<td>9.3</td>
<td>9.3</td>
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</tr>
<tr>
<td>14</td>
<td>2.7</td>
<td>5.3</td>
<td>7.8</td>
<td>7.8</td>
<td>7.8</td>
<td>7.8</td>
<td>7.8</td>
<td>7.8</td>
<td>7.8</td>
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</tr>
<tr>
<td>16</td>
<td>2.3</td>
<td>4.6</td>
<td>6.7</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
<td>7.4</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>1.8</td>
<td>3.7</td>
<td>4.5</td>
<td>5.4</td>
<td>6.7</td>
<td>6.7</td>
<td>6.7</td>
<td>6.7</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>1.7</td>
<td>3.1</td>
<td>3.9</td>
<td>4.5</td>
<td>6.1</td>
<td>6.1</td>
<td>6.1</td>
<td>6.1</td>
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<tr>
<td>28</td>
<td>1.4</td>
<td>1.7</td>
<td>2.7</td>
<td>3.4</td>
<td>3.9</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
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<tr>
<td>36</td>
<td>1.1</td>
<td>1.5</td>
<td>2.1</td>
<td>3</td>
<td>3</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>1</td>
<td>1.5</td>
<td>1.9</td>
<td>2.9</td>
<td>2.7</td>
<td>4.2</td>
<td>4.2</td>
<td>4.2</td>
<td>4.2</td>
<td></td>
</tr>
</tbody>
</table>

- Side key: 0.7-1m
- Bottom key: 0.5m
- Height: 1-1.5m excluding foundation.
- Base Width: 1.5 - 3.5m
- Downstream stone face vert/horiz = 1:3, 1:4 for increased stability.
- Drop structure placed for gully bed slope of greater than 15% before the apron (ladder placed stones up to half the height between apron and spillway level)
- Spillway (trapezoidal) with 0.25m free board and 0.25-0.3 m permissible depth, width minimum 0.75m and maximum 1.2m (for small catchments);
- Apron at least 50 cm wide both sides of spillway fall (total width 1.5-2m) and length towards water flow of minimum 1 m, with stones placed vertically (15cm high).
- The gully sides should be reshaped and soil filled against the check-dam wall. Gully sides should be planted with rows of grass and possibly re-enforced with sisal plantations along the upper and/or lower side of the dam.
5.2 Brushwood check-dam

**Definition and purpose:** brushwood check-dams are temporary structures constructed with tree branches and poles. Plant species, which can easily grow vegetatively through shoot cuttings, are ideal for this purpose. The purpose is to retain sediments and slow down run-off velocity, enhance re-vegetation of gully areas. They are constructed in single or double rows. These types of structures are possibly constructed where there is sufficient wood resource and gully control is worth compared to conservation of woody materials.

**Technical Specifications**
- Brushwood check-dams are suitable for plugging small gullies of depth less than 2m.
- Brushwood check-dams should be combined with planting multipurpose plant species.
- Posts with vegetative propagation should be used.
- Straight branches of diameter 3-8 cm are ideal. The thicker branches are used as vertical posts (Figure 62). Their height depends on the height of particular gully but not exceeding 1m above ground. Vertical posts are driven into the soil at least 50-60 cm depth. Spaced apart at 30-50 cm. The posts should lean to the upper stream side for better resistance and stability. After the posts are driven into the soil across a gully, the thinner branches are interwoven alternatively through the posts and built up, to for a wall. Each branch should be pushed into the banks up to 50 cm inside.
- Spacing of the check-dams: A simple rule of thumb for spacing between two consecutive dams is levelling the base of upper check-dam with top of lower check-dam. Another approach is to use the same calculation for stone check-dam and divide by two/three.

*Figure-62 Brushwood Check-dams*
5.3 **Sand bags check-dam**

For the areas where stones are not available, sandbags check-dams can be the best alternatives. But the filled soils should not be easily washed or eroded by the flood water and better if it be sandy/white clay /termite soil “Kuyisa” as this gives more support and strength. Also better to reinforce it with woody materials/logs (Figure 63).

*Figure-63 Sand bag check-dams with wooden post (left)*;

*Figure-64 Retained soil and moisture made it ready for planting*
Figure 65 Sand Bag Checkdam (Alaba, SNNP)

5.4 Gabion check-dam

Galvanized gabion: is a box of wire mesh filled with stones. Gabions may be laid in courses like large bricks to form bank revetment, etc. The gully side should be strong for side key foundation. When suitable soil condition do not exist, sidewall reinforcement is required. A good foundation must have sufficient strength to withstand the weight of the structure and prevent sliding/bulging, it should be tight enough and uplift must be reduced as much as possible and also not be damaged by overflow discharge and outlet discharge (Figure 66, &Table 22).

Material selection: the selected stones should not be easily eroded/ hard rocks and better if it is round shape. Use large stones (preferably of 30 cm diameter or more) for casing the dam wall. Use smaller stones to pack the centre. Finish a top layer with large stones.
5.5 Sediment Storage Dams

It is a flood mitigation and land reclamation measures structure constructed in wide gullies and it can convert wide, deep and series of gullies into productive areas just by trapping the sediments and moistures that are flowing through it. It is more useful in dry and degraded areas (Figure 67 & 68). Well compacted soil forms the inner dam body while well shaped stones and gabions can form the outer part. Similar to an earth dam consideration of spillway on either side is required. By constructing sediment storage dams it is like creating a land which does not exist before. Series of sediment storage dams in a cascaded arrangement can recharge the groundwater for later abstraction through hand dug wells and springs.

What makes SSDs different from check-dams is that one they are very big in size. Also different from check-dams they can store water as a surface pond until the space/volume is overtaken by the incoming sediment. Unlike check-dams SSDs can be constructed cascading from downstream upwards. This is depending on sediment yield. To mention few, SSDs have been constructed in Adama, Adwa, Ambassel, Bati, Delanta, Dire Dawa, Gidan, Kalu, Konso, Meket, Omosheleko, Wukro. Where it is introduced cropping systems can be changed to high value fruit and other tree crops just to make use of the moisture and fertile soil accumulated by the structures. For detail technical specifications consult infotechs or other specific manuals.
Figure-67 SSD in Enderta (Tigri), see the spillway on the left side of the dam - photo in courtesy of Yonatan Ayalew.
Figure-68  Newly Constructed Sand Storage Dam (Deder)

**Work norm:** 0.5 m$^3$/PD  
Check-dam dimensions could vary based on estimation of catchment area and run-off for designing the size and spillway of a check-dam structure.

**Management requirement**  
- Check-dams require proper regular follow-up and maintenance work through group of people sharing the gully area. Maintenance key during and rainy season (after first heavy rains undertake all repairs)
- Gully protection/closure is important for quick recovery of vegetation through agreement of community/group members.
- Fertility improvement (compost, etc) within 1-2 years
- Stabilization (seasonal, permanent, etc)
- Moisture plot management (depending on AGCZ)
- Supplementary measures as required
6. Use of Simple Surveying Techniques

6.1 Use of the Line Level for Surveying

A) General

1. The line level is a simple surveying instrument, which can be used for laying out contours and gradients and also to measure the slope of land. It is simple to operate and is easier to transport than other similar surveying tools such as the A-frame. It is especially quick and very accurate when used properly. However a line level does require three people to operate.

2. A line level consists of two poles, between which a length of string is suspended (Figure 69). A spirit level is hung on the string. The level is the type used by builders, but has small hooks at either end.

3. The poles should be of even height (about 1.5 m) and the string (about 2 mm in diameter) and precisely 8m in length. A notch is made in each pole at exactly the same height (say 1.4m above ground level) and the ends of the string tied around these notches.

4. The centre of the string (4 m from each end) is marked and the level itself is suspended there.

B) Laying out a Contour

5. The poles are held apart by operators with the string extended and the spirit level positioned exactly in the middle of the string. When the bubble in the level is between the two marks this means that the poles are positioned on level points on the land - in other words on the contour. The poles must be held vertically.

6. For laying out a contour across a slope, the team begins at the edge of the field. The operator holding the pole at the field’s edge (operator A) remains stationery while the operator holding the other pole (operator B) moves up and down the slope until the third operator is satisfied that the bubble is centred. Points A and B are then marked (with stones or pegs). Operator A then moves to B and operator B moves onwards and the process is repeated. This continues until the contour line reaches the far end of the field.

7. Care should be taken those small obstacles, such as minor high spots, or rills, are avoided by skipping forward a pace or two. This avoids sharp irregularities in the contour.

8. When the contour has been laid out, the curves can be smoothed by eye according to the guidelines given for stone or earth bunds.
C) Laying out a Graded Contour

9. A graded contour deviates slightly from the true contour and is normally used to align a channel, such as a diversion ditch, or to stake out a graded earth bund (not soil bund).

10. In order to layout a graded contour, further notches must be made on one of the poles. These notches are made below the original notch at intervals of 2 cm.

11. The usual gradient for a structure such as a division ditch is 0.25%. The string of the near side operator (A) should be affixed to the second notch down his pole (2 cm below the original) and the far operator (B) retains his string at the original notch. When the bubble in the level is between the two marks, this now implies that A is 2 cm above B, which is equivalent to a 0.25% slope over the distance of 8m. For a slope of 0.5%, Operator A fixes his string to the third notch down his pole (4 cm below the top notch) and, when Operator B finds a position where the level reads dead centre, he/she is at a ground level 4 cm below that of Operator A. Over a distance of 8m the slope is then 0.5%.

12. The operation now proceeds as before, operator A moving forward to the spot occupied by B, and B moving onwards — slightly down slope. Once again minor irregularities should be avoided and the curve smoothed.

13. If a diversion ditch must follow a precise field boundary it can be excavated so that the bottom of the ditch is given a suitable gradient. Surveying will therefore take place during excavation.

Figure-69 Use of the line level.
D) Measuring the Slope of the Land

14. It is simple to use the line level to measure the slope of the land. Operator A stands exactly up slope of Operator B and adjusts the string to the notch which gives a level reading. For example if this notch is the 3rd (i.e. 4 cm below the top notch) the gradient is 0.5%, if the notch is the eleventh (i.e. 20 cm below the top notch) the gradient is 2.5%, etc (Figure 70).

15. Up to 21 notches should be marked on pole A and the following table shows the percentage slope indicated by each.

<table>
<thead>
<tr>
<th>Notch on Pole A</th>
<th>% slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>0 (level)</td>
</tr>
<tr>
<td>2nd (2 cm below top)</td>
<td>0.25</td>
</tr>
<tr>
<td>3rd (4 cm below top)</td>
<td>0.50</td>
</tr>
<tr>
<td>4th (6 cm below top)</td>
<td>0.75</td>
</tr>
<tr>
<td>5th (8 cm below top)</td>
<td>1.00</td>
</tr>
<tr>
<td>7th (12 cm below top)</td>
<td>1.50</td>
</tr>
<tr>
<td>11th (20 cm below top)</td>
<td>2.50</td>
</tr>
<tr>
<td>21st (40 cm below top)</td>
<td>5.00</td>
</tr>
</tbody>
</table>

*Figure-70 Measuring the slope with a line level*
6.2 **Important Points to Remember**

1. Always check the spirit level by placing it on a horizontal surface and noting the position of the bubble, which should be between the two marks.
2. Check the centre-point of the string each day and its length also.
3. Remember that when laying out a gradient that operator (A) is upslope.
4. Make sure poles are held vertically.
5. Avoid placing the poles is depressions or on top of minor high spots in the field.

6.3 **Use of the Water Tube Level for Surveying**

A) **Introduction**

1. A very accurate and simple instrument for measuring the level differences of two points is the "tube water level". The water tube level is straightforward to use, and farmers can be quickly taught to layout contours. The concept itself – of matching up levels of water – is especially easy to understand. Advantages of the water tube level are that it can be operated by only two people and is more sensitive than the line level on very low slopes. It is, however, slightly less portable than the line level, and is not so simple to use for determining slopes or laying out graded contours.

2. The components of the water tube level are as follows:
   - A length of transparent plastic tubing, 6-10mm inside diameter and about 14m long.
   - Two poles (levelling staffs should be of the same length) of about 2m in length. Four rubber straps (easily made from a bicycle inner tube) to attach the plastic tubing to the poles - one to two litres of water.
   - Muddy water is preferable as it is easily more visible in the tube.

3. The plastic tubing is firmly attached to the poles using the rubber straps, or other securing devices. The ends of the tube should be about 10 cm from the top of each staff and the bottom fixing point about 20 cm from the bottom of each staff (Figure 71 & 72).

4. The tube is then filled with muddy water until the water level is about halfway up each staff. It is essential that no air bubbles are trapped in the tube and, if necessary, they can be removed by tapping with the finger, wherever the two poles are set, the free water surfaces in each tube will be at the same level.

B) **Laying out a Contour**

1. The two poles are placed back to back at the starting point, marked with a peg (A). After any air bubbles have been removed and the water has come to rest, a mark is made on both poles, indicating the water level.
2. The lead man takes one staff and drags the tube in what seems to be the direction of the contour line. When the tube is almost stretched, the lead man moves slowly up and down the slope until his staff is at a position where the water level in the tube coincides with the mark. The staff is then at a point where the ground level is the same as at peg A. A second page (B) is placed at this point. The back man now moves from peg A to the other side of peg B where the lead man remains stationary. It is now the back man’s turn to find the correct spot which is marked by peg C. This procedure continues until the end of the field.

3. The operators then measure, or pace, the horizontal distance required between the contours and begin to layout the second contour.

4. The contour may then be “smoothed” by eye, according to the design specifications.
C) **Important Points to Remember**

1. Work should be carried out during the coolest time of the day because heat causes the plastic tube to stretch and this affects the water levels, which may have to be re-marked.

2. It is important to avoid spillage of water, or the water levels will need re-marking. Water is usually spilled during movement of the poles and this can be avoided by closing the ends of the tube with plugs during movement. It is, however, essential to remove the plugs while making measurements.

3. The poles should always be held vertically.

4. Minor depressions or isolated high spots in the field should be avoided.

---

*Figure 72* The tube level is used to locate the contour precisely before ridge construction. Low in cost and easy to use by farmers.

6.4 **Use of the A – Frame for Laying Out Contour Lines**

A – Frames can also be used for making contours (see picture below). Two wooden stuffs are connected hinged at the top while the other legs are stretched sideward. A third wooden stuff is fixed across the legs resembling the A letter. A stone or heavy material is tied with the string and released from the top fixings of the wooden stuff to act as a plum bob. When the A – Frame is on a level ground the string with a weight passes exactly at the centre of the horizontal bar. By placing 1 or 2cm marks towards both sides of central mark then it is possible to read whether the ground under survey is upward sloping or downward sloping (Figure 73). The advantage of the A – Frame over the line level and water tube level is that it can be operated by one person.
A – Frame

Figure-73 A – Frame on display
### Tree management and use of some useful species

<table>
<thead>
<tr>
<th>No.</th>
<th>Tree species</th>
<th>Management</th>
<th>Uses</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Acacia abyssinica</em></td>
<td>Lopping and pollarding</td>
<td>Fuel, construction, handles, medicine, fodder, bee forage, soil improvement, and shade</td>
<td>Drought resistant. Plant on marginal lands &amp; gullies.</td>
</tr>
<tr>
<td>2</td>
<td><em>Acacia albida</em> (Girar)</td>
<td>Pollarding and lopping</td>
<td>Fuel, furniture, medicine, fodder, soil cons., shade and wind break</td>
<td>If planted mixed with millet and sorghum, gives good prod. It flushes leaves in dry season, fodder for animals.</td>
</tr>
<tr>
<td>3</td>
<td><em>Acacia decurrense</em> (Girar)</td>
<td>Coppicing</td>
<td>Fuel, post, fodder, soil improvement, shade, windbreak and for tannery.</td>
<td>Protects landslide, produces good harvest if planted as wood lot.</td>
</tr>
<tr>
<td>4</td>
<td><em>Acacia melanoxylon</em> (Girar)</td>
<td>Pollarding or lopping</td>
<td>Fuel and lumber.</td>
<td>Fast growing for lumber production</td>
</tr>
<tr>
<td>5</td>
<td><em>Acacia nilotica</em></td>
<td>Lopping and pollarding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td><em>Acacia polyacantha</em> (Gmarda)</td>
<td>Coppicing, lopping or pollarding</td>
<td>Fuel, timber, farm tools, medicine, fodder, soil cons., nitrogen fixation, live-fence, shade and wind break</td>
<td>Fast growing and termite resistant.</td>
</tr>
<tr>
<td>7</td>
<td><em>Acacia saligna</em> (Girar)</td>
<td>Coppicing, lopping or pollarding</td>
<td>Fuel, fodder, soil conservation, shade and food preservation.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td><em>Acacia tortilis</em> (Girar)</td>
<td>Lopping</td>
<td>Fuel, lumber, fodder, Apiary and roap making.</td>
<td>Avoid goats until the tree grows.</td>
</tr>
<tr>
<td>9</td>
<td><em>Albizia gummifera</em> (Sesa)</td>
<td>Lopping and coppicing</td>
<td>Fuel, lumber, utensils, fodder and bee forage</td>
<td>Shade for coffee, leaves used to ripen banana.</td>
</tr>
<tr>
<td>10</td>
<td><em>Albizia lebbeck</em> (Sesa)</td>
<td>Lopping, pollarding and coppicing</td>
<td>Fuel, post, lumber, fodder, medicine, apiary, soil cons., tannery and soap making (roots)</td>
<td>If planted along rivers, minimizes soil erosion</td>
</tr>
<tr>
<td>11</td>
<td><em>Albizia schimperiana</em> (Sesa)</td>
<td>Pollarding and coppicing</td>
<td>Fuel, lumber, apiary, soil improvement and shade</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td><em>Annona muricata</em> (Gishita)</td>
<td>Regular weeding, Prune to induce branching and height control and pollarding</td>
<td>Food, medicine, insecticide, fish poison and ornamental</td>
<td>Good fruit tree in home gardens</td>
</tr>
<tr>
<td>13</td>
<td><em>Azadirachta indica</em> (Kinin)</td>
<td>Lopping and pollarding</td>
<td>Fuel, lumber, medicine, fodder, pesticide, oil and soap making</td>
<td>Has medicinal value and is useful tree in degraded areas.</td>
</tr>
<tr>
<td>14</td>
<td><em>Balanites aegyptica</em></td>
<td>Coppicing</td>
<td>Fuel, lumber, post, handles, food(fruits), fodder, gum, and soil improvement.</td>
<td>Good for dry areas, produces fruits in dry season and termite resistant. Juice from fruits and bark kills Bilharzias and Guinea worms.</td>
</tr>
<tr>
<td>No.</td>
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<td>Uses</td>
<td>Remarks</td>
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<tr>
<td>15</td>
<td><em>Cajanus cajan</em> (Yergib ater)</td>
<td>Needs weeding and care as it is easily attacked by pests.</td>
<td>Fuel, food, fodder, bee forage, basketry and, soil fertility</td>
<td>Good in dry areas. It produces fruits 4-5 years continuously</td>
</tr>
<tr>
<td>16</td>
<td><em>Cassia siamea</em> (Yefeerenj digita)</td>
<td>Lopping and coppicing</td>
<td>Fuel, lumber, fodder, soil conservation and wind break</td>
<td>Fast growing, if eaten by pigs it can be poisonous. Termite resistant.</td>
</tr>
<tr>
<td>18</td>
<td><em>Casuarina cunninghamnia</em> (Shewshewe, Arzelibanos)</td>
<td>Pruning produces good quality lumber.</td>
<td>Fuel, lumber, post, fodder(young twigs), soil conservation and windbreak</td>
<td>Hard for sawing and may bend or twist while drying.</td>
</tr>
<tr>
<td>20</td>
<td><em>Catha edulis</em> (<em>Chat</em>)</td>
<td>Pollarding</td>
<td>Fuel, medicine and drug.</td>
<td>Cash generating plant</td>
</tr>
<tr>
<td>21</td>
<td><em>Citrus aurantifolia</em> (<em>Lomi</em>)</td>
<td>Pollarding to induce branches.</td>
<td>Food and medicine</td>
<td>Income generating plant</td>
</tr>
<tr>
<td>22</td>
<td><em>Citrus reticulata</em> (<em>Menderin</em>)</td>
<td>Same as for 18 above.</td>
<td>Food</td>
<td>Produces good in areas 1500-1800 m. a.s.l.</td>
</tr>
<tr>
<td>23</td>
<td><em>Citrus sinensis</em> (<em>Birtukan</em>)</td>
<td>Prune to induce branching and height control.</td>
<td>Food</td>
<td>It is a good income generating plant.</td>
</tr>
<tr>
<td>24</td>
<td><em>Cordia africana</em> (<em>Wanza</em>)</td>
<td>Pollarding, lopping and coppicing.</td>
<td>Fuel, lumber, utensils, food, shade and soil conservation.</td>
<td>Good for homestead and on farm plantations.</td>
</tr>
<tr>
<td>25</td>
<td><em>Croton macrostachyus</em> (<em>Bisana</em>)</td>
<td>Pollarding, lopping and coppicing.</td>
<td>Fuel, lumber, post, handles, fodder, mulching and medicine.</td>
<td></td>
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<tr>
<td>27</td>
<td><em>Eucalyptus camaldulensis</em> (Key bahirzaf)</td>
<td>Coppicing and pollarding</td>
<td>Fuel, post, bee forage and windbreak</td>
<td>Susceptible for termite attack.</td>
</tr>
<tr>
<td>28</td>
<td><em>Eucalyptus saligna</em> (Key bahirzaf)</td>
<td>Coppicing</td>
<td>Fuel, pulp, utensils, medicine, bee forage, shade and windbreak.</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td><em>Eucalyptus viminalis</em> (Key bahirzaf)</td>
<td>Coppicing</td>
<td>Fuel, post, lumber, bee forage and pulp.</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td><em>Kigelia aethiopica</em> (<em>Sausage tree</em>)</td>
<td>Coppicing</td>
<td>Fuel, post, timber, fodder, bee forage, dye, medicine, and soil fertility</td>
<td>Unripe fruits are poisonous. The tree is not competitive with crops</td>
</tr>
<tr>
<td>31</td>
<td><em>Kigelia africana</em> (<em>Sausage tree</em>)</td>
<td>Coppicing</td>
<td>Fuel, post, timber, fodder, bee forage, dye, medicine, and soil fertility</td>
<td>Unripe fruits are poisonous. The tree is not competitive with crops</td>
</tr>
<tr>
<td>32</td>
<td><em>Lawsonia inermis</em> (<em>Henna</em>)</td>
<td>Lopping</td>
<td>Fuel, fodder, dye, medicine, perfumes, thatching and ornamental</td>
<td>Produce volatile oils with pleasant odour. Dye is good for colouring of</td>
</tr>
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7-157
<table>
<thead>
<tr>
<th>No.</th>
<th>Tree species</th>
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<th>Uses</th>
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<tbody>
<tr>
<td>33</td>
<td><em>Leucaena leucocephala</em> <em>(Lusina zaf)</em></td>
<td>Lopping and coppicing</td>
<td>Fuel, post, fodder, bee forage, green manure and soil fertility.</td>
<td>Control expansion as it reproduces rapidly. Do not feed more than 20% as a mix for fodder.</td>
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<tr>
<td>34</td>
<td><em>Lonchocarpus laxiflorus</em></td>
<td>Coppicing and pollarding</td>
<td>Food, fodder, bee forage</td>
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<tr>
<td>35</td>
<td><em>Mangifera indica</em> <em>(Manago)</em></td>
<td>Lopping and grafting</td>
<td>Fuel, fodder, bee forage, shade, windbreak, soil conservation and gum making.</td>
<td>Grafted mangoes give quality fruits.</td>
</tr>
<tr>
<td>36</td>
<td><em>Markhamia lutea</em></td>
<td>Coppicing and pollarding</td>
<td>Fuel, charcoal, poles, post, timber, tool handles, medicine, mulch, bee forage and soil conservation</td>
<td>The wood is fairly termite resistant</td>
</tr>
<tr>
<td>37</td>
<td><em>Melia azedarach</em></td>
<td>Lopping, pollarding and coppicing</td>
<td>Fuel, post, handles medicine, bee forage, shade and windbreak.</td>
<td>Fruits are poisonous.</td>
</tr>
<tr>
<td>38</td>
<td><em>Millettia ferruginea</em> <em>(Birbirra)</em></td>
<td>Coppicing and pollarding</td>
<td>Fuel, construction, handles utensils, shad and fishing.</td>
<td>Good shade tree for coffee.</td>
</tr>
<tr>
<td>39</td>
<td><em>Moringa oleifera</em> <em>(Shiferaw)</em></td>
<td>Coppicing, pollarding or lopping</td>
<td>Food (leaves and fruits), medicine, fodder, bee forage, soil conservation, shade, windbreak, spice, oil and water purification.</td>
<td>Vegetable oil, cosmetics and soap making.</td>
</tr>
<tr>
<td>40</td>
<td><em>Olea africana</em> <em>(Weira)</em></td>
<td>Pollarding</td>
<td>Fuel, post, panelling, milk flavouring and floor making</td>
<td>Slow growing but very hard wood.</td>
</tr>
<tr>
<td>41</td>
<td><em>Perkinsonia aculeata</em> <em>(Ye yerusalem ishoh)</em></td>
<td>Pollarding</td>
<td>Fuel, fodder, bee forage, mulch and soil conservation.</td>
<td>Good for rehabilitating degraded areas.</td>
</tr>
<tr>
<td>42</td>
<td><em>Prosopis juliflora</em></td>
<td>Lopping, pollarding and coppicing</td>
<td>Fuel, food, fodder (Fruits), bee forage and soil conservation</td>
<td>Fast growing, competes with food crops therefore avoid planting with them.</td>
</tr>
<tr>
<td>43</td>
<td><em>Psidium guajava</em> <em>(Zeitun)</em></td>
<td>Pollarding, lopping or coppicing</td>
<td>Fuel food and handles.</td>
<td>Termite resistant, leaves easily decompose.</td>
</tr>
<tr>
<td>44</td>
<td><em>Rhamnus prinoides</em> <em>(Gesho)</em></td>
<td>Coppicing</td>
<td>Fuel, medicine and beverage,</td>
<td>Hoeing and watering produces good production &amp; Income</td>
</tr>
<tr>
<td>45</td>
<td><em>Ricinus communis</em> <em>(Gulo)</em></td>
<td>Coppicing</td>
<td>Oil for medicine and lotion. By-product can be used as fertilizer.</td>
<td>Drought and termite resistant. Poisonous to animals.</td>
</tr>
<tr>
<td>46</td>
<td><em>Schinus molle</em></td>
<td>Pollarding, lopping and coppicing</td>
<td>Fuel, bee forage, soil conservation, windbreak, pesticide &amp; spice/seeds.</td>
<td>Good for road side planting</td>
</tr>
<tr>
<td>47</td>
<td><em>Sesbania sesban</em> <em>(Girangire)</em></td>
<td>Pollarding and coppicing</td>
<td>Fuel, post, fodder, mulch, soil conservation, shade, nitrogen fixing and soap making (leaves)</td>
<td>Good for combining with annual crops.</td>
</tr>
<tr>
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<tr>
<td>48</td>
<td><em>Tamarindus indica</em> (Humer)</td>
<td>Lopping, pollarding and Coppicing.</td>
<td>Fuel, lumber, food (Fruits), beverage (Fruits), fodder, mulch, nitrogen fixing.</td>
<td>Beverage from the pulp is rich in vitamin C.</td>
</tr>
<tr>
<td>49</td>
<td><em>Tamarix aphylla</em></td>
<td>Coppicing</td>
<td>Fuel, lumber, fodder, mulch, soil cons., nitrogen fixing, windbreak and fire control</td>
<td>Produces salty elements, need not be planted mixed with agric. crops.</td>
</tr>
<tr>
<td>50</td>
<td><em>Terminalia brownii</em> (Abalo)</td>
<td>Lopping, pollarding and coppicing.</td>
<td>Fuel, hand tools, handles, mulch soil improvement and paint</td>
<td>Termite resistant and its shade does not affect crops to grow</td>
</tr>
<tr>
<td>51</td>
<td><em>Ziziphus moritania</em> (Kurkura)</td>
<td>Lopping, Coppicing or pollarding.</td>
<td>Fuel, utensils, fodder, soil conservation, fencing and food</td>
<td>Propagation possible via seed, cuttings, root suckers.</td>
</tr>
<tr>
<td>52</td>
<td><em>Ziziphus spina-christi</em> (Kurkura)</td>
<td>Lopping and pollarding</td>
<td>Fuel, utensils, fodder, soil conservation, fencing and food</td>
<td>Good for dry areas</td>
</tr>
</tbody>
</table>

Source: Useful trees and shrubs for Ethiopia, Identification, Propagation and Management for Agricultural and Pastoral Communities, Regional Soil Conservation Unit, SIDA, 1993

Annex II

<table>
<thead>
<tr>
<th>No.</th>
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<th>Management</th>
<th>Uses</th>
<th>Remarks</th>
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<tbody>
<tr>
<td>1</td>
<td><em>A. falcata</em></td>
<td>Lopping and pollarding</td>
<td>Fuel, lumber, food (Fruits), beverage (Fruits), fodder, mulch, nitrogen fixing.</td>
<td>Propagation possible via seed, cuttings, root suckers.</td>
</tr>
<tr>
<td>2</td>
<td><em>A. falcata</em></td>
<td>Lopping and pollarding</td>
<td>Fuel, lumber, food (Fruits), beverage (Fruits), fodder, mulch, nitrogen fixing.</td>
<td>Propagation possible via seed, cuttings, root suckers.</td>
</tr>
<tr>
<td>3</td>
<td><em>A. falcata</em></td>
<td>Lopping and pollarding</td>
<td>Fuel, lumber, food (Fruits), beverage (Fruits), fodder, mulch, nitrogen fixing.</td>
<td>Propagation possible via seed, cuttings, root suckers.</td>
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<td>Data 40</td>
<td>Data 41</td>
<td>Data 42</td>
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*Note: The table is generated from the text data.*
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7-162
Source: Adopted from training materials prepared for watershed development technical training of training, PWCU, Natural Resources Management Directorate, MoA, 2010
Annex III. Recommended species for agroforestry based land management system on different agro-climatic zones

**Dry Weina Dega, 1500-2300m.a.s.l., Annual rainfall 1400mm**

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<tr>
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<th></th>
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<th></th>
<th>No. of seeds per k.g. (000)</th>
<th>Germination period (Days)</th>
<th>Germination %</th>
<th>Period in Nursery (Months)</th>
<th>Treatment before sowing</th>
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<td>7-21</td>
<td>25-60</td>
<td>8-9</td>
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Moist and Wet Weina Dega, 1500-2300, Annual rainfall over 1400mm.
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<th>Germination %</th>
<th>Period in Nursery (Months)</th>
<th>Treatment before sowing</th>
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<td>8-9</td>
<td>Immerse in boiled water and cool for 48hrs</td>
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Moist and wet Dega, 2300-3200 m.a.s.l., Annual rainfall over 1800mm
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25. Tree Nurseries, an illustrated technical guide and training manual, Booklet No.6. UNDP.