MANUAL OF SLM TECHNOLOGIES FOR THE CONTEXT OF AGRICULTURE IN DOMINICA

Preface

Dominica is a tropical country characterized by steep undulating lands with high rainfall, impacts from which is being exacerbated by climate change. Primary agricultural production remains a major contributing factor to national development. Information from the elevation map (featured below) suggests that approximately 50% of the total land mass falls within the slope class of >30 degrees (i.e.,375 km^2), 20% falls within 20 – 30 degrees (150 km^2), 15 % within 10 – 20 degrees (112.50 km^2) and 15% falls within the class that is less than 10 degrees of the slope (112.50 km^2). The majority of agricultural lands that fall within the project areas of St. Joseph, St. Paul, St. Georges, St. Patrick and St. David falls within the slope range of 20 to > 30 degrees. The combination of these two factors (high slope and rainfall) increases the susceptibility of soils to erosion, nutrient leaching and eventual degradation.

Runoff and soil erosion are responsible for about 83% of the land degradation worldwide. (Isaiah I.C. et al., 2007). Within this context, it is critical that technicians, farmers and farm managers understands the basic requirements for operating and farming on sloping land to avoid, and in some cases, reverse the impacts of land degradation associated with erosion and nutrient leaching. Key technologies requiring consideration includes soil type identification and management, contour farming, agronomic and mechanical conservation practices, nutrition management and crop and livestock management.

This manual is intended to be a guide for implementation of standard soil and land management (SLM) technologies that address the identified limitations on farmlands. It is directed for use by technical officers and other trained personnel tasked with the planning, supervision and implementation of SLM technologies within jurisdictions with similar conditions to Dominica. The term 'farmland' may cover all land that is used for agricultural and forestry activities. However, in this manual, farm land includes only land used directly for growing crops, forest trees and pasture.

The manual will be divided into two sections;

Section 1 – Focuses on 'how to' or skill building,

Section 2 – Provides information on approaches for implement SLM, and other supporting information on some of the technologies identified in section 1.

TABLE OF CONTENTS

SECTION 1 **SLM TECHNOLOGIES HANDBOOK**

SECTION II **APPROACHES FOR IMPLEMENTATION OF TECHNOLOGIES AND OTHER CONSIDERATIONS AND SUPPORTING INFORMATION ON SELECTED TECHNOLOGIES**

Acknowledgements

The critical importance of sustainable land management to improved food and nutrition security for low to middle income countries cannot be over emphasize. This is why tremendous gratitude must be extended to Global Environment Fund (GEF) in collaboration with United Nations Environment Programme (UNEP) for funding this initiative under the project title Sustainable land management in the Commonwealth of Dominica: Strengthening resilience of Agricultural lands and forest in Dominica.

Gratitude is also extended to IICA, who through the team of Mr K. Coipel, Dr. C St. Martin and Ms N. Carrai guided the final content and presentation of this manual.

The effort of the local support team to include staff of the Division of Agriculture, the PiSLM project, together with the other project consultants also provided valuable feedback during the review stage of the manual and must be acknowledged. The contribution of agronomist Dr. Gregory Robin is also acknowledged for his contribution to the technologies that benefitted root crop production.

SLM Consultant
Bernard Nation

Introduction

These manual addresses output 2 of the exercise to strengthen resilience of agricultural and forest land in Dominica through the incorporation of SLM practices. Output 1, which consisted of a review process to provide guidance and a basis for making recommendations about a suite of Sustainable Land Management Approaches and Technologies (SLM-AT) appropriate for agricultural lands in Dominica, concluded with the recommendation of required action in nine (9) focus areas. The measures identified to address each of the identified foci areas were also provided. It will be recognized that the listing of these measures goes beyond technologies and also addresses areas of training, legislation, research and institutional strengthening. This manual however will be primarily focus on technologies identified to address the foci areas.

Focus areas identified included:

Soil fertility and management

Soil fertility and management on farmlands within Dominica has transitioned from being wholly naturally regenerative (shifting cultivation) to being primarily based on the introduction of external nutritive inputs into the production space. This area has become increasingly important due to the introduction of high productive varieties of various crops and livestock requiring higher levels of nutrition. In order to generate a greater understanding of this area technologies considered will aim to create a greater awareness of the soil (know your soil) and to:

- Build capacity in the knowledge and properties of local soils among extension staff and farmers (Soil test – physical and chemical characteristics- soil type, pH, CEC, and other common parameters explained)
- Promote composting techniques
- Investigate options for innovative, locally-developed organic soil amendments
- Provide support for routine soil and plant tissue analyses
- Build capacity on crop nutrient demand to optimize fertilizer regimes and timing of applications
- Investigate options for integrated soil fertility management using leguminous cover crops

Soil erosion and land slippage /subsidence management

Soil erosion is among the most critical factor impacting soil degradation in Dominica. Erosion, which also takes place on naturally occurring landscape of varying slopes and rainfall depth, is significantly increased by anthropogenic activities. Water erosion is the most prevalent form of erosion in Dominica.

In order to facilitate and incentivize the implementation of on- farm soil conservation measures as a means of managing soil erosion, the following technologies will be addressed:

- Contour drains
- Live barriers -Vetiver strips etc.
- Dead barriers - stone wall, trash barriers
- Terracing
- Contour planting
- Cover cropping

Land degradation management

A measure of land degradation provides insight to the degree of departure from the ideal of SLM, which is described as the use of land resources including soils, water, animals and plants for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and maintenance of their environmental function. Land degradation management in Dominica, is increasingly becoming critical given the increased intensive cropping of areas not ideally suited for the types of cropping systems being practiced. Further, limited farm size and available farm lands has necessitated attention be directed to technologies and research of innovative options to:

- Prevent land degradation and restore degraded lands
- Build local capacity in land restoration
- Investigate options for managing invasive plant spp.
- Alternative more sustainable trellising stake

/ material for yam and other crops to reduce land degradation from deforestation.

Agroforestry systems

- Investigate traditional and non-traditional companion trees/crops based on compatibility re economic returns, nutrient demand and cycling
- Integrated crop – livestock farming
- Investigate options for integrating small ruminants/poultry/honey production within the farms -

Complete studies and document cost-benefit details

- Riparian buffers

Improved crop productivity

- Investigate improved cultivars and cropping systems best suited for various agro-eco-zones and
- Promote successes using Farmer Field Schools
- Build capacity in record keeping and productivity assessments per crop

Land use planning and management

- Explore options like the high nature value index (HNVI) to guide land users within and near buffer zones of protected areas and other high value natural resources (Rivers etc.)
- Establish demonstrations to show best practice and promote strategic partnerships with individuals and groups.

Wet – Dry season technology

- Rain water harvesting
- Irrigation
- Soil moisture conservation with crop residue mulching
- Water diversion drains
- Live check dams
- Other cross slope measures

Soil pollution management

Soil pollution is defined as the presence of toxic chemicals (pollutants and contaminants) in soil at high enough concentrations to pose a risk to human health and or the ecosystem.

- Flag soil pollution as a cause of land degradation
- Investigate potential pollution threats from point and nonpoint sources
- Investigate available farm products and generate risk profiles as unsuspecting products like fertilizers can be culprits
- Set related guidelines for importers, distributers and the general public that will regulate the sale, purchase and use of products that could pollute the environment
- Educate extension staff, farmers and land users on the potential dangers and consequences
- Ensure that farm certification protocols seriously consider the threat of soil pollution in its regulatory framework

The following section provides the “how to” for some of the identified technologies. It must be noted that many implemented technologies highlighted under a key area / section may have crosscutting impacts over multiple key areas. One obvious example is the impact of composting and organic matter application on the key areas of soil fertility and management, soil erosion control, improve crop productivity, land degradation and management, dry season production and soil pollution management.

Familiarity with the soil type being targeted for action is critical to effective implementation of any technology and so a presentation on soil testing “how to”, and identification via the hand-feel method precedes other SLM technologies.

SECTION 1

SLM TECHNOLOGIES HANDBOOK

Soil Fertility and Management

1. Soil testing

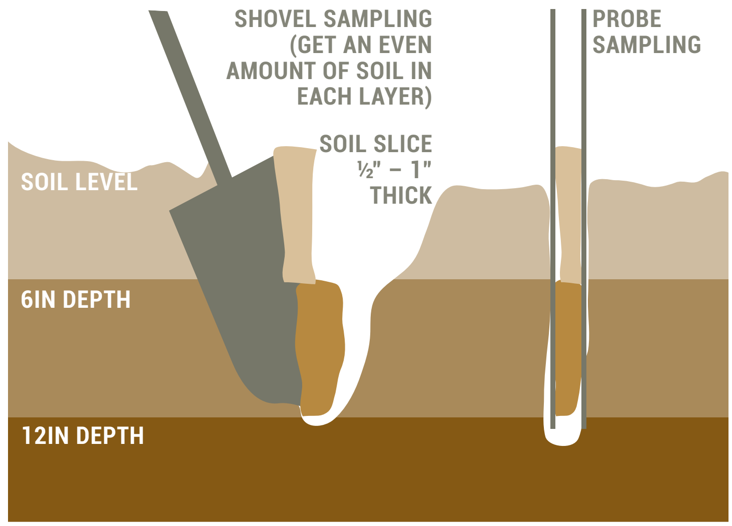
Definition

Soil testing provides information of the physical and chemical properties of the soil. It describes the soil type, which is critical in determining the most appropriate SLM technologies and approaches that should be employed to maintain its effective function. Soil tests are often done within a laboratory especially when a high degree of accuracy is required. In recent times however, mobile field labs have been developed and used to provide more rapid assessments. There are also other methods to include colour and feel that is used to indicate the presence of particular chemicals and particles that can impact soil management.

1.1 Testing the soil

Collecting of soil sample for analysis is very important. An effective methodology for collecting soil samples in the field is detailed in Figure 1. A flow diagram for performing texture by feel analysis is presented in Figure 2. The soil test results from the laboratory will also provide information on soil pH and available soil nutrients informing more accurately the requirements for optimal plant growth.

Place soil samples collected into a clean bag, label – location of collection, date and name of person collecting sample. Secure the sample in a cool area prior to transporting to the laboratory.



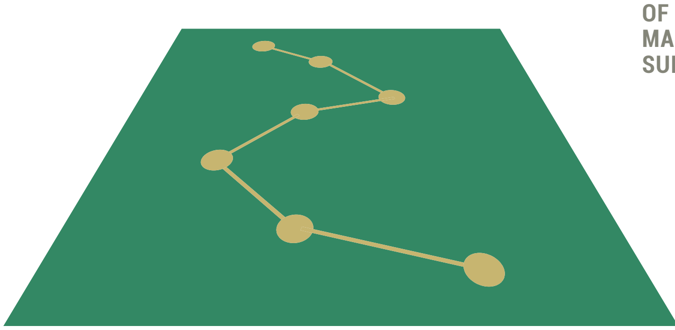


Figure 1: Soil testing illustration using shovel and soil probe. Location for sample collection

1.1.1 Testing soil pH in the field

Dig a small hole in the soil to a depth of about 2–4 inches (5.1–10.2 cm) deep. Break up clumps/ aggregates within the hole and remove any twigs or foreign debris.

Fill the hole with distilled water to ensure the water is neutral, (i.e., neither acidic nor alkaline). Fill the hole until you have a muddy pool at the bottom.

Insert the test probe into the mud. Make sure your tester is clean and calibrated (for a more exact measurement). Wipe the probe with a tissue or clean cloth, and insert it into the mud. Hold it there for 60 seconds and take a reading. pH is usually measured on a scale of 1-14, though the tester may not include this entire range.

- **A pH of 7 indicates neutral soil.**
- **A pH > 7 indicates alkaline soil.**
- **A pH < 7 indicates acidic soil.**

Take several measurements in different areas in the garden. A single reading may not be representative of the entire plot, so it's good to get an idea of the average pH within the plot. If they are more or less similar at all points, take the average and amend the soil accordingly. If one spot is very different than the rest, however, you may need to "spot treat" it.

If pH test stripe is being used, a mixture of soil can be added to a clean container and distilled water added to it. The resulting mixture should be the consistency of Milkshake. Stir the mixture to ensure good consistency. Dip and hold a pH test strip into the mixture for about 30 seconds or according to the manufacturer's recommendation. When the test time is up, rinse the pH strip briefly in distilled water to wash off any excess soil. Compare the pH strip with the colour coded key to estimate the pH. Like the preceding procedure perform test on multiple areas of the plot.

1.1.2 Texture by feel methodology

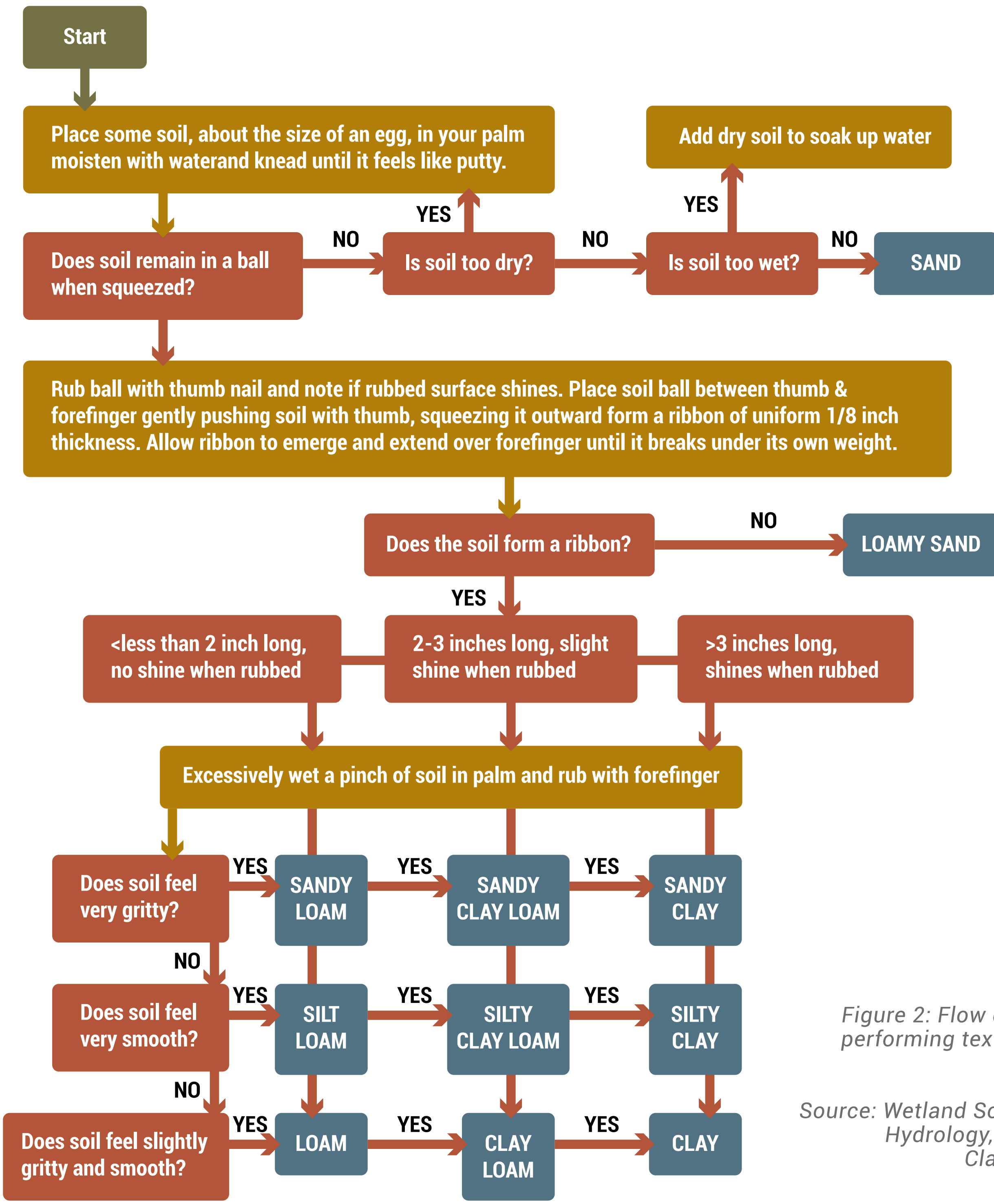


Figure 2: Flow diagram for performing texture by-feel analysis

Source: Wetland Soils Genesis Hydrology, Landscape Classification.

2. Fertilizer Application Rate

2.1 Definition

Application rates refers to the volume of the particular nutrient product to be applied to meet the plant nutrient needs. Application rates depend on the nutrient need of the soil / plant being grown and the percent of nutrients in the specific fertilizer. It should also be noted that nutrient requirement for a particular plant will vary with the stage of growth. In products containing multiple nutrients, the application rate is always based on the nitrogen content.

2.2 Calculating area to be fertilized:

___ ft. long X ___ ft. wide = _____ Sq. ft. eg: 40 ft. long X 100 ft. wide = 4000 sq.ft

Calculating fertilizer application rate:

$$\frac{\text{\_\_\_lb. of nutrient per \_\_\_ sq. ft.}}{\text{\_\_\_\% nutrient in fertilizer}} = \text{\_\_\_\_lb. fertilizer per \_\_\_ sq. ft.}$$

$$\text{Eg: } \frac{\text{1 lb. of nutrient per 1000 sq. ft.}}{\text{20\% nutrient in fertilizer}} = \text{5 lb. fertilizer per 1000 sq. ft.}$$

Lawn or garden area x application rate = lbs of fertilizer per garden or lawn

$$\frac{\text{\_\_\_ sq. ft.}}{\text{Garden/lawn}} \times \frac{\text{\_\_\_ lbs fertilizer}}{\text{\_\_\_ sq. ft.}} = \frac{\text{\_\_\_lbs fertilizer}}{\text{Garden or lawn}}$$

$$\text{Eg: } \frac{\text{4000 sq. ft.}}{\text{Garden/ lawn}} \times \frac{\text{5 lbs fertilizer}}{\text{1000 sq. ft.}} = \frac{\text{20 lbs fertilizer}}{\text{Garden / Lawn}}$$

3. Composting

3.1 Definition

Composting is an aerobic method (meaning that it requires the presence of air) of decomposing organic solid wastes to produce plant nutrients and enhance ecosystem health.

3.2 How to compost

Step 1 – collect compostable waste. This includes acceptable kitchen waste, crop residue, grass cuttings, animal manure and home scraps

Step 2 – pick out a spot to set up the compost pile. Or purchase a pre-made compost bin from the stores or you can even construct a particularly designed compost bin for your compost. Select a shaded spot out of the direct sunlight.

Step 3 – to begin setting up the compost pile add some twigs and other quick draining material at the base. Add dry light brown leaves and dry scraps from the garden. If you don't have it then just add some dry garden soil or any existing compost soil, to begin with.

Step 4 – Ensure that items being places into the compost pile or bin is cut into small pieces or crush so that it takes less time to break down and decompose. Put in the green materials that are high in nitrogen and can be used to activate the heating process in your compost. Fruits, vegetables, coffee grounds, manure etc all can be added at this stage or the so-called second layer of the compost yard. Make sure that you don't put large quantities and there is a space for them to breath and have enough oxygen and space and microbes to develop and decompose.

Step 5 – then comes the brown materials which are high in carbon and serve as a fibre. This can include dried leaves dead plants flowers hays etc.

Step 6 – add other items like fallen hair, paper towers napkins, eggshells paper bags cotton fabric etc. Apply moderately.

Step 7 – then repeat the cycle of 3-4 layers of light brown to dark brown to green in thin layers.

Step 8 – cover the bin or the pile with general garden waste. Covering is important because compost pile can attract insects, flies and animals and also generate odours-. Ensure that the wet waste or the green waste is one layer under or not at the top.

Step 9 – ensure that your compost bin is moist for the organic materials to break down easily. Sprinkle with water lightly to moisten the pile. Do not over wet - not too wet not too dry. Create a balance.

Step 10 - mix the compost pile at least once every 2 – 3 weeks, drawing the internal part of the heap outward and the external part inward. Add new material – green or brown accordingly to increase activity of the pile.

Step 11 – start to determine if the compost is ready. When your compost turns into a deep brown colour, it no longer gets warm and your see that things are almost broken down and then is less activity happing then you should stop putting fresh material more and finish it off. It usually takes 3-4 months to get it done.

4. Green Manure

4.1 Definition

A green manure crop is grown specifically to improve soil and act as a fertilizer. It is plowed into soil while still green, or shortly after it matures.

4.2 Design

(I) Selection of green manure crops: These should be adapted to local conditions, easy to raise, fast growing, high yielding, rich in nutrient content, and should have no adverse effects on the main crop. It is desirable that green manure crops be free seeding, so that a farmer may readily collect his own seed supplies. Crops suitable for slope land are *sesbania, desmodium*, alfalfa, *intortum*, lupin, white clover, velvet bean, etc.

(2) Spacing of green manure crops: Spacing vary based on plant species being used. Adjustments may be made depending on the spacing and growth habit of the main crop.

4.3 Operational procedures

(1) Inoculation: Legume seed should be inoculated with the proper strain of rhizobia bacteria.

(2) Planting time: During the rainy season, when there is adequate soil moisture.

(3) The nitrogen content of a green manure crop is usually at its highest level during the early stages of flowering, when it is succulent and easily decomposed. It should be cut or plowed in at this stage of growth.

4.4 Fertilizing:

For legumes, 10 kg of nitrogen, 60 kg of P_20_5, and :30 kg of K_20 should be applied to each hectare of land.

5. Mulching

5.1 Definition

Mulching describes the technology of application of organic and or inorganic protective covering over the ground between crop rows or around the trunks of fruit trees to cover the soil surface.

5.2 Operational procedures

1. Cover crops or grasses planted in orchards are a readily available source of mulching material. The residues of crops may be left in the field after harvest as mulch.
2. Polyethylene sheets and other artificial materials may be used for mulching. However, these materials are suitable mainly for mulching on ridges of planting rows.

<u>Application</u>

1. Application of mulching material before crop establishment is advisable when using plastic mulch or other fabric weed barrier. Organic mulch material can be applied after planting.
2. Clear area to be mulched of weeds and unwanted debris.
3. Lay down irrigation lines according to planned or established crop spacing, if applicable. Irrigation lines should be tested to ensure functionality and to identify and repair any leakage.
4. Lay fabric mulch according to crop spacing and land preparation technique used, ensuring that area for crop establishment is completely covered. Mulch can be applied along rows for row crops, around trees in orchards. Mulching may be continuous, where adjacent sheets of fabric are overlapped to provide continuous cover, or it can be applied only within the cropped areas or orchard plants.

5. The edges of the mulch fabric should be secured with weighted objects such as sand bags or rocks or alternately, they can be fixed into a shallow trench and covered with soil.
6. Planting holes are made along the fabric at predetermined spacing for crop establishment. Due care should be employed not to damage the irrigation lines when making planting holes in mulch fabric. Some fabric can also be purchased with planting holes already established.
7. When applying organic mulch media, crops are usually established prior to application. The same process indicated in section 1 – 4 are followed. The mulching media thickness should be applied following the manufacturers recommendation, which are usually in the range of 2- 4 inches or 50 – 100 mm.
8. It is best to apply mulching material when the soil is moist.

5.2.1 Essential points to be observed

1. Attention should be paid to pest and disease control and to the elimination of fire hazards.
2. When polyethylene sheet is used as mulch, runoff will increase, and thus an adequate drainage system will berequired.
3. Large pieces of crop residue should be cut or broken up before application.
4. When organic materials are used as a mulch in orchards, the mulch should not be too thick. If the entire planted area is to be mulched, the mulch should be laid in strips.

Figure 3: Mulching in pineapples and bananas

Figure 4:: Illustration of discontinuous mulching

Soil Erosion and Land Slippage /Subsidence Management

6. Establishment of contours

6.1 Definition

Contouring refers to the practice of conducting farm cultural practices (the preparation of soil, planting, and the cultivation of soil after planting) on sloped land along lines of consistent elevation in order to conserve rainwater and to reduce soil losses from surface erosion. The conduct of cultural practices along the contour e.g., arrangement of plants, drains etc, intercept water flow down the slope, reducing the speed of flow and thus its erosive potential.

6.2 How to establish contours

Simple tools and equipment used to establish contour lines

A number of tools (some listed below) can be used to establish a counter line. Emphasis will however be placed on the A-frame, line level and water line, whose operations are similar and are considered low-cost options.

- A-frame
- Abney level
- Clinometer
- Optical level
- Water line level

6.2.1 How to build and use an a-frame level

A-Frame Tools	A-Frame Materials
Screwdriver	3 - 1"x2" lumber or straight sticks,
Hand or electrical saw	3 nails or screws
Carpenter's level	Thin string,

A plumb-bob/screw-capped glass bottle/uniform shaped rock

Step 1. Measure and cut

Decide yourA-frame height (Dimension should be such that it allows ease of handling while covering maximum distance). Cut two of your lumber or sticks the same length to be used as the legs of the A-frame.

Step 2. Join the legs

Lay the legs on a flat surface and place the lumber or sticks squarely on top of each other. At on end, join the legs with a screw or nail.

Step 3. Centre Spreader

Stand up your A-frame level with the legs spread to the distance you decided on earlier. Take one of the end scraps you cut of the lumber or stick and hold across the legs at the height you feel would be comfortable to read the level while standing. Mark this location on the leg. Screw or nail the third piece of lumber/stick (centre bar) on one leg where you marked. Place the other end of the lumber/stick where you marked on the second leg. lay your level on the centre bar (temporarily). Check to be sure the centre bar is level (and be sure your ground where you are doing this is level). Once level, screw/nail the centre bar to the second leg.

Step 4. Attached plumb bob or Carpenter's level

Attached one end of the string to the centre of the A-frame where the two legs intercept, and the other end to the plumb bob or other weight, in a manner that the string does not deflect to either side when the level is centered. Alternately, attached a small carpenter's level at the midpoint of the centre spreader.

Important considerations when constructing the A-frame level:

a. The two legs should be the same length and crossbar should be positioned identically on the legs so that it is parallel to the ground (fig 5).

b. Dimensions may vary, but if constructed in larger dimensions, it is advisable that the level be assembled with screws so that it can be disassembled for transportation. The smaller the dimensions, the more time it takes to complete a contour of set length. Dimension should be such that it allows ease of handling while covering maximum distance. Measuring an exact distance (2 m) between the feet makes calibrating the 1% slope position easier.

c. The plumb-bob must be attached so that it does not deflect the string to either side. If a screwcap bottle is used, it should be hung by a hole made exactly in the centre of the cap. If a rock is used, it is important that a very uniformly shaped rock be chosen.

6.2.2 Calibration

The level should be calibrated every day before use, as warping of the wood from moisture exchange can greatly change the results.

a. Calibration of 0%

1. The level should be positioned with both feet on firm surfaces but with one end obviously higher than the other.
2. The level is gently rocked, allowing the string with the plumb-bob to gently strike the crossbar.
3. When the plumb-bob stops swaying side to side and the string strikes the crossbar at the same point repeatedly (5-10 times), mark this position in pencil on the crossbar.
4. Reverse the position of the level so that the other foot is now at the higher point. Care must be taken to position the feet of the level in exactly the same points as before.
5. Repeat steps 2 and 3, obtaining a second mark on the other side of the centre of the crossbar.
6. The 0% position of the level is exactly in between the two marks obtained in this trial. This position can be marked by measuring with a ruler or paper (half the distance between the 2 marks). Now when the feet of the level are even the string will strike the crossbar at the 0% position. This position is used to survey contour lines for barriers, terraces, or ditches being used for retention, rather than diversion, of water.
7. Once calibrated, a small carpenter's or line level can be fastened to the crossbar to facilitate use on windy days.

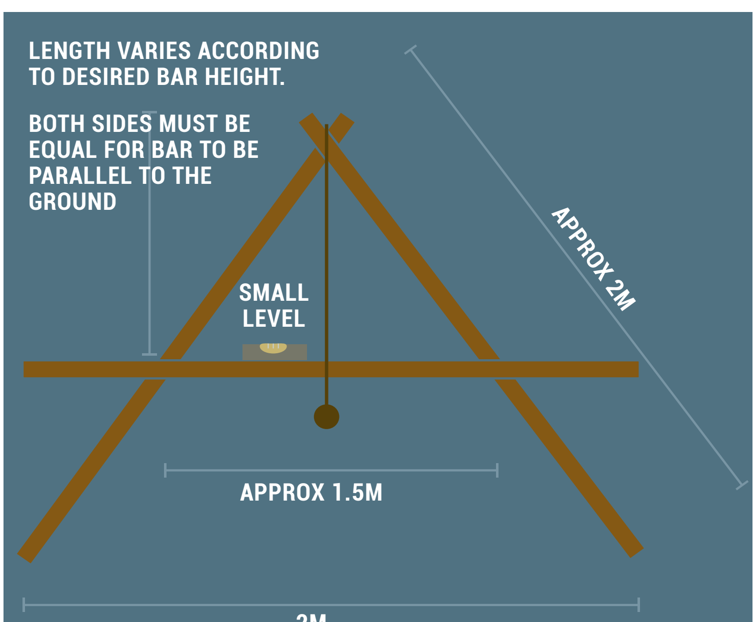
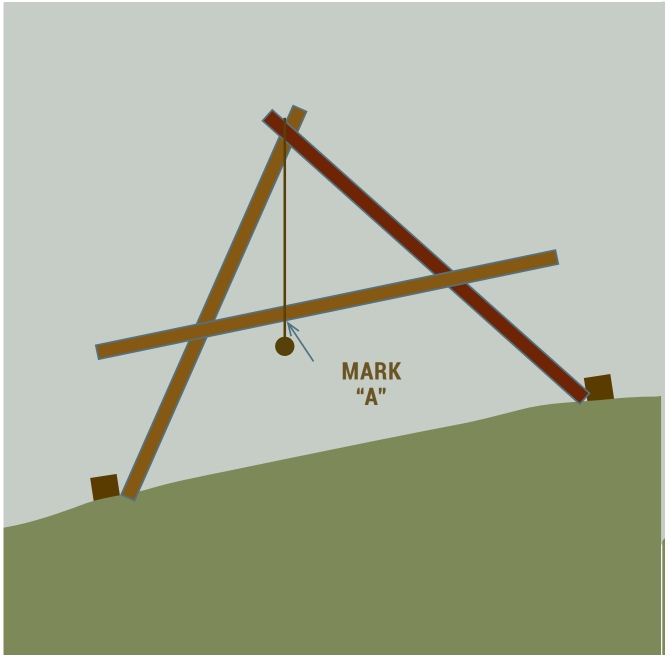


Figure 5: Materials and suggested dimension for A-Frame

Figure 6: Calibrating the A-frame: steps 2-5



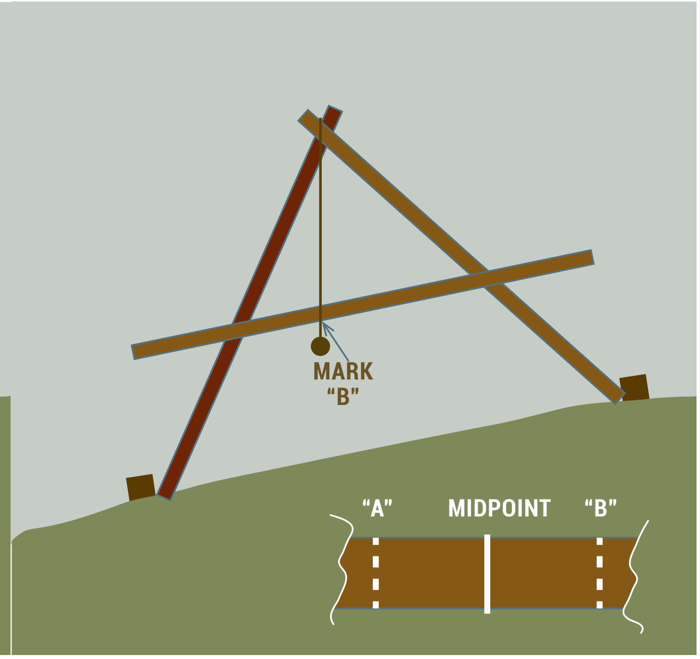


Figure 7: Calibrating the A-frame, final step

b. Calibration of 1%

1. Position the level so that the feet are on the same level and the string strikes the crossbar at the 0% position. The feet should be on firm surfaces.
2. Raise one foot by the distance required to position the level at a 1% slope. For example, if the distance between the feet is 2 m (200 cm), then a 2 cm tall object (e.g., a 2 cm tall stack of coins) should be placed under one foot. [2 cm (raised foot)/200 cm (distance between feet) = 0.01; 0.01 × 100% = 1%.]
3. Rock the level gently, now the string strikes the 1% slope position. Mark this position on the crossbar.
4. Since this type of contour line will be used to construct structures to divert water, an arrow should be placed pointing toward the lower foot to indicate the direction of water flow.
5. As in previous calibration, if desired, a small level can be fastened to the crossbar.

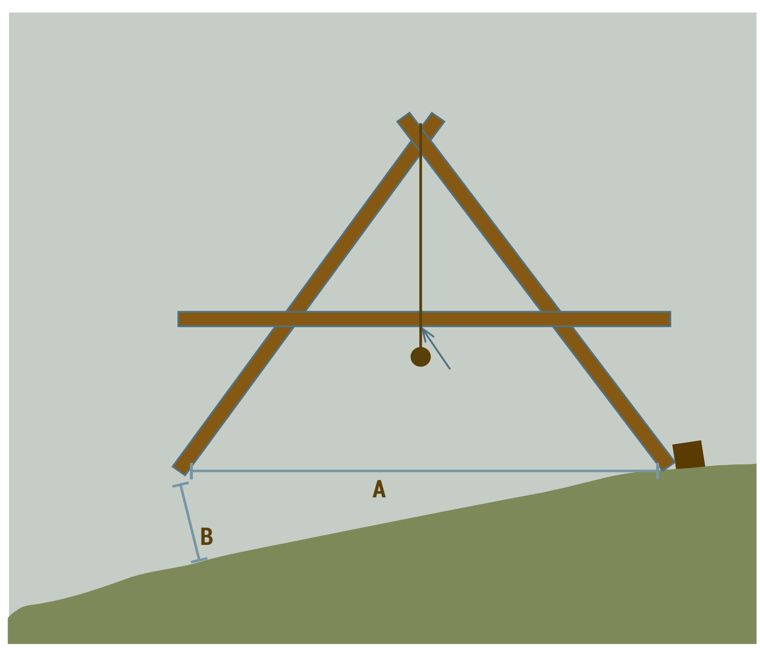


Figure 8: Using A-frame level to determine percent slope.

A. distance between legs and B. distance to ground.

Example: 1.2 m between legs, 305mm to ground = 305mm/1200mm = 0.254 = 25.4% slope

6.2.3 Using the A-frame level

The A-frame level is used to survey contour lines by placing stakes at the position of the feet when the level gives the desired reading. Stakes should all be placed on the same side of the level, all upslope or all downslope, in order to avoid errors. Run a string or line along the stake or pegs; adjusting obviously offlaying pegs to smooth out contour lines. When not being used, the level should be stored in a dry, shady place.

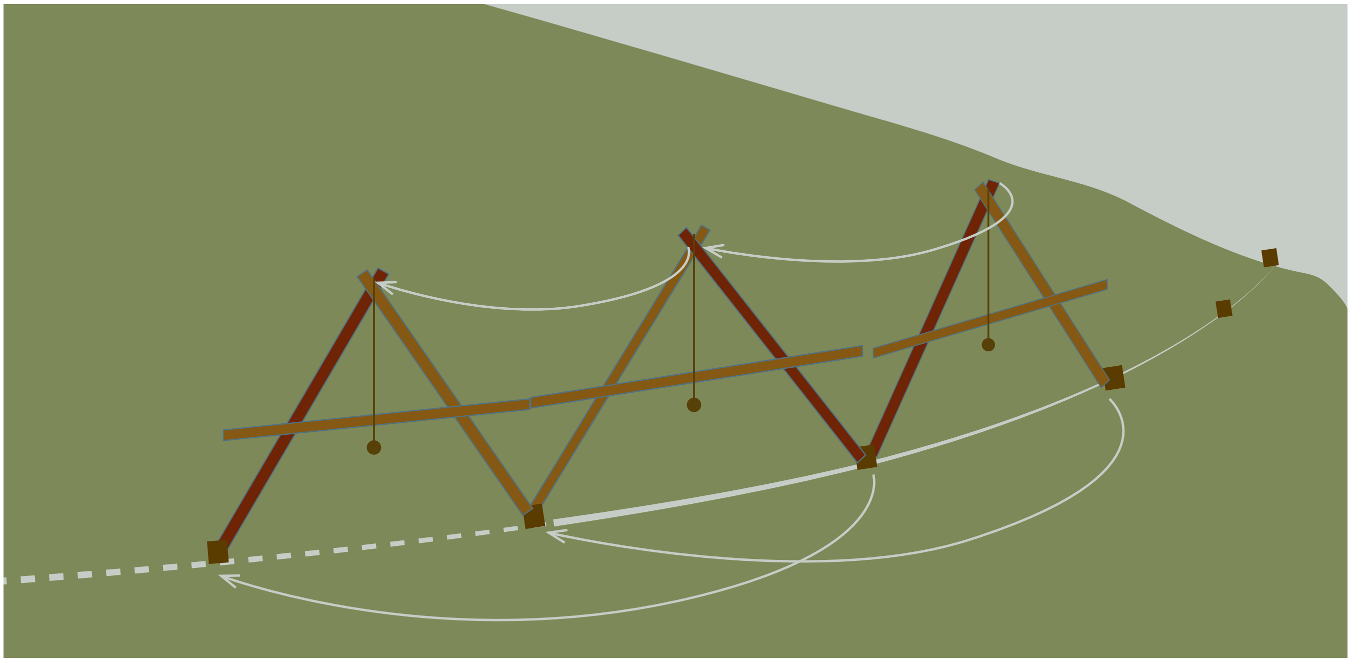


Figure 9: Using an A-frame level, finding and marking a level contour line

6.3 How to build and use a line level

Line level materials

2 straight pieces of lumber or sticks of equal length,

string of desired length,

line level (Figure 11).

6.3.1 Construction

step 1: Slots are cut in each stick at the same distance from one end.

Step 2: Securely fasten either ends of the string into each of the slots on either stick or piece of lumber.

6.3.2 Calibration

Level calibration should occur every day before use as bending of the hooks on the line level or warping or chipping of the sticks can alter the results.

a. Calibration of 0%

1. Hook the line level on the string and find a place on firm ground which gives a level reading.
2. Reverse the direction of the line level on the string while maintaining the position of the sticks. If the reading changes, the hooks of the line level must be adjusted slightly by bending them.
3. Repeat steps 1 and 2 until the line level gives identical readings upon reversal.

b. Calibration of 1%

1. Repeat the steps as in the calibration of 0%. However, this time the slots on the sticks should be placed so that a 1% drop occurs over the distance of the string. (For example, if the string measures 2m, then the slot on one stick should be 2 cm higher than on the other.)

2. Remember that the stick that has the slot located higher actually represents the lower ground surface when the reading of the string is level. Remember to mark the sticks so that no confusion as to the direction of water flow will arise when surveying contour lines.

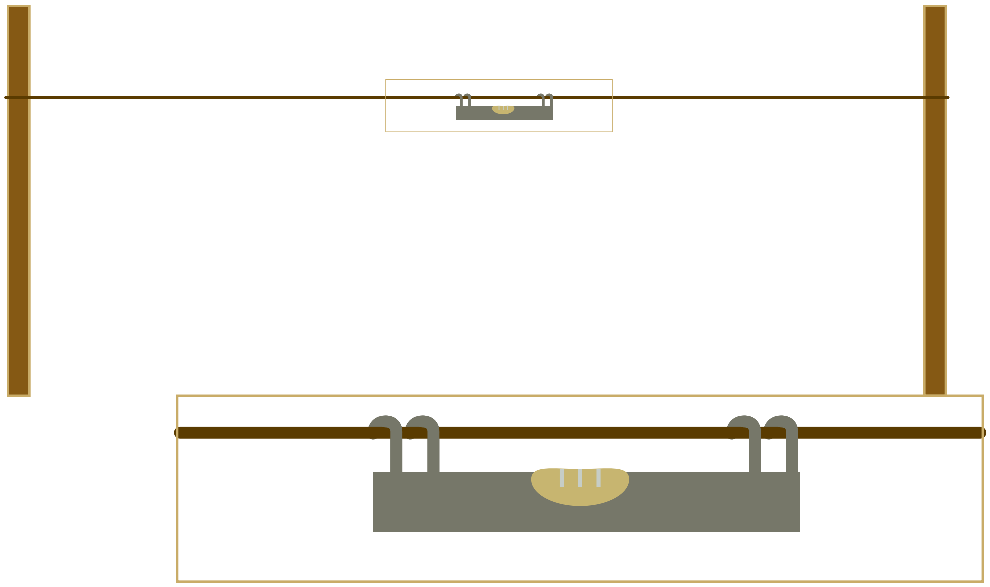


Figure 10:Line level model operation

6.4 How to build and use a hose level/ flexible tube water level

6.4.1 Construction:

A simple hose level (Figure 9), useful for laying out a grade line, can be constructed using the following materials:

a. A transparent plastic hose, 16 m long and 1.5 to 2 cm in diameter.
b. Two thin rods or boards, or other thin, rigid material about 2.6 m long.
c. Strips of wire, rubber, or string with which to tie the hose.
d. White and black paint.
e. Measuring tape.

The level can be constructed as follows:

a. Mark the rods every 5 cm, starting 10 cm from one end.

b. Tie the hose to the graduated rods so that it lies against the rods from top to bottom.

c. Place the two rods side by side on the same level. Stretch the hose downhill on a slope.

d. Fill the hose with water so that is rises to the 1 m mark on each end of the hose. Make sure that no air bubbles remain in the hose. The simple level is complete!

6.4.2 Use of line level / flexible tube water level:

1. Separate the rods by 10 m.
2. Note how much the water has changed in the hose. If the water level at both rods is equal, then the two points are at the same elevation. The slope between the two points is 0%.

If the water level lowers 5 cm from the 1 m mark on the upper rod, it will rise 5 cm above the 1 m mark on the lower rod. (10 cm total difference.)

With each 5 cm change against either of the rods, there is a 1 percent change in slope, so that with a 5 cm change the slope is 1 percent, with a 10 cm change the slope is 2 percent, with a 50 cm change the slope is 10 percent, and with a 1 m change the slope is 20%.

If the water in the downhill end goes over 2 m, the slope is greater than 20% and should be measured as described below.

3. Slopes between 20 and 40 percent can be measured as follows:

a. Separate the rods by 5 m.

b. Note the change in water level on either side. A 50 cm change indicates 20 percent (for each 5 cm change there is 2% more slope). If the water level changes 75 cm, the slope is 30%. If the water level changes 100 cm, the slope is 40%.

The simple level can be used to mark a level contour line in the field in the following way:

1. Select a starting point and mark it with a stake.
2. Separate the rods by 10 m or some convenient distance.
3. Move the leading rod up or down, until its water level is the same as that in the rod at the initial point. Mark this point.
4. Follow the same procedure from point 2 to point 3, point 3 to point 4, and so on.

We can also mark lines with one, two, or three percent slope.

1. Choose a starting point.

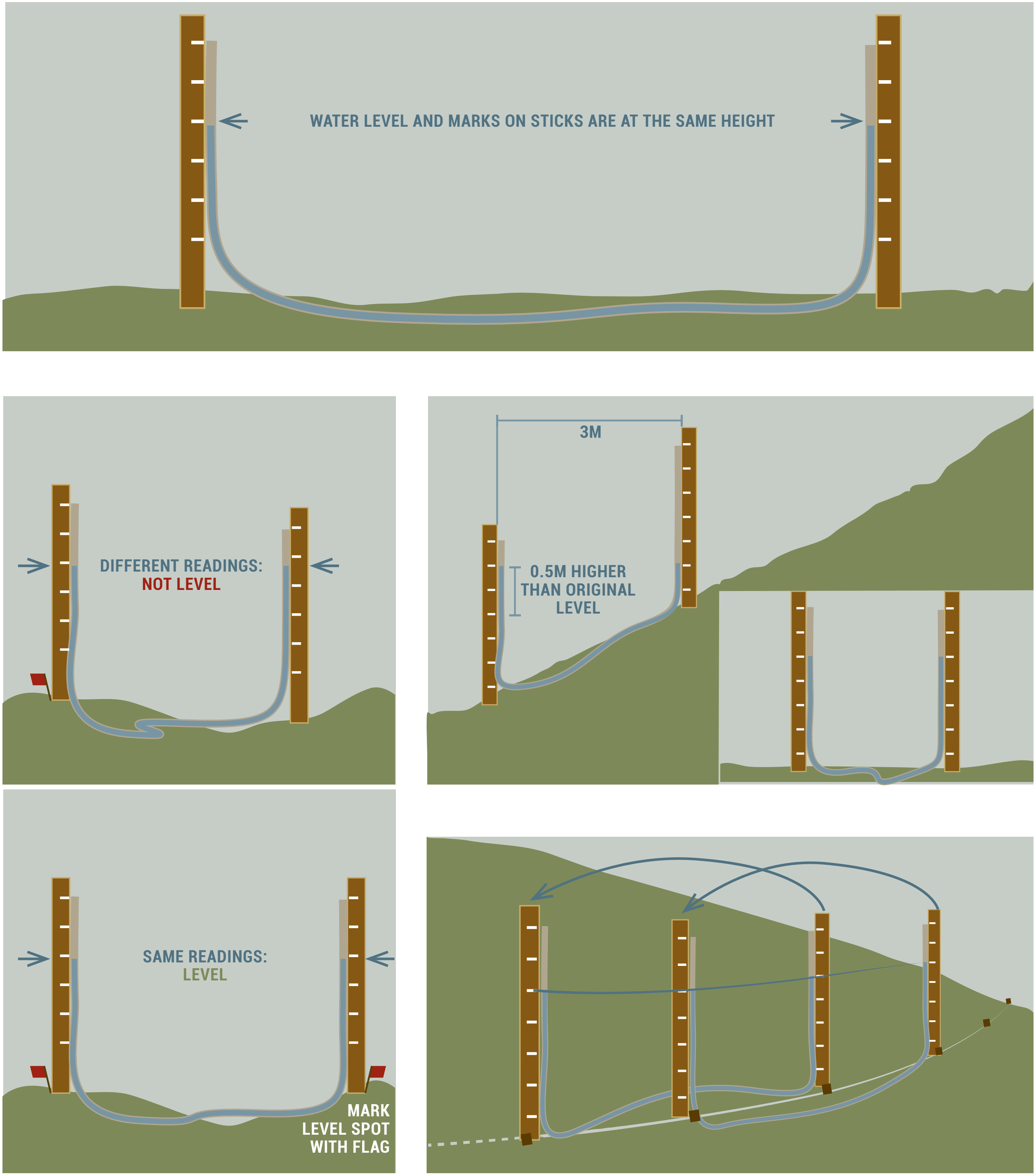
2. Separate the rods by 10 m. The water level at each rod must change:

5 cm for 1% slope
10 cm for 2% slope
15 cm for 3% slope

If the water level indicated in the leading rod rises, the slope is downhill. If the water level drops, the slope is uphill.

3. Repeat the procedure for succeeding points.

Figure 11:Hose level use illustration and calibration



Source: Rainwater harvesting for drylands and beyond

7. Diversion Ditches – storm drain

7.1 Definition

A ditch constructed approximately along the contour of a slope for the purpose of intercepting surface runoff and diverting it to a suitable outlet. This measure is implemented mainly to protect farmland and farm buildings from runoff from surrounding slopes and also to control gully erosion. Grass should be planted along the completed ditch for protection. The inside wall and base may also be lined with cement mix or stones for added protection, especially in sandy soils. Intercepted runoff should be drained off to a safe place.

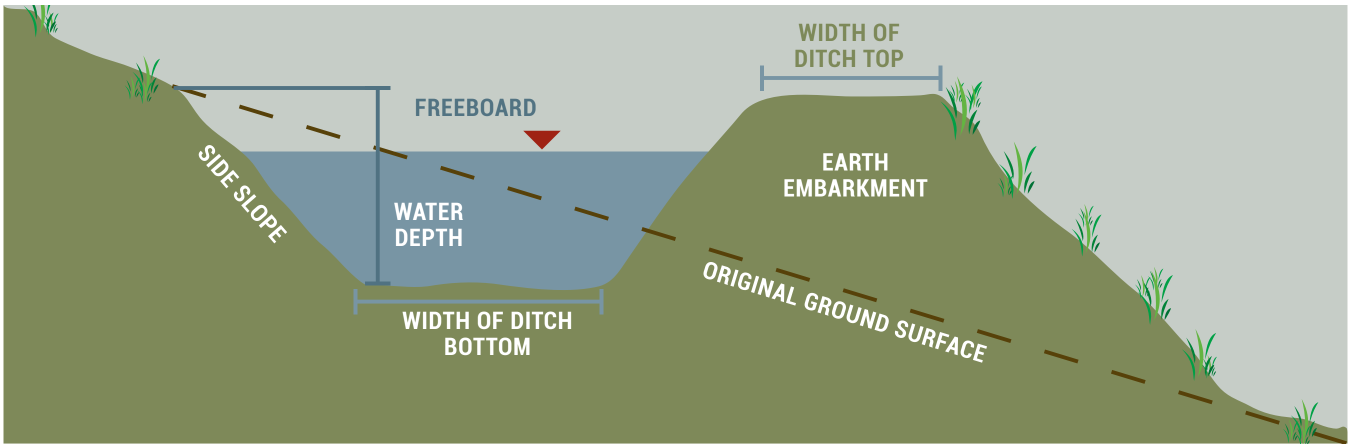


Figure 12: Illustration of diversion ditches

7.2 Design

Determine the volume of runoff, with reference to the gradient of slope and the area of watershed.

Design the cross-section of the ditch with the assistance of the following tables, on the basis of the lining of the ditch, soil characteristics, gradient of ditch sides and bottom, or by the following procedures:

a. On the basis of the volume of runoff and gradient of the ditch, decide the type, depth and area of cross-section.

(i) The area of cross-section should be in proportion to the volume of runoff.

(ii) Steeper gradients permit a smaller cross-section. Due attention must be given to the maximum velocity of flow that should be tolerated.

(iii)The more the soil is prone to erosion, the less steep the gradient of the ditch should be. The slope of the sides of the ditch also should be lower/gentler.

(iv) A freeboard of 0.1-0.3m should be included in the design.

b. Estimate roughness coefficient: On the basis of the texture (smoothness) of the lining of the ditch. (See Table 10-1)

c. Calculate hydraulic radius with the following formula:

$$R = \frac{A}{P} = \text{Hydraulic radius(m)}$$

The area of a trapezoidal cross-section may be calculated as follows: (see annex 2)

$A = bd + zd^2$ = Cross-section area (m^2) of flow

b=Width of base of ditch (m)

d=Depth of water (m)

z=Slope of ditch side (1: z-Vertical: Horizontal)

P=Wetted perimeter(m)

=Length of cross-section in contact with water

= **$b + 2d\sqrt{1+z^2}$**

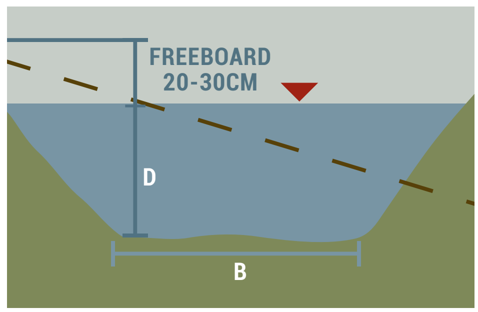
If cross-section is rectangular, and the width of ditch bottom and water bottom are known, hydraulic radius can be obtained from Figure 30.

d. Compute average velocity V from Fig.14 or from the following formula. The average velocity computed should not be greater than the maximum permissible velocity. The maximum permissible velocities for different types of ditch conduits are given in Table 7-2.

when V= average velocity (m/sec)

n = roughness coefficient

$R = \frac{A}{P}$ = Hydraulic radius(m)



S = gradient of the waterway bottom (%)

e. Calculate channel capacity to accommodate the discharge Q from the following formula:

Q=AV

Q=discharge(m^3/sec)

A=cross-section area(m^2)

V=average velocity(m/sec)

f. If channel capacity is equal to or a little greater than the designed runoff, the design of the cross-section is suitable. If it is too small, the cross-section area has to be increased and re-calculated to accommodate the estimated runoff that may occur. If it is too large, the design will be uneconomical.

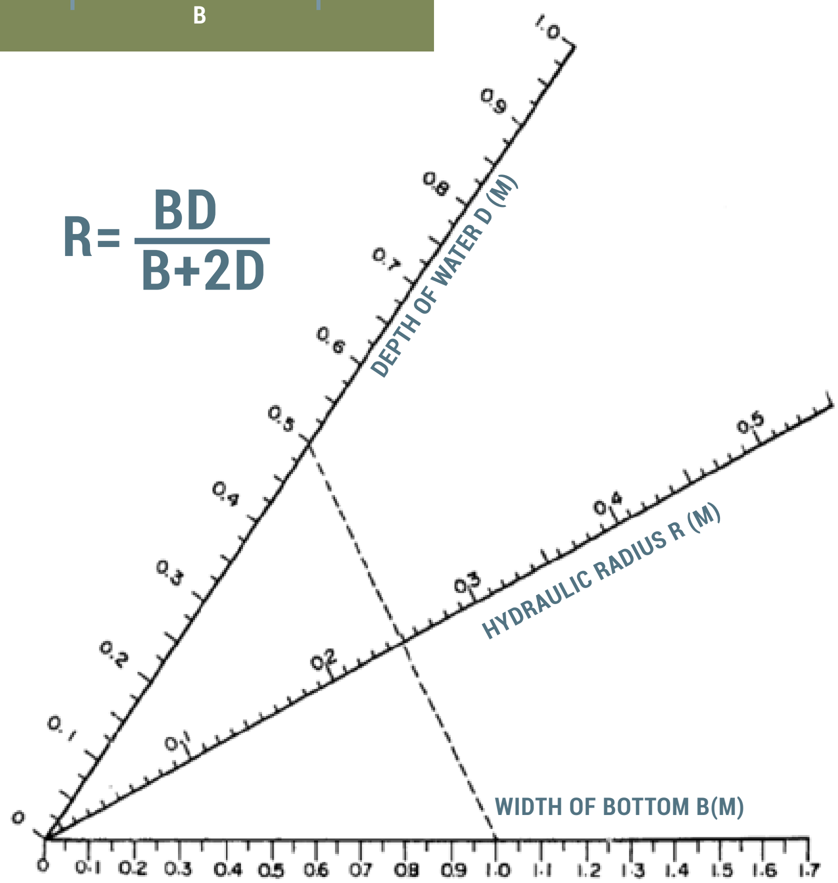


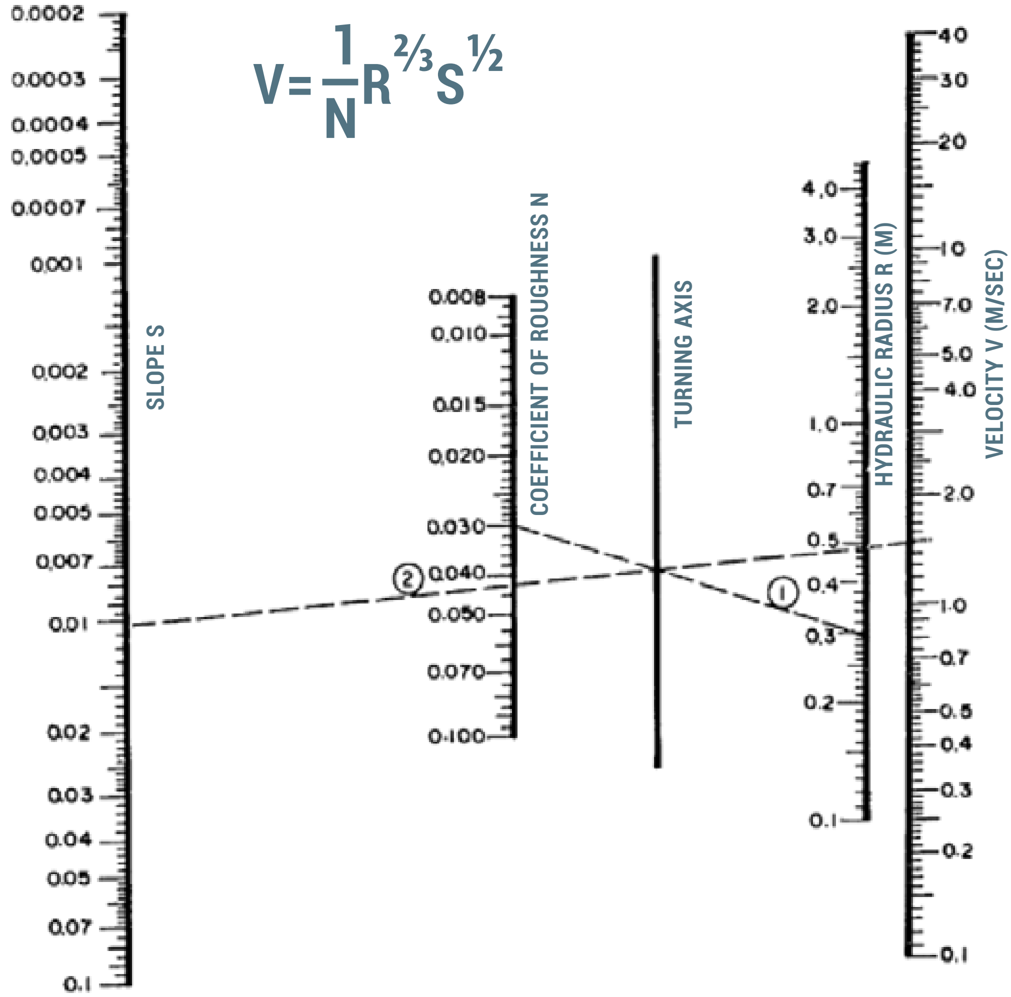
Figure 13: Estimation of Hydraulic radius of a diversion ditch with rectangular cross section nomograph

Example: If d=0.5m b= 1.0m

Find R

Solution: Draw a line connecting d axis (0.5) with b axis (1.0), R is obtained when this line crosses the R axis. Answer: R=0.25rn

Figure 14: Estimation of average velocity of flow nomograph



Example: if n=0.08 R=0.3 s= 1/100 =0.01

Find V

Solution: Draw a straight-line CD connecting n axis (0.03) with R axis (0.3). This line intercepts the turning axis at c. Then connect c with s axis (0.01) and project this line to V axis. Answer: V = l.5 m/sec.

Table 71: Roughness coefficient n for the Manning formula

Ditch surface materials	n Calues	
	Range	Mean
Without lining		
Clay soil, smooth	0.016-0.022	0.02
Sanely loam or clay loam, smooth	-	0.02
Loosely grassed	0.035-0.045	0.04
Densely grassed	0.040-0.060	0.05
Mixed with gravels from l to 3 cm in diameter	-	0.022
Mixed with gravels from 2 to 6 cm in diameter	-	0.025
Smooth, homogeneous rock	0.030-0.035	0.0325
Rough surface rock	0.035-0.045	0.04
With lining		
Brick mortar pitching	0.012-0.017	0.014
Cobble mortar pitching	0.017-0.030	0.025
Cobble dry pitching	0.025-0.035	0.033
Smooth earth base, cobble pitching on sides	-	0.025
Rough earth base, cobble pitching on sides	0.023-0.035	0.03
Smooth mortar lining	0.010-0.014	0.012

Table 72: Maximum safe velocities for different types of ditches (m/sec)

Type of ditch soil	Maximum safe velocity
Pure silt	0.23-0.30
Soft silt	0.30-0.46
Coarse stone and fine gravel	0.46-0.61
Ordinary sand	0.61-0.76
Sandy loam	0.76-0.84
Hard loam and clay loam	0.91-1.14
Ordinary gravel	1.23-1.52
Dense grass	1.50-2.50
Coarse gravel & sand	1.52-1.83
Gravelly rock, hard earth layer, soft aqueous rock	1.83-2.44
Hard rock	3.05-4.57
Concrete	4.57-6.10

8. Hillside Ditches / Drainage Ditches

8.1 Definition

A series of shallow ditches / drains built along the contour lines of a hillside slope at appropriate intervals to reduce the velocity of runoff. They can be of varying width.

8.2 Construction:

Cross section

Figure 15: Cross-section of hillside ditch – Narrow and broad

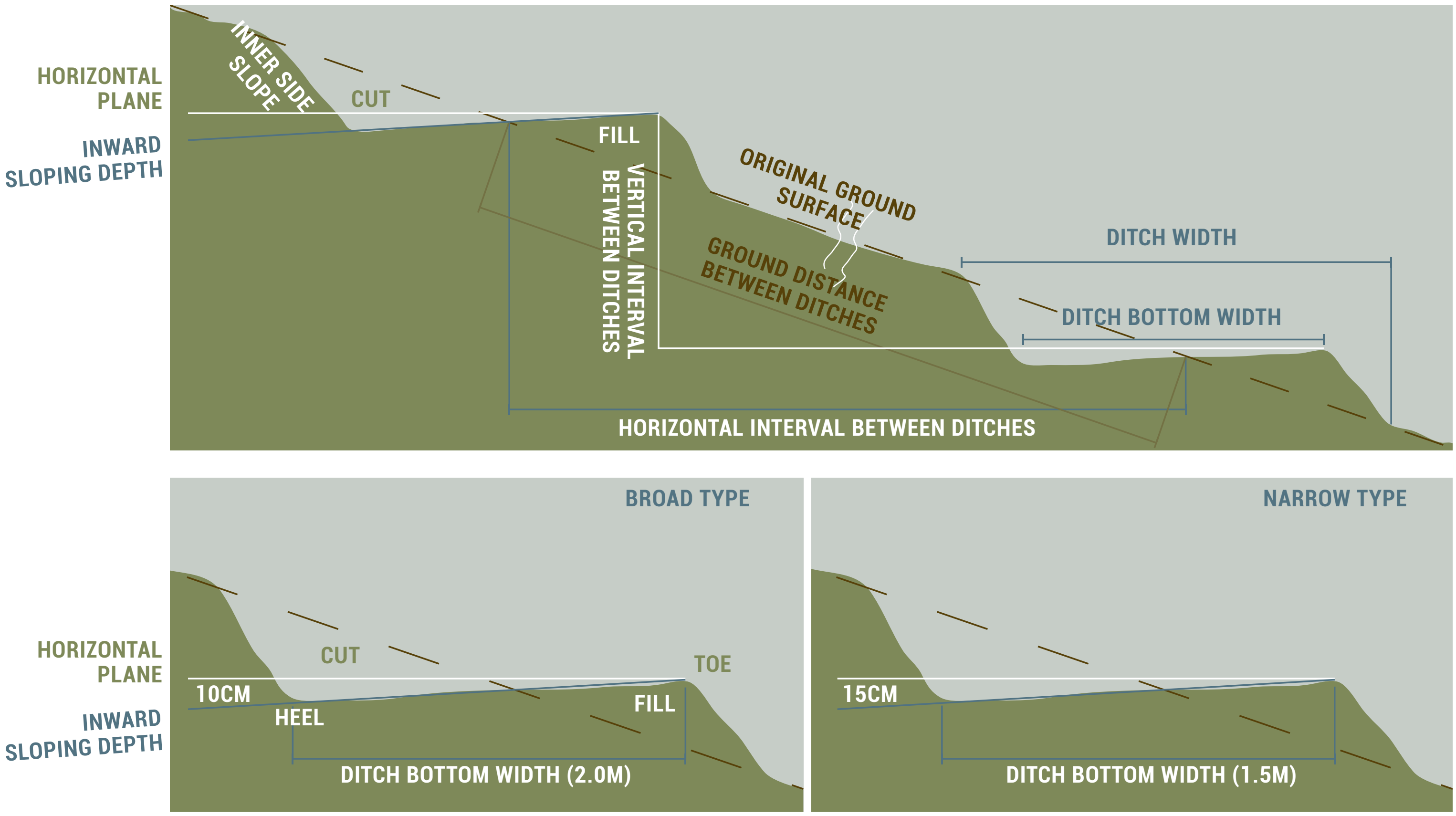
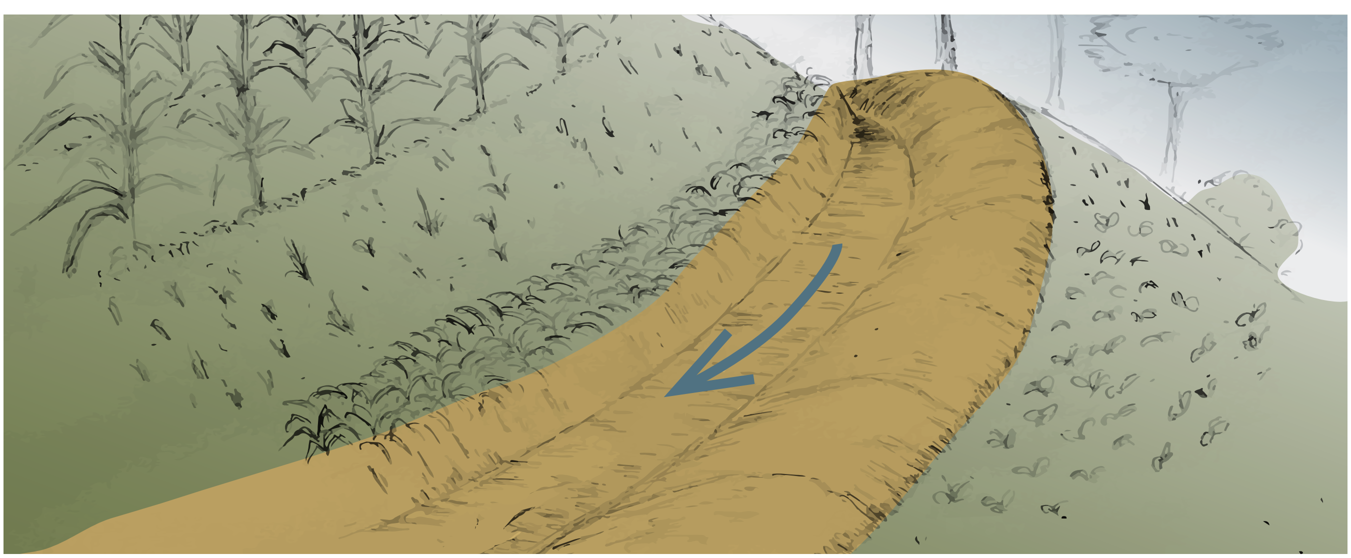


Fig 10B: Plan view of hillside ditch



8.3 Design

Spacing: The space in metres between ditches is determined by the following formula:

$$VI = \frac{S+6}{10} \quad HI = \frac{VI}{S} X100 = \frac{S+6}{S} X10$$

VI = Vertical interval between ditches (m)

S = Gradient (%)

HI = Horizontal interval between ditches (m)

Table 81: Quick conversion of gradient and spacing

Gradient	Slope	Space between ditches (m)	
%	*Degree*	*Horizontal interval (HI)*	*Ground surface distance*
3.0	1.7	30.0	30.0
4.0	2.3	25.0	25.0
5.0	2.9	22.0	22.0
6.0	3.4	20.0	20.0
7.0	4.0	19.0	19.0
8.0	4.6	18.0	18.0
9-10	5.1 - 5.7	16.5	16.6
11-15	6.3 - 8.5	15	15.1
16-20	9.1 - 11.3	13.3	13.5
21-25	11.9 - 14.0	12.6	12.9
26-30	14.5 - 16.7	12.1	12.5
31-40	17.1 - 21.8	11.7	12.4
41-55	22.3 - 28.8	11.0	12.0

Source: Soil conservation handbook, Council of Agriculture, ROC 1995

8.4 Operational procedures and other considerations

The spacing given in this table may be adjusted within a range of ±25%, depending on the permeability of the soil and the degree of erosion, the types of crops being grown and the types of farming practices being employed. When slopes are covered by grass to be used for cut and carry system, the spacing may be increased by 100%. However, if the area is to be grazed by livestock directly, the spacing *may only* be increased by approximately 50%.

When the ditches are being designed, the spacing of crop rows and the requirement for farm mechanization should be taken into consideration. For the benefit of mechanization, the design should be so arranged that short crop rows can be avoided.

In an orchard, within the permitted range of’ interval between ditches, interval spacing is determined by the number of rows of trees of rows of trees to be planted. Up to 3 rows may be accommodate in one interval.

Selection of a type: The broad type (2 m wide at bottom) is used on gentle slopes while the narrow type (1.5 in wide at bottom) is suitable for steeper slopes.

Gradient: The gradient of the ditch should be 1- 1.5% in principle. When necessary, it may be extended to5%.

Length: The length of a ditch should be no more than **100**m if the ditch drains in one direction. When a ditch is longer than 100m, the drainage water should be directed to both ends or to the centre of the ditch.

Drainage: Normally, water in hillside ditches is drained by waterways built along the slope. Where the waterway and the hillside ditches meet, the bottom of the waterway should be built into a shallow curve, and paved with bricks or stones, or planted with grasses, to facilitate passing of farm machinery on wheels. A small culvert can be installed instead when necessary.

Ditch Outlet: At the outlet, the width and the gradient of the ditch should be increased. The junction between the hillside ditch and the waterway should be even and smooth.

Grass planting: Grasses should be planted on the bottom and side slopes of the ditches (see fig 16).

As cover for the ditch bottom, carpet grass (Axonopuscompressus and A. affinis) Bermuda grass (Cynodondactylon), bahia grass (Paspalum rotatum), centipede grass (Erernchloaopiuroides) and sour grass (Paspalum conjugatum) are generally suitable, while indigenous creeping grasses are also useful.

(2) For protection of the side-slopes and the edge of the ditch, bahia grass or vertiver is recommended; spacing: 30 cm X 30cm or 1ft X 1 ft.

Planting should be done as soon as ditch construction is completed. Thorough vegetative cover should be maintained. Replanting should be done without delay hen wilting or damage of any part of the grass cover occurs.

Survey and Planning: Investigation and survey should be undertaken for the entire farm to be developed. All existing drainage structure must be noted. The location and type of the main drains to be developed must be decided in keeping with the topography, soil type, degree of erosion, natural waterways and production characteristics.

Determination of VI: Check over the average slope of the area in which the ditches are to be constructed, and, from the above Quick Conversion table, find out the most desirable vertical interval between ditches.

Order of construction:

Construct the first ditch at the top of the slope and proceed downslope.

1.Staking the ditch lines:

a. Commence at the outlet of the ditch, and place a stake every 5 – 10 m following the contour line. In case of sharp curves, increase the number of stakes.

b. After the ditch line has been staked out it., check its accuracy and make necessary adjustment to avoid sharp turns or to reduce curvature.

2.Construction

The ditches are usually constructed using pickaxes and shovels. In some cases, a mini-excavator may be used to excavate the ditch. Finishing however, is accomplished manually with shovel and picks. If possible, ploughing the contour line where the ditch is to be excavated makes the construction much easier.

Excavate a 12- 18 inch wide by 12- 18-inch-deep ditch (ditches can be constructed of any size, if desired). Then the banks are formed by cutting a slanted wall at each side (higher degree of slope for clayey soil – 65 - 80, lower for sandy soil – 45-60). The removed earth is placed in a mound 6 - 9 inches below the lower lip of the ditch. A live barrier is necessary above the upper edge to prevent filling with soil. Especially on steeper slopes, it is often advantageous to plant the live barrier first, several months or one season in advance, so that the ditch will be adequately protected once built.

Table 3-1 or the equation in section 3.3 should be consulted for the appropriate distance between ditches on hillsides of a given slope. If the ditches are to be dug with a 1% slope to drain excess water, the 1 or 2 meters before emptying into a protected drainageway should have a slightly steeper slope, (1-2%) to facilitate drainage.

3.Soil settlement:

Approximately 10% additional earth should be put in the fill, depending on the soil conditions, to allow soil settlement.

4.Finishing:

Once the ditches have been constructed, recheck the work to see whether it follows the designed cross-section and gradient, and make necessary corrections accordingly.

The depressions and gullies where a hillside ditch cross, should be filled, and the fill should be firmly compacted. At these points, the sides and bottom of the ditch should be reinforced with rocks, concrete etc.

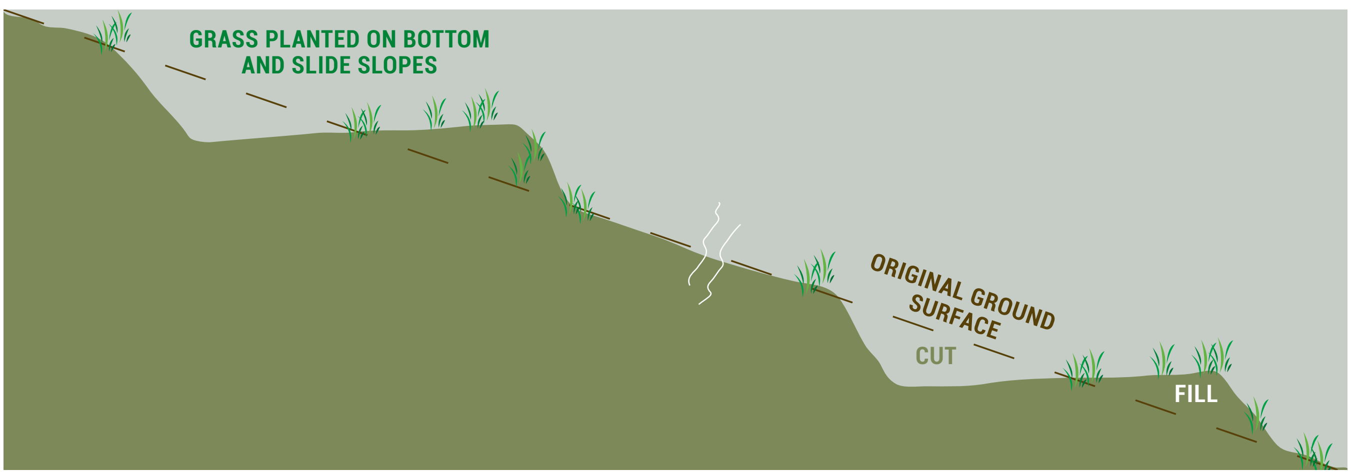


Figure 16: Grassing of ditches

9. Grass / Live Barriers

9.1 Definition

Contour planting of suitably spaced strips of grass or other appropriate plant type on slope land to intercept overland water flow is another effective technology to combat soil erosion and wash off of nutrients.

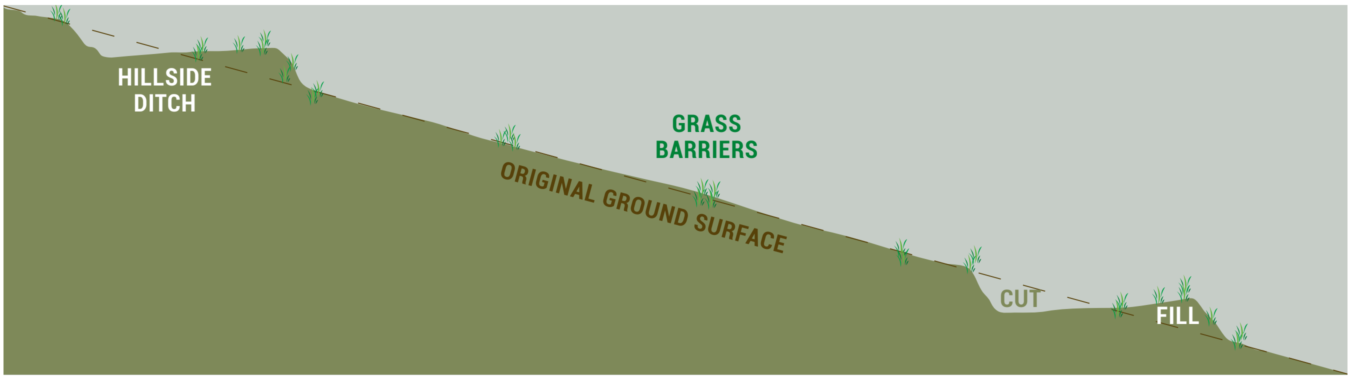


Figure 17: Illustration of Grass/live barriers

9.2 Design

Some grass species that can be used include Bahia grass -Paspalum notatum, weeping love grass - *Eragrostiscurvula* and Vetiver- *Chrysopogonzizanioides* -, lemon grass or other species which will not affect the crops and are relatively easy to manage. Species that don't readily produce seeds are often preferred to limit the chance of propagation with the cropped area.

Spacing: The spacing of the barriers is governed by the spacing of the crop rows, and normally should be 4-8 meters.

Establishing grass barriers

Use the hillside ditches or other features established along contours as guide lines to stake out the barrier lines. In the absence of these features, establish contour line utilizing A-frame, line level, or hose level. Place stakes every 5 to 10 m along the contour line. When necessary, the space between hillside ditches may be adjusted to coordinate with the barrier.

Clear all trees, shrubs, stones, grasses and other obstacles off the slope and level the rough, uneven places as required.

When fresh root cuttings are used as planting material, set out 2 to 3 cuttings per hill. Plant 2 to 3 rows closely to form one grass barrier. In cases where weeping love grass is used, the row spacing and distance between plants should *be* 20 cm and 10 cm, respectively; for Bahia grass, vetiver and lemon grass these distances should be 50 cm and 20 cm. Prick fork the soil along the contour line to a depth of about 20 – 30 cm. Plant selected material in a triangular pattern. If seeds are sown, the width of the barrier should be no less than 50 cm.

10. Trash lines

10.1 Definition.

This technology refers to placement of suitably spaced strips of vegetative materials made of crop residues, weeds and prunings along the contour lines to slow down the flow of run-off and also promote in-situ natural composting.

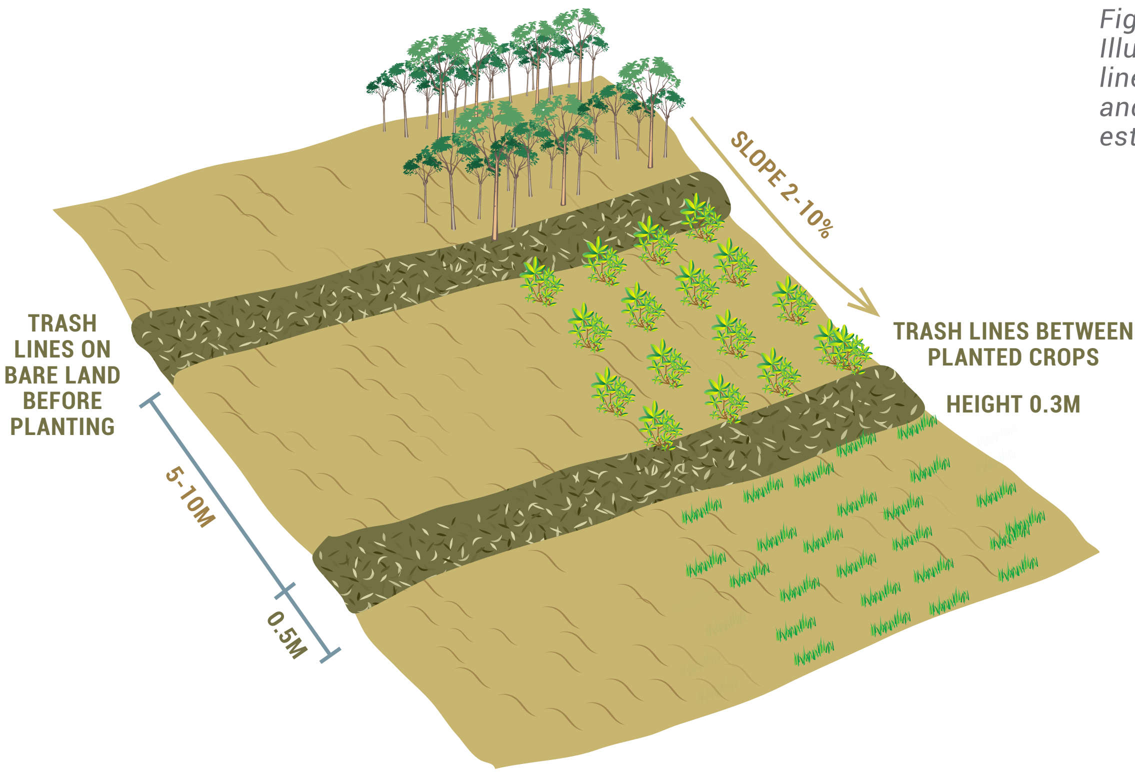


Figure 18: Illustration of trash line on bare land and in between established crops

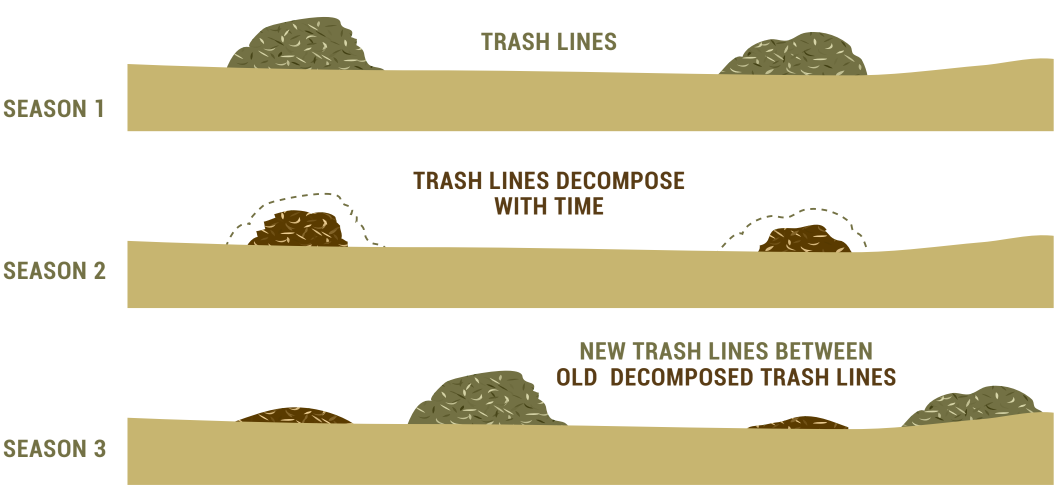


Figure 19: Replacement of decomposed trash lines

10.2 Design

Peg contour line with stakes up to 60 cm or 2ft in height. Spacing of stake is dependent on length of vegetative material to be placed within trash lines but must be close enough to provide sufficient support. Lay vegetative material along the counter line with trimmings and sturdier vegetative material providing the backing/support against the stakes to provide a continuous barrier. Complete the trash line by layering with leaves and other finer vegetative material until barrier is about 30 – 60 cm or 1 – 2 ft high. Compact finer material to increase interception and filtering of surface flow.

Spacing: The spacing of the barriers is governed by the spacing of the crop rows in cultivated field and also the slope of the land, and normally should be approximately 4-8 meters or 12 – 25 ft.

11. Stone Walls / dead barriers

11.1 Definition

Using stones to construct walls at a suitable spacing on slope land along contour lines. This technology is particularly useful in areas with an abundance of stone/rocks of varying sizes.

Figure 20: Stone wall or dead barriers installation

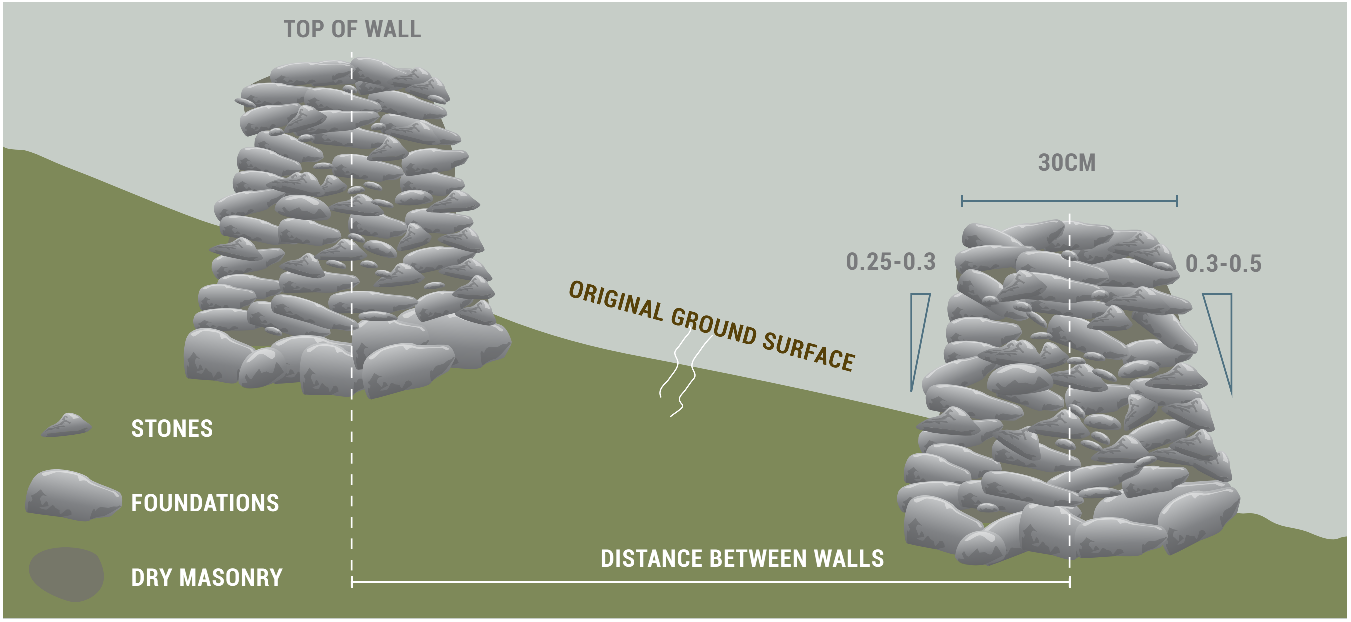


Figure 21: Log & brush barrier installation– pilot site at Livingston area, Guatemala.

11.2 Design

11.2.1 Cross-section

Size of the walls cross-section depends on the availability of stones and labour resource. The gradient ratio (height to base) for the outside face of the walls is usually 1 :0.3 to l :0.5, and that of the inside face 1:0.25 to 1:0.3. The top of the wall should be as level as possible, with a width of at least 30 cm or 1 ft.

11.2.2 Spacing

a. In cases where bench terraces will ultimately be built, the stone walls should be built where the risers will be situated.

b. In cases where hillside ditches will ultimately be built, the stone wall should be built along the lines of the ditches.

c. To reduce the gradient of slope, stone walls may be constructed at a spacing according to the row width of crops and the requirements of mechanized operations.

Stone walls should be as nearly parallel as possible. For ease of cultivation, interception of crop rows should be avoided.

11.3 Building the stone wall

Stake out the basic wall line and excavate along the base to a minimum depth of 30 cm. Select the largest rocks to form the foundation of the wall. Selection of the bottom row of stones should be carefully done for enhanced stability.

Stone walls should not be too high, if they are to be developed into bench terraces in the future. Further, stone walls may be built in stages, depending on the availability of stones.

When the walls are expected to become bench terraces or hillside ditches, earth accumulating on the upper side of the wall should be leveled to fit the specifications of bench terrace or hillside ditches.

12. Bench Terraces

12.1 Definition

Terraces are constructed/formed earthen structures that intercept runoff on moderate to steep slopes. They are a series of level or nearly level platforms built along contours at suitable intervals. They transform long slopes into a series of shorter slopes. Terraces reduce the rate of runoff and allow soil particles to settle out.

Types:

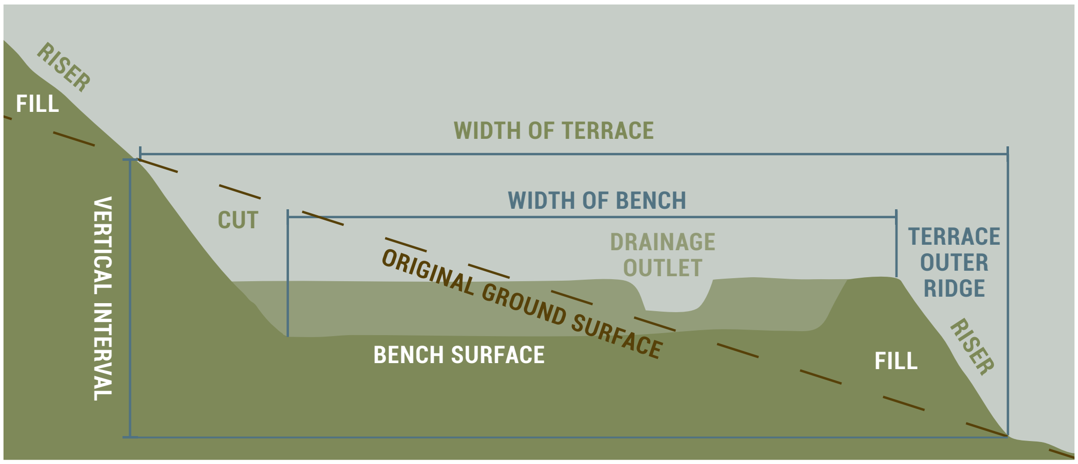


Figure 22: Level and retention type bench terrace

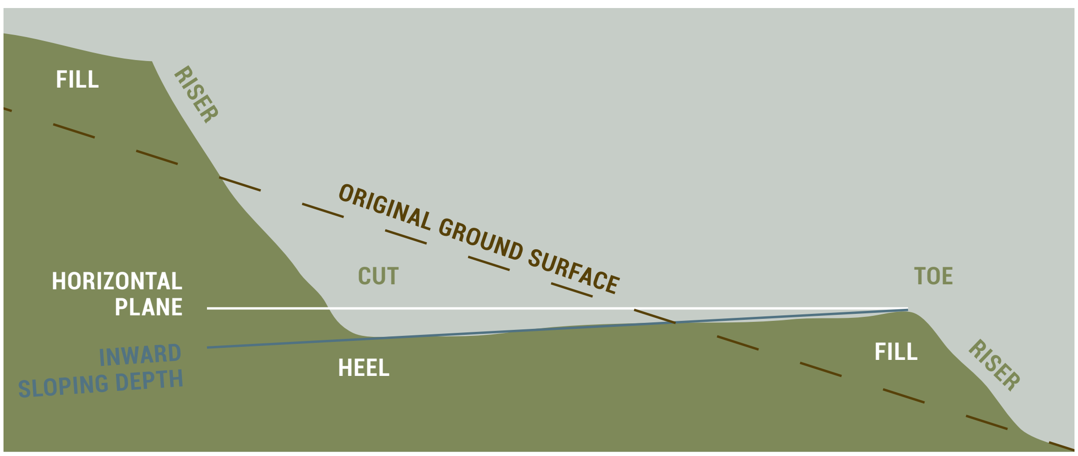
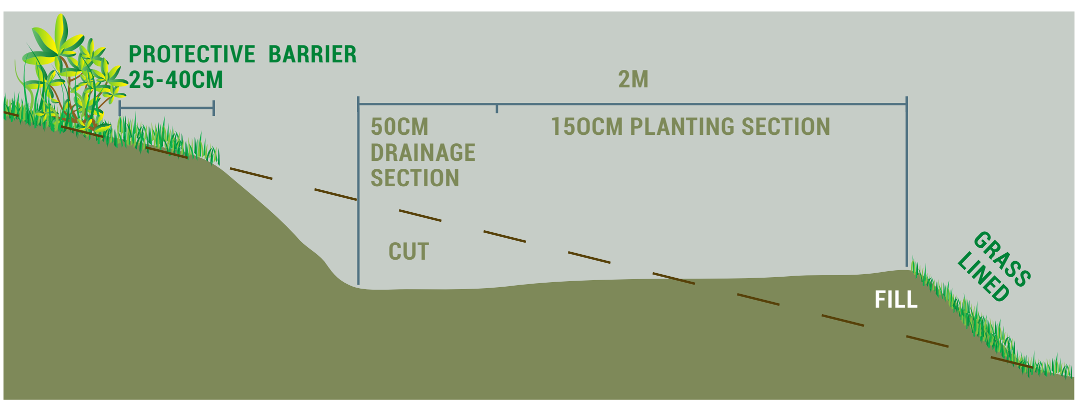


Figure 23: Reverse (inward) sloping bench terrace



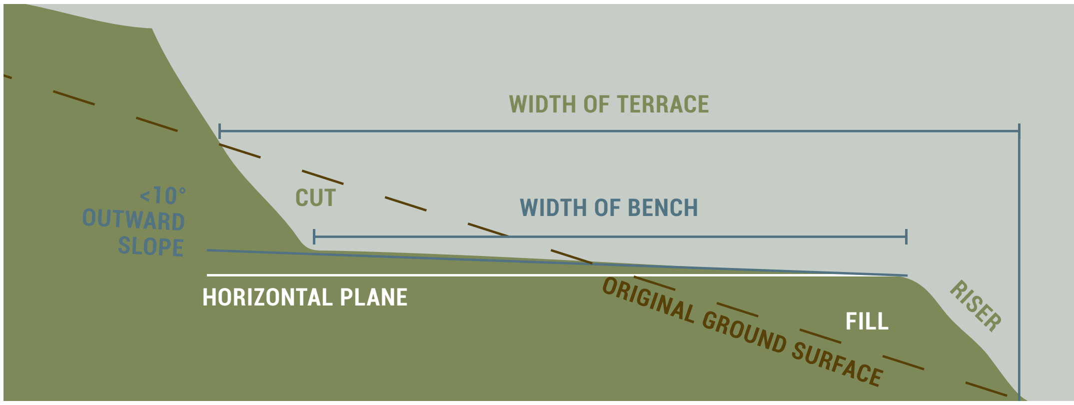


Figure 24: Outward sloping bench terrace

Continuous bench terraces are staircase-like structures which diminish erosion because the reshaping of the Land surface results in the planting of all crops on gently inversely sloping platforms (Fig. 27). The mast feasible application is in intensively worked vegetable plots where each planting bed may be a separate terrace.

12.1.1 Other types of Terraces

Discontinuous narrow terraces (orchard terraces and narrow bench) provide both -a flat platform for planting crops and an inverse slope which allows it to serve as a drainage or infiltration ditch.

Figure 25: Individual plant terrace

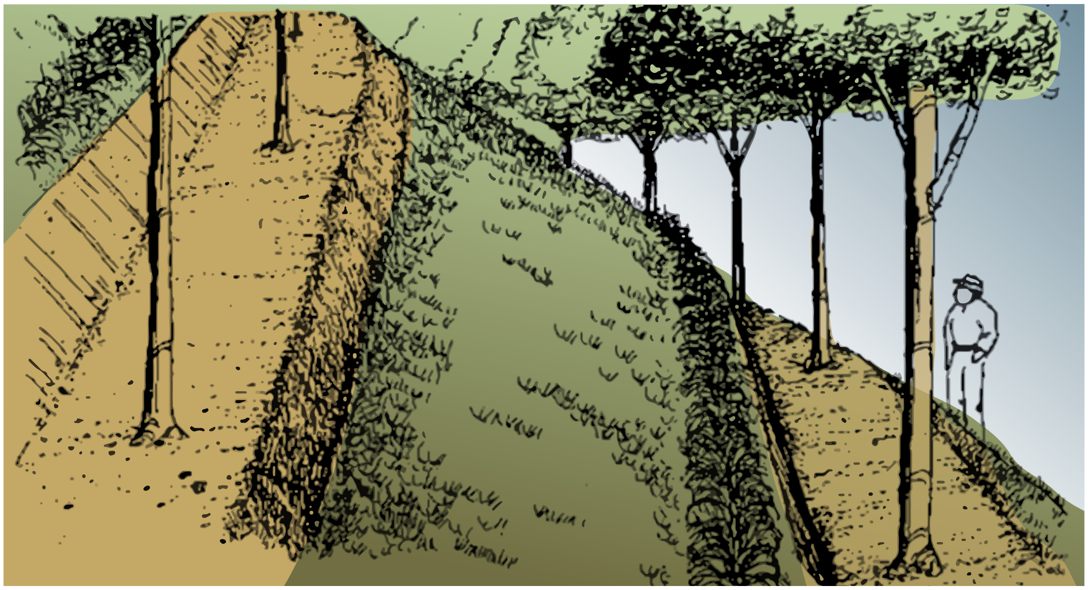


Figure 26: Discontinuous bench terrace

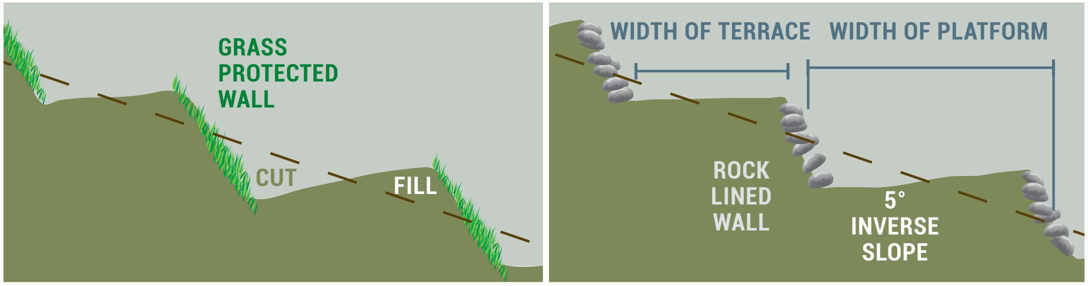


Figure 27: Continuous Bench terrace

12.2 Design

Bench Width: Depending on the gradient of slope, depth of soil, crops and types of farm machinery used. The width of an outward-sloping bench terrace normally should not exceed half of the distance between hillside ditches.

Riser: The upper riser-slope ratio is 1: 0.5 and the lower riser slope ratio is 1: 1-0.5. However, adjustments may be made depending on soil type and whether the risers will be covered with grass or faced with stone. The outward sloping bench should be provided with dense grass cover.

Vertical interval: The vertical interval between benches may be calculated by the following formulas:

Level type: $VI = \frac{W.S}{100-S\,.\,\mu} = \frac{W.(S/\mu)}{100/(\mu-S)} = \frac{d.S}{100}$

Inward sloping types: $VI = \frac{W.S+k.S.\mu}{100-S\,.\,\mu} = \frac{W.\,(S/\mu)+k.S}{100/(\mu-S)} = \frac{d.S}{100}$

Outward sloping types: $VI = \frac{W\,.\;S\text{-}k\,.\;S\,.\;\mu}{100-S\,.\,\mu} = \frac{W\,.(S/\mu)+WzS}{100/(\mu-S)} = \frac{d.S}{100}$

VI = vertical interval (m)

W = width of bench (m)

S = slope of original surface *(%)*

d = width of terrace (m)

k = difference in height between front and back of bench (in the case of inward sloping and outward-sloping benches) (m)

z = slope of the outward-sloping bench (vertical: horizontal ratio)

μ= slope ratio of riser (vertical: horizontal = l: u)

Width: The width of the bench terrace must fit in with crop spacing and mechanized operations.

Level type: $d = \frac{100VI}{S} = W+VI^{*}S$

Outward – sloping and inward – sloping types: $d = \frac{100VI}{S} = W+(VI \pm k)\ \mu = W+(VI \pm W \cdot z)\mu$

Note: K and Z are positive figures for reverse-slope type benches and negative for the outward-slope type.

Gradient: The gradient should be 0.5% to 1% for inward type bench, while that of the outward type is the same as for hillside ditches.

Length: The length of a bench terrace should not exceed 100m when water running along the bench is drained in only one direction.

Height of the reverse slope: On reverse-sloping benches, the height of the toe above the heel should be more than 10cm once the soil is well settled. When the width of the bench exceeds 3m, the difference in height may be reduced to 5cm.

Outward slope: On outward-sloping benches, the outward slope should be less than 10%.

Bench ridge: A bench ridge is built along the outer edge of level type terraces. This ridge should be 20cm in height and 20cm in width at the top.

Outlet: For level type terraces, a water outlet about 10cm deep and 20cm wide should be constructed at the ridge to drain water into the waterway.

12.3 Implementation procedures and observations

1. *Survey and planning:*

An overall survey should be made of the area, to include topography, slope, depth of soil, soil texture, whether the soil is stony, erosion status, drainage sites etc. The type of terraces selected should fit in with cropping pattern, farm machinery to be used and the road system.

2. *Staking terrace lines:*

Terrace lines are set by selecting a site with a relatively uniform slope, and placing the first guide stake at the top of this slope. Then, working down the slope, other guide stakes are set to mark lower terraces according to the designed spacing. Each terrace line is staked out from its guide stake, along the contour of the slope. The stakes within a terrace line are set 5 to 10 m apart. The width of the terraces should be as uniform as possible, to permit ease of cultivation and management. In places where topographical changes are found, localized adjustments of slope gradient and short interrupted contour lines can be made. Terrace lines should be rechecked and any sharp curves smoothed out as much as possible. Attention should also be paid to the connection of the Terrace and the waterway.

3. *Land clearing:*

Before the commencement of construction, all grasses, tree stumps, stones, etc. should be cleared from the surface of the ground.

4. *Cut and fill:*

Cuts are made by excavating the soil from the uphill side of the center line. The excavated soil is then removed to fill the downhill side of the center line. The filled soil must be in close contact: with the original ground surface and should be well compacted at every 30 cm layer to ensure the solidity or the fill.

5. *Riser reinforcement:*

If stones are available, they may be used to face the risers. A foundation must first he made along the base of each riser. Stones are then laid to form the riser face. Riser facing should start from the bottom of the terrace and proceed uphill.

6. *Finishing:*

During and after construction, the work should be regularly checked and modified, if necessary, to make sure that design specification of bench width and slope gradient are being met.

7. *Construction sequence:*

Generally, the construction of terraces should start at the top of the slope and work down the slope so as to facilitate the work and to avoid possible damage by heavy rainfall while the work is in progress. However, in cases where the topsoil has to be replaced, or if the risers are to be faced with stones, construction should start at the bottom and move uphill. During heavy rains, a temporary water diversion ditch should be built if necessary.

Bench terraces are constructed using pickaxes, hoes, and rakes. In some areas, large, especially designed hoes are available. Mechanical means utilizing mini-excavators are also possible. Construction is much easier if the section of earth to be removed (cut section) is ploughed beforehand to loosen the soil. If construction is being undertaken during the rainy season, it is advisable to begin construction near the drainage area and with the uppermost terrace. In this way, any rainwater will drain off without damaging the terraces.

There are several ideas as to the best method of constructing a series of terraces. One, which may require several years for completion, is the planting of a live barrier grass or the construction of rock walls along the contour. Over time terraces are formed as soil fills in behind them. Two other construction sequences are presented in fig 28 & 29.

8. *Topsoil replacement:*

a. Topsoil is removed from the upper terrace site to cover the terrace bench just finished below. This procedure is followed for one terrace after another.

b. Topsoil is collected in one or more sections of the terrace or along the central line of the terrace. After the section of terrace from which topsoil has been removed, is completed, the topsoil is returned. The same procedure is repeated in the other sections of the same terrace.

9. *Mechanical excavation:*

When a bulldozer or excavator is used in construction, the risers should be finished off manually from time to time during and after construction.

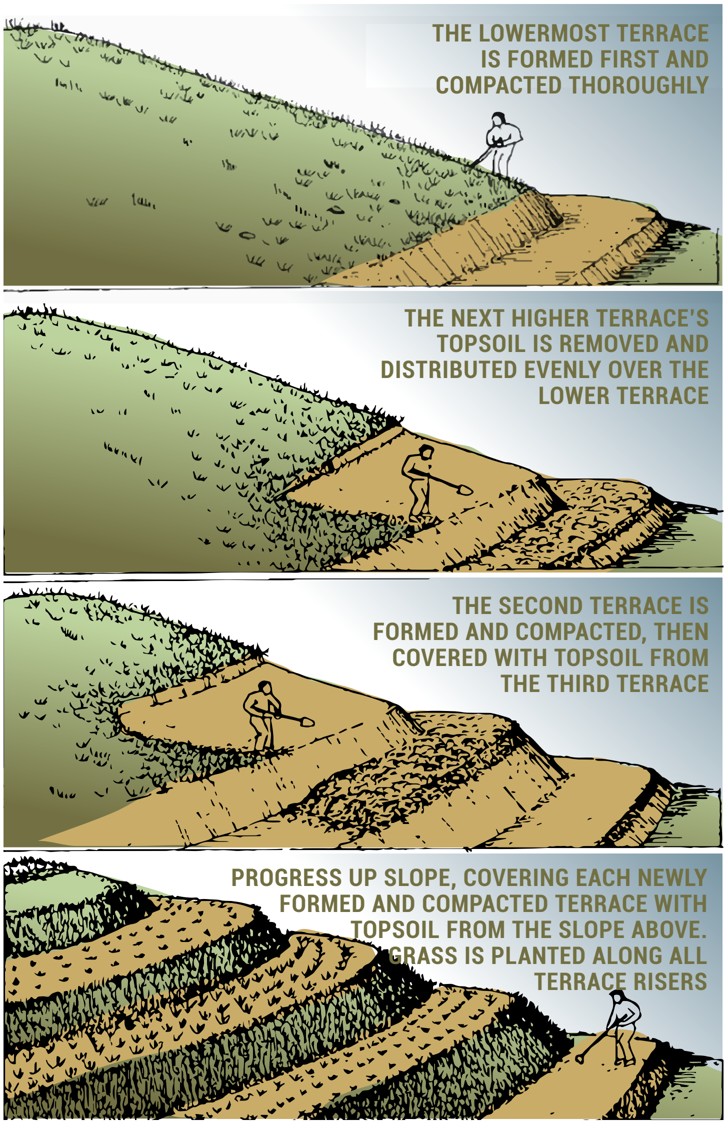
10. *Plant Grass on riser:*

Plant grass on risers as soon as construction is completed.

11. *Alignment of contour*

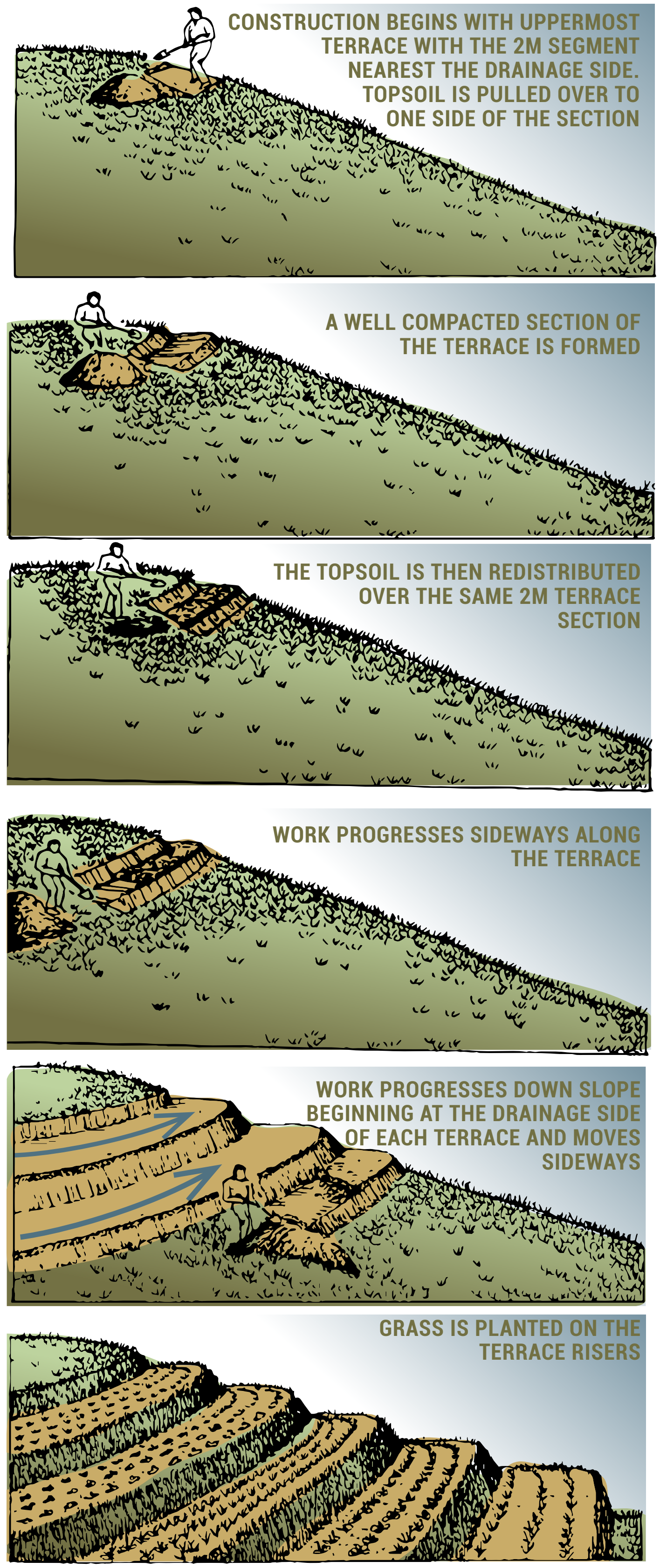
In sections where the terrace counter, owing to impediments, is out of line, particular attention must be directed to drainage and erosion control to avoid overall failure of the terrace.

Figure 28: Bench terrace construction sequence "A"



Source: Food from Dry land Gardens - An Ecological, Nutritional, and Social Approach to Small-Scale Household Food Production

Figure 29: Bench terrace construction sequence "B"



12.3.1 Calculation of earthwork

(1) The volume of soil per hectare (v/ha) to be cut and filled is calculated as follows:

$$V/ha = A^* \frac{100^2}{d} = A^* \frac{100^2}{(W+(VI \pm k)\mu)} \ (m^3)$$

A is the area of the cross section to be excavated or filled, and

$$A = \frac{W.\ VI \pm d.k}{8} = \frac{W.VI \pm (W.k+k.VI.\mu \pm k^2.\mu)}{8} = \frac{d.VI - VI^2 \mu \pm (d.k - VI.k\mu)}{8} \ (m^2)$$

Note: Other symbols such as W, VI, k, μ and d are the same as defined in the design formula.

(2) The total man-clays required for the job may be calculated on the basis of the volume of soil to be excavated per hectare and the working efficiency of excavation, filling, levelling and compaction.

12.3.2 Planting grass on risers of terrace

It is essential to plant grasses on the risers of bench terraces unless they are faced with stone. Bahia grass, broadleaf Carpet grass, Centipede grass and Bermuda grass are recommended choices. Other native creeping grasses and crops that maintain foliage continuously are also acceptable.

Objective of actions:

To prevent soil erosion from the risers and to maintain the stability of the terraces.

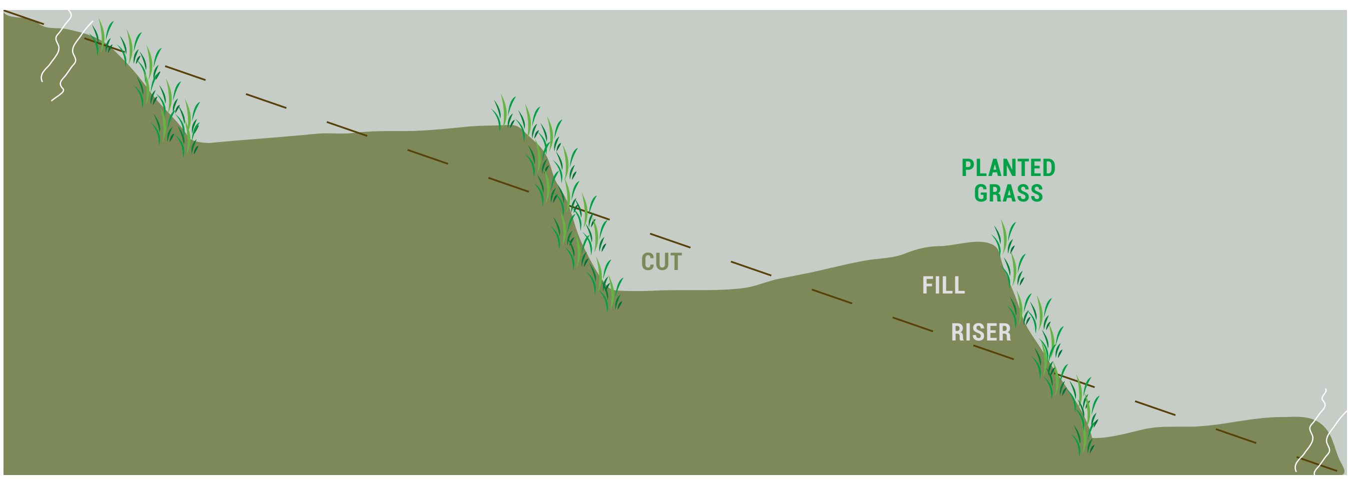


Figure 30: planted grass on risers of terrace

12.3.2.1 Application

The grass should be established immediately after the terraces have been constructed. The area should be treated with organic manure and other nutrient sources to ensure rapid cover. For species such as Bahia grass, planting material may be obtained by splitting clumps of the grass into tillers, which should be planted in rows in a triangular pattern at a maximum spacing of 30 cm X 20 cm. Alternatively, grass seed mixed with asphalt emulsion may be sprayed over the area.

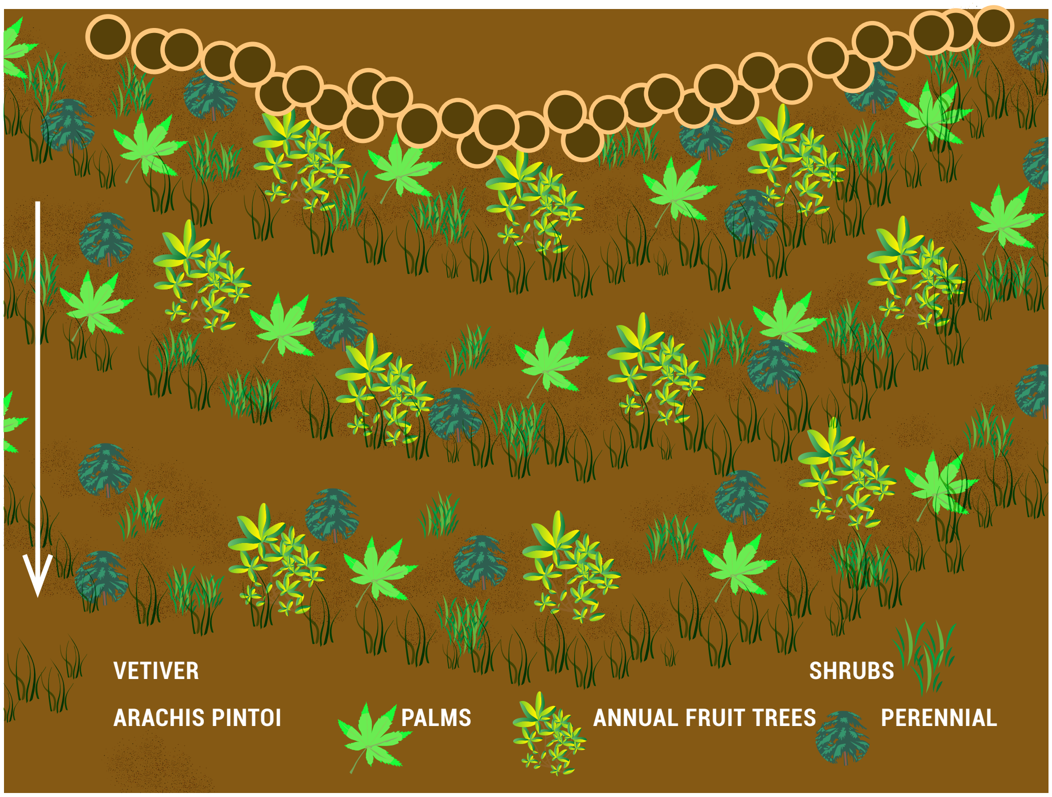
When seeds of other species are used, the seeds may be mixed with emulsion and spread on the surface of the riser. Seed belts may also be used.

13. Contour planting

13.1 Definition

Contour planting describes the technology that involves plowing, furrowing and planting along the contour lines of a slope.

Figure 31: Contour planting illustration (triangular spacing)



BAMBOO

ACCESS

CROPS

SLOPE

Figure 32: Topical view of design for contour planting

Source:https://issuu.com/permatree/docs/acap_permatree_top_3800px

13.2 Implementing contour planting

When hillside ditches, grass barriers or stone walls exist, they should be used as guide lines for plowing, ridging & furrowing and other cultivation operations. The most adequate number of long rows along the guidelines is 4-6, with the short rows positioned in the middle between two guide lines. Crop establishment usually follow a triangular distribution between successive rows.

14. Cover cropping

14.1 Definition

Cover crops describes plants which are grown to cover the surface of the soil with dense foliage, to control soil erosion, limit weed growth and improve the soil. Cover crops are also selected to positively influence physical soil properties.

Figure 33:Cover crop illustration

Figure 34: Banana with legume Neonotoniawightii (Perennial soybean, wild soya bean, Rhodesian kudzu) cover crop (CIRAD -Martinique)

14.2 Establishment of cover crops

Cover crops are mainly applicable for orchards or other long-term crops in combination with other soil conservation treatment. Mowed grass should be placed directly under the canopy of the crop as a mulch. For young orchards, strip covering and mulching are recommended, (see fig 33).

Planting of cover crops is often most effective when established prior to cash crop establishment to ensure proper coverage. Seeding, planting of cuttings and stolon are all planting method that differs depending on the cover crop species and the available planting material. Once cover crop establishment is completed, conservation tillage is employed to effect main cash crop establishment.

Planting with grasses / tillers, vines

When Bahai grass or other grass types are used, prepare planting material by splitting healthy clumps. Plant in a triangular pattern with spacings of 30 cm X 30 cm or 1ft X 1 ft, planting 2 or 3 tillers per mound. Establishment should be done when there is an abundance of moisture during the rainy season.

Planting with seeds

When direct seeding cover crops, plant seeds in rows. The spacing of the seeds will be dependent on the plant characteristics. Seeds must be planted close enough to get total coverage. Multiple seeds must be planted per mound.

Land Degradation Management

15. Gully erosion control

15.1 Definition

To stabilize active gullies in farmland with vegetative cover and/or engineering measures, for the purpose of preventing anticipated disaster, or restoring land for production.

Objectives

To stabilize gullies.

To divert discharge of sediment for protection of properties downstream. (3) To restore the productivity of eroded land.

To provide a green vegetative cover to eroded land, so as to improve the landscape.

15.2 Planning and design

The preparation of a specific plan for gully control involves many elements, e.g, the size and location of the gullies, the acreage of watershed, gradients of the gullies, soil texture, drainage condition, vegetation, land use, wildlife habitat, landscape maintenance, extent of gully control needed, etc. Only when all these elements are thoroughly evaluated can the most feasible plan be worked out. Furthermore, a pragmatic approach is essential for ensuring that a reasonable objective is attained at minimum cost. The plan should be integrated with the soil and water conservation measures in headwater watershed areas. Usually, it is not feasible to expect any one measure to fulfill the objectives of a gully control project. Nearly always several different measures have to be put together in order to work out the desired effect. These gully control measures are described individually as follows:

(1) Adjustment of farming practice: Suitable for small gullies on farmland.

a. Correction of improper land use: The following situations may cause the formation of small gullies:

Routing of farm roads or paths without following soil and water conservation principles; making furrows up and down slopes; bench terraces, hillside ditches and diversion ditches without safe runoff outlets or with runoff outlets in disrepair; over grazing or trampling by livestock.

b. Elimination of small gullies: To plow over small gullies and level the ground, or fill

gullies with debris.

(2) Diversion of runoff: To reduce the amount of runoff discharged into gullies.

a. Diversion ditch or ridge: To be built at the head of the gully or on the upper side of the banks, to direct runoff into a safe course. When it is built at the head; the site should be away from the gully head at a distance three times the depth of the gully. (For details see Chapter 7. Diversion Ditches.)

b. Hillside ditches or terraces

Hillside ditches or inward-sloping terraces may be built at suitable intervals across a gully to divert runoff to a safe collection or drainage point. This measure is particularly desirable for small to medium size gullies on farmland, which do not serve as water courses. The hillside ditches and terraces should be designed as an integral part of the soil and water conservation scheme for gully control. (For details see Chapter 8. Hillside Ditch and Chapter 12. Bench Terraces.)

(3) Vegetative cover

Plants can prevent erosion by providing anchorage for soil and gravels. They may also help in landscaping. Therefore, except at those places where plants cannot grow, vegetative cover is the best measure for permanent control of gully erosion.

a. Natural vegetation

Natural vegetative cover can be established by protecting the land with fences or other measures against abuse or ravages, e.g. fires, trampling of livestock, etc. This method is mainly used for rehabilitation of pasture land, and is rarely applied on its own to crop-land.

b. Planted vegetation

This type of vegetative cover is established by planting or encouraging plants in a specific area. Often preparatory procedures are required, e.g., leveling the surface of the slope, staking and wattling etc. Unstable rocks and trees on the banks should be removed, so that they will not fall into the gully and impede runoff flow.

At an appropriate distance from the banks, rows of trees may be planted along the banks to shade plants on the ground so as to help their growth. The shade may help to reduce ambient temperature. maintain soil moisture, minimize temperature variation, and increase relative humidity on the ground. The shade zone should be located on the south side of the gully. The *trees* are planted at 0.6-1.0 m intervals, in 3 - 10 rows separated by 1 - 1.5 m space.

All trees, big or small, shrubs vines and grasses may *be* used for gully control. The qualifications arc 1) high resistance to acidity, aridity and sterility of soil, 2) highly adapted to local climate, 3) vigorous and deep root system, and 4) strong disease and pest resistance.

(4) Gully surface treatment

This treatment is necessary for gullies with unstable runoff flow, and for those grass waterways which also provide passage for farm vehicles. For the purpose of stabilizing the flow, the slope of the gully should be reduced if possible. Rocks and plants on the sides, which are likely to fall into the gully should be removed to prevent stoppage.

(5) Conversion of a gully to a drainage ditch and Grass waterway

On cropland, gullies which are not filled by water all the time may be converted into grass waterways. in doing this, the surface of the gully should first be cleared and leveled, and then planted with grass, preferably Bahia grass or centipede grass. At appropriate intervals, drop structures should be installed to dissipate the energy of runoff. In order to accelerate the formation of grass cover, grass sprigs may be densely planted in strips. It may be necessary to drive stakes and bury twigs or brushes into the base of the ditch.

b. Lined ditch

This will enable additional useful land to be made available along its sides. (For details see chapter: Drainage Ditches.)

(6) Installation of check dams. Check dams are often installed in gullies for the purpose of: 1) reducing gully gradient, 2) controlling the course of runoff, 3) blocking sediment, 4) stabilizing the gully, and 5) helping vegetation growth. Check dams fall into two categories:

a. Temporary dam

This kind of dam is needed only in the early stage of development of the vegetative cover. It helps in stabilizing the banks of a gully, before vegetative cover becomes fully established. It is easy to build with materials available in the field. Therefore, low cost is its main advantage. However, it is also short-lived and requires frequent maintenance. Generally, the life span of a temporary clam is shorter than one year. For safety, its height should not exceed one meter.

The more popular construction materials for this type of check dam are: sandbags, timber, animal skins and rocks. (For details see Chapter 16. Check Dams.)

b. Regular dam

These dams are more durable and built to higher safety standards.

(i) Pervious dam: Built of piled rocks, wire cages, pickets, rubber tires, wood cribs, and precast concrete slabs, etc.

(ii) Impervious dam: Built of concrete and stone or concrete alone, masonry, bricks, or earth. Special care should be taken, if this type of dam is to be built where there are landslides or where land tends to slip or slide.

15.2.1 Precautions

(1) All work should be coordinated with soil conservation along the gully.

(2) When the working area is inaccessible by road, cable conveyor should be used to transport materials and equipment. Avoid building new roads whenever possible.

(3) Earth work should be done in the dry season.

(4) Planting should be finished before the rainy season arrives.

(5) The leftover excavated earth, that is not needed for earth fill should be dumped in safe places.

(6) During the progress of construction, efforts should be made to avoid damaging the slope surface and vegetation unnecessarily.

(7) Other methods of gully control

Soil stabilizer is an organic or inorganic chemical. A water solution can increase *the* bonding among soil particles, and consequently reduce detachment of these particles, thus making them more resistant to erosion. It may also be helpful to plant growth, because it can reduce soil moisture evaporation and protect seeds. In addition to soil stabilizer, there are other manufactured products, e.g. fibre pads, plastic mesh, screens, etc., which are useful in soil erosion prevention and gully control.

16. Check Dam

16.1 Definition

A structure installed across an active gully to stabilize the gully through control of the erosion of gully bottom and banks.

16.2 Application

Temporary dam

The purpose of this kind of dam is to temporarily maintain the stability of a gully to make possible the establishment of vegetative cover. It is not durable and needs frequent tending, though it is inexpensive and easy to build. Construction materials are usually available at the site.

Types of temporary dams

i. Timber dam

(a) Brush dam: One or more rows of poles are lined across a gully and driven into the bottom. Behind each row of poles, twigs are packed to form a dam. When there is only a single row of poles, the twigs should be laid crosswise. With more than one row of poles, the twigs should be laid lengthwise.

(b) Plank or log dam: Logs of 15 - 20 cm in diameter or planks more than 5 cm thick arc laid one on top of another horizontally across the gully.

(c) Wood crib dam: A crib is bult of logs, the space in the crib filled with rocks or boulders.

(ii) Wire mesh dam: Wire mesh is stretched along a picket across the gully.

(iii) Sandbag dam: Used nylon or jute fertilizer bags are filled with dirt and stacked into a dam. Grass seeds or roots may be mixed with the dirt, to help the development of a vegetative cover.

(iv) Riprap dam: Piling up boulders or rocks across the gully to form a dam.

Application

i. This type of dam is used for stabilization of a gully before vegetative cover is fully established. Its expectancy of life is no more than one year. Only the riprap dam may last longer.

(ii) It is desirable in places where construction materials are readily available at the site or nearby, and labor is inexpensive. It is also appropriate when no difficult technical problem is involved.

(iii) The height of the dam should not exceed one meter.

(iv) For gullies consisting of large boulders or rocks, only a riprap dam is suitable.

Regular dam

Regular dams are more durable structure for gully control. These include:

a. Pervious dam

Types of regular dams

(a) Dry masonry dam: Stones are laid into a dam without mortar.

(b) Gabion dam

i. Wire Sausage dam: A dam consists of horizontally laid sausage-shaped wire cages which are filled with rocks.

ii. Wire Box dam: A dam consists of box-shaped wire cages filled with rocks.

(c) Fence dam

i. Single fence dam: A picket consisting of steel pipes or concrete poles is planted across a gully. Wire is woven between the poles. Rocks are piled up on the upstream side of the fence to form a dam.

ii. Double fence dam: Two rows of pickets are set up across the gully, with a space of 0.6-1.0 meter in between. Wire mesh is stretched along each row. Rocks are filled into the space between the rows.

(d) Tire dam

Scrap-tires are stacked up with a pole of concrete or steel in the center for anchorage. The inner space of the tire is filled with rocks. Stacks of tires closely placed will form a dam.

(e) Concrete slab dam

A dam assembled with concrete poles and slabs.

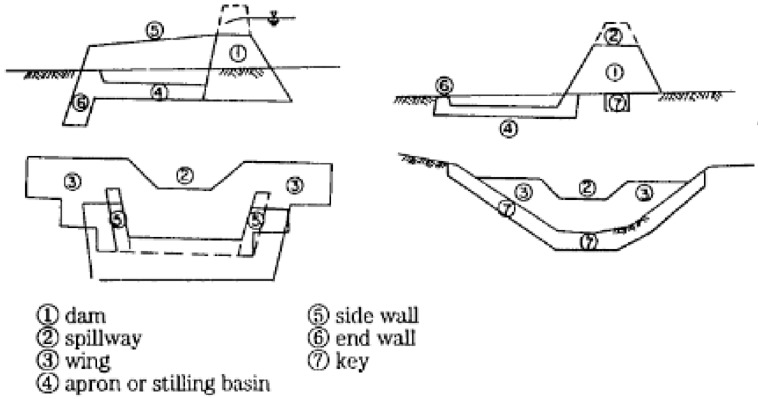


Figure 35:Dam structure nomenclature

Figure 36: Fence Dam a. Single fence   b. Double fence

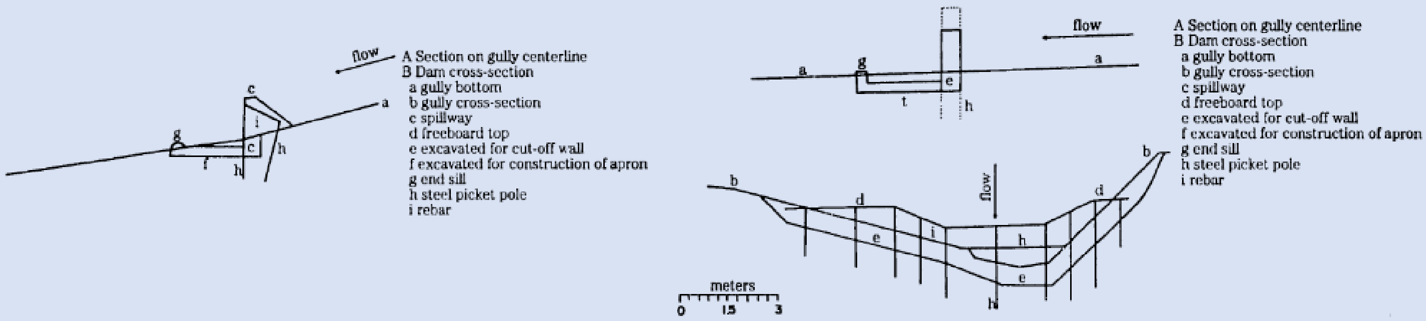
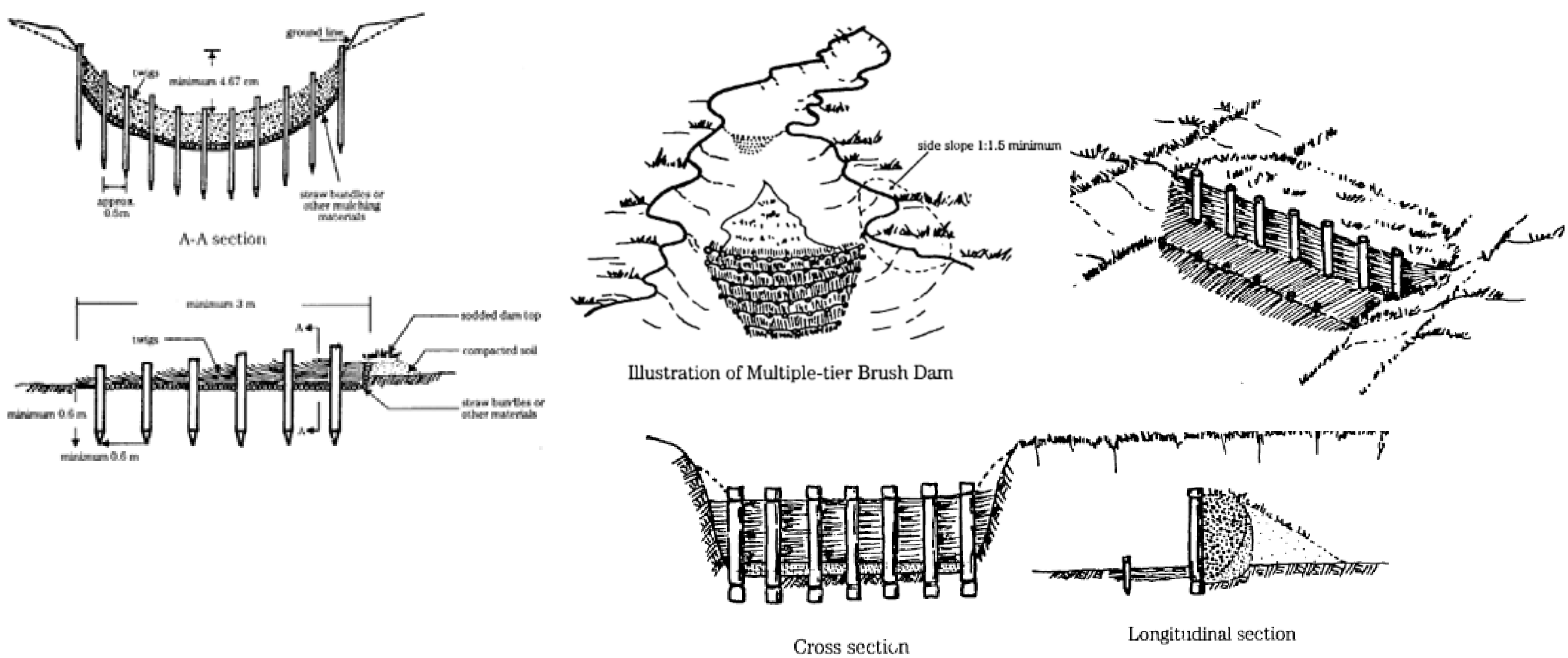


Figure 37: Brush Dam



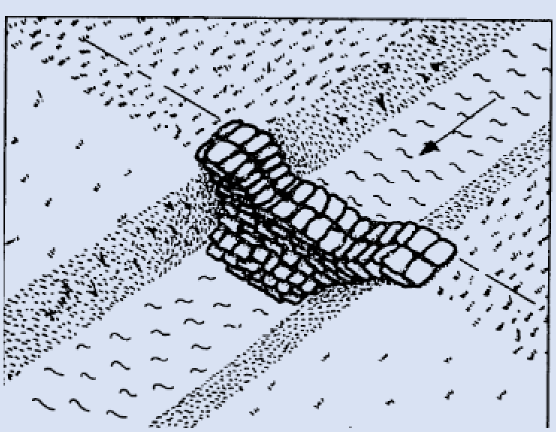


Figure 38: Sand bag dam

Figure 39: Wire mesh dam *Cross section* *Longitudinal section*

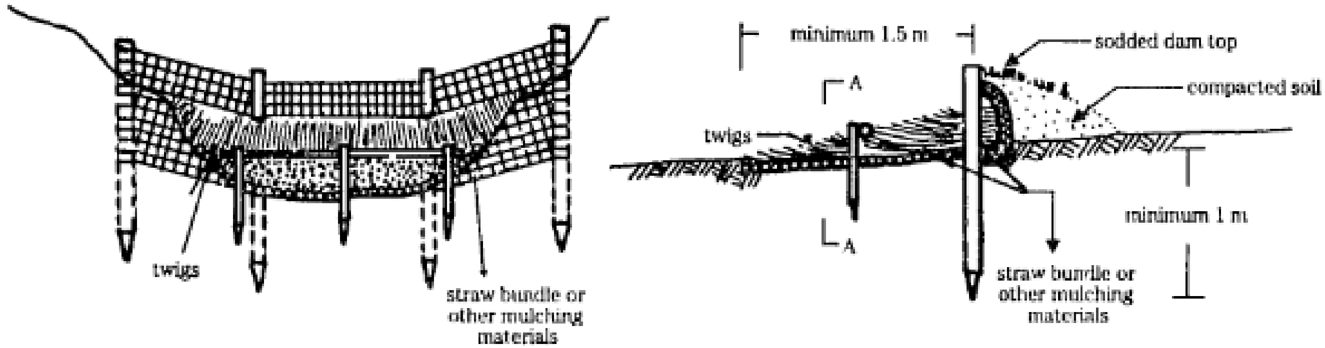


Figure 40: Timber dam
Wood crib dam

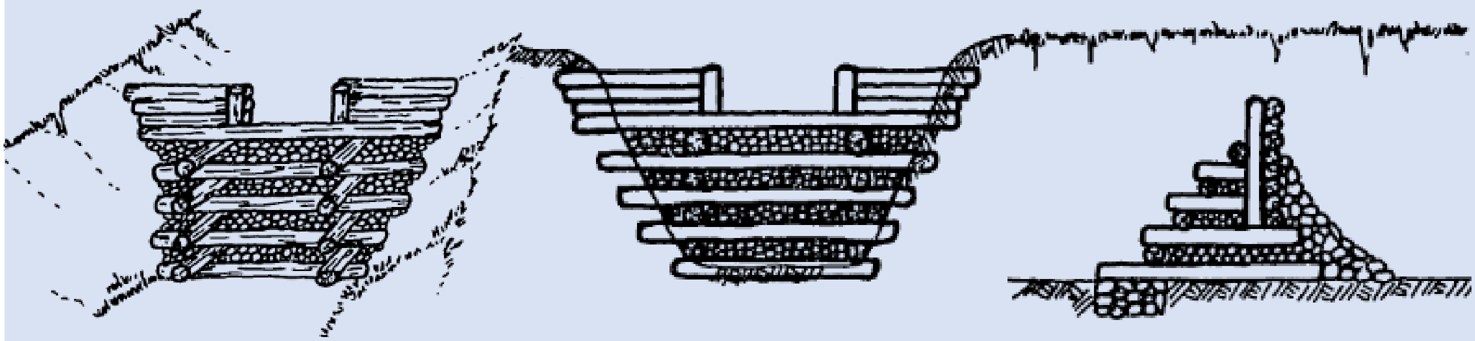


Figure 41: Plank dam

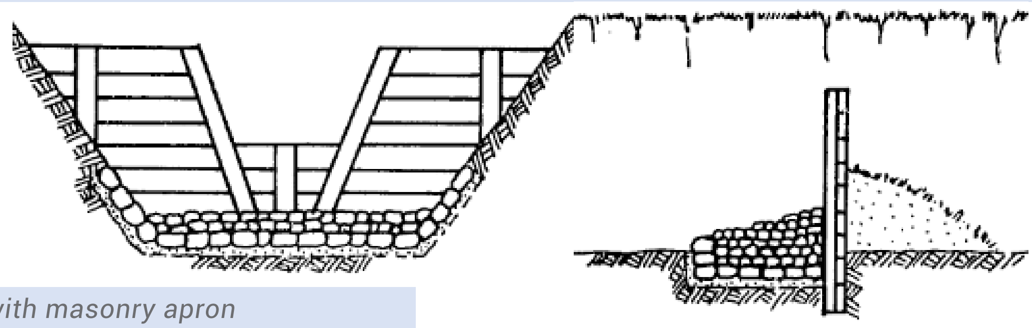
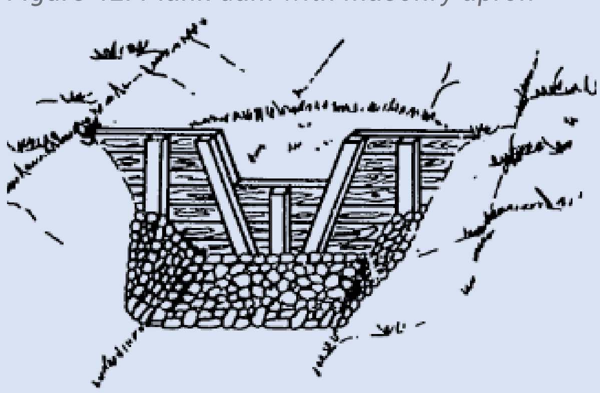
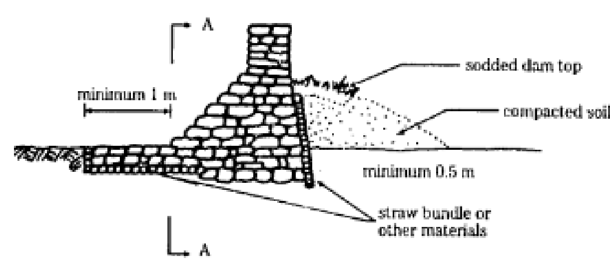


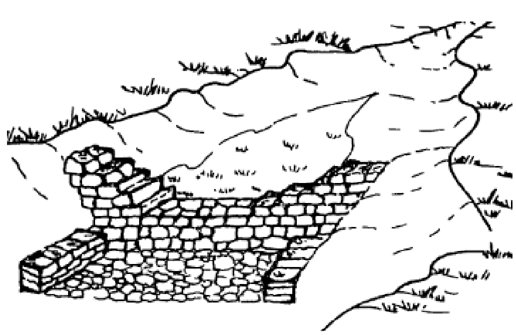
Figure 42: Plank dam with masonry apron

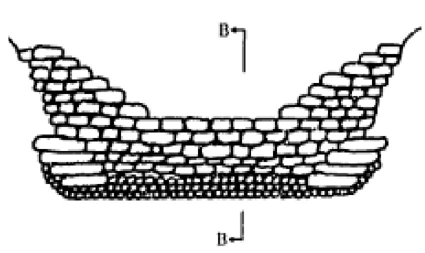




B-B section

Figure 43: Masonry dam





A-A section

Figure 44: Lumber Crib dam under construction

Source: Brian Mann - www.northcountrypublicradio.org/news/story/26774/20141201

16.3 Planning and design

(1) General principles

a. Peak flow estimate: For permanent dams, estimate should be based on 25 – 50 years' rainfall frequency. For temporary dams, 10-15 years' rainfall frequency will be adequate.

b. Designed silt gradient should beequal to 0.5 - 0.7 gully bottom slope; 0.5 is more frequently used.

c. As a protective measure, such devices aswater cushion etc.should beprovided for energy dissipation.

d. When there is a choice, the easiest construction method should be adopted. Construction materials available in the vicinity of the dam site should be utilized whenever possible.

(2) Dam site selection

a. The dam should be located where the gully is narrowest,

b. When a sequence of dams is constructed, the lowest dam should be located at a safe spot, or where the geological features of the banks are sound.

c. A dam should not be built at a bend. When there is a bend, it is better to locate the dam downstream from the bend.

(3) Interval between sequential dams

When several dams are built along a gully at close intervals for erosion control, they are called sequential dams. It is essential that a lower dam is able to protect the neighboring upward dam. The most suitable interval between dams may be determined with the following formula:

$$L = \frac{1}{\tan \alpha - \tan \beta} * He = \frac{1}{m - n} * He$$

L = Interval between dams (m)

He = Effective dam height (m)

m = Gully bottom gradient = tan α

n = Planned silt gradient = tan β

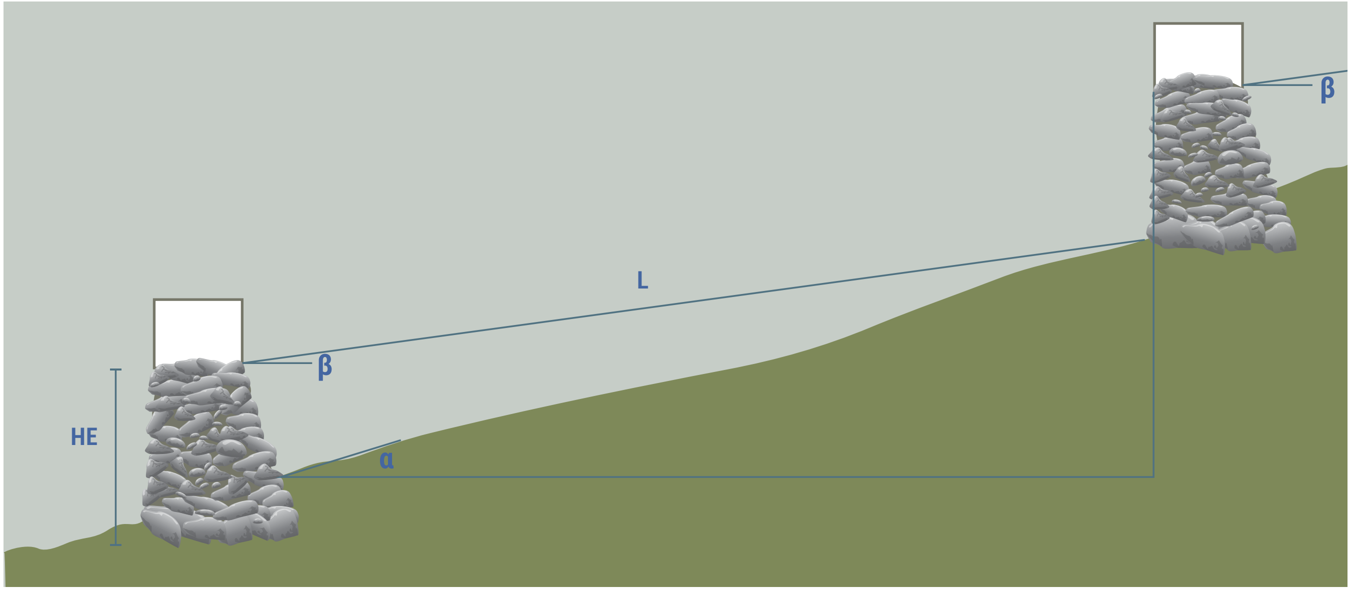


Figure 45: Illustration of sequential dam

(4) Height of dam

a. Factors which affect the height of a dam include: the shape of the gully, soil characteristics, terrain, land stability, construction costs and expected benefits from the dam.

b. In principle, a low dam is preferred. If a higher dam is needed, it is better to construct a sequence of dams as a substitute.

c. The height of silt is the distance from gully bottom to spillway, which is also known as effective dam height. The most economic effective dam height is 0.6meters for a riprap dam, 0. 7 meters for a single line picket dam and 1.1 meters for a double line picket dam.

(5) Spillway cross-section

a. Direction

(i) The center line of the spillway should be perpendicular to the downstream

flow center line. It should also be so aligned that damage or erosion to the banks is minimized.

(ii) At a bend. the spillway center line should be perpendicular as to the tangent of the flow center line.

b. Form: Depending on the type of dam, the following forms are most popular:

Dams

(i) Trapezoidal: Usually used on rubble masonry dams filled with concrete mortar, rubble masonry dams and crib dams.

(ii) Rectangular: Suitable for brick dams, box cage dams, crib dams, timber dams and stone dams.

(iii) Parabolic: For brush dams, wire mesh dams, picket dams and sand-bag dams.

(iv) Complex form: Mainly for impervious dams, and dams across very wide gullies.

c. Cross-section

(i) Width of spillway: The width of spillway should be commensurate with the width of the downstream gully bottom, so that the spilt water is kept from damaging the banks.

(ii) Height of spillway: Equal to the depth of overflow at designed peak flow plus free board.

(iii) Freeboard: 0.3 - 1.0meter is appropriate.

(iv) The size of the cross section should be larger, if the quantum of floating twigs and debris in the flow is excessive.

d. Calculations related to cross-section

After a specific form is chosen for the spillway, the following equations, which were originally used for the design of broad-crested weirs, may be used to calculate discharge capacity. This should be equal to or larger (by no more than 5%) than the runoff.

(i) Trapezoidal cross-section

At side slope 1 :1, **Q = (1.77b + l.42h) h213**

At side slope 1:0.5, **Q = (l.77B + 0.7lh) h213**

At side slope 1:0.3, **Q = (1.77B + 0.425h) h213**

(ii) Rectangular cross-section

Q = l.767bh

Q =Discharge capacity (m3/sec)

b = Width of spillway bottom (m)

h = Depth of overflow (m)

(6) Thickness of spillway: Spillway thickness depends on the type of dam, materials used in construction, size of rocks and pebbles in the gully bottom, and safety factors.

Table 161: Suggested thickness of spillway for various types of dams

Dam Type	Gravity Dam	Brick Dam	Wood Crib Dam	Wire Cage Dam	Rock Fill Dam	Riprap Dam
Spillway thickness	more than 0.8 x spill way depth or 1.5 - 2m	2b-4b	1-2m	1 - 1.5m	1 - 2m	1.5 - 2m

(7) Slope of dam surfaces

a. In order to prevent damage to the dam from stones and gravel discharged from the spillway, the slope of downstream surface should usually be fairly steep, while the slope of the upstream surface may be moderate.

b. If the dam is quite long, except the section where the spillway is located, the arrangement can be reversed in order to minimize dam volume, i.e. the slope of downstream side may be gentle, while the upstream side is made steep.

c. The gradient of the downstream surface of the gravity dam generally falls in the range of n = 0.2 - 0.3, while the upstream slope is larger than 0.45. However, the safety of the dam should be considered when these gradients are decided.

d. Gradient of both surfaces of stone dam: 1: 1.25 - 1.50.

(8) Apron or stilling basin: Built to protect dam foundation from water erosion on the downstream side, and to prevent collapse of the banks.

a. Calculation of apron length

(i) L = l.5(H + h), if gully bottom gradients 15%

(ii) L = l.75(H + h), if gully bottom gradient> 15% L = Apron length

H = Dam height

h = Depth of spill flow

b. Apron thickness: Depends on the volume of water coming down the gully and what it is carrying; whether it contains, e.g., gravel, boulders, etc. It also depends on whether the apron base or the apron itself possesses any water cushion. The thickness should be sufficient to sustain the impact of the spill flow and the uplifting buoyancy produced by the base. Concrete and gabion are the popular materials for apron construction. Suggested apron thickness in relation to construction material and height of dam is provided in table 12-2.

(9) End sill

a. The height of the end sill for a pervious dam, e.g. a picket dam or riprap dam, should be 0.15 - 0.25.

b. For permanent impervious dams, the end sill height should be 0.20-0.60 m, depending on dam height and length of stilling basin.

Table 162: Apron thickness in relation to materials

Height of Dam (m)	Material	Apron thickness (m)
<2	Concrete	0.2
2 – 3	Concrete	0.20-0.30
3 – 5	Concrete	0.30-0.50
<2	Riprap or dry masonry	>0.30

10) Key trench

a. These are rock-filled trenches built crosswise into the banks and bottom of the gully to protect the dam foundation and the banks against water erosion. Pervious dams, e.g. picket dams, riprap dams, dry masonry dams, wire cage dams and brush dams, all need key trenches.

b. Ordinarily the width and depth of key trench are both 0.6m. This may be extended to 1.2-1.8 m, if the banks are unstable.

c. Mixed boulders of various sizes, with 80% of the boulders smaller than 14cm, are the most desirable fill for a key trench.

11 Stone for pervious dams

a. Stone is the basic material for the construction of pervious dams. Flat rocks and rounded boulders are not suitable for pervious dams, e.g., picket dams, rock-fill dams, etc.

b. Stones used in a pervious dam should not be smaller than 10 cm in diameter, and25% of the stones should fall in the 10 - 14 cm class.

17. Alternate trellising - Yams, Passion fruit & Christophine

17.1 Definition

Trellising refers to the practice of providing support to (usually) a vining crop to allow upward growth that allows the leaves to benefit from more advantageous presentation to sunlight thus increasing photosynthesis, allow leaves stems and fruits to remain off the ground, increasing air movement, reducing rotting from direct contact with the ground, ease of harvest, ease of conduct of cultural practices among many other benefits.

17.2 Implementation

5/8 steel 8 ft apart with 3 rows of binding wire or guying cord as per the typical fence trellis. Design can also be modified to include one row of trellis wire at the top as for the fence arrangement with guying rope extending to top adjacent ridges as in the fig 46.

Figure 46: Single fence wire trellis with vining guy cord. (Wood stakes in photo should be replaced with 5/8 steel rod)

18. Windbreaks

18.1 Definition

Strips of trees or tall grasses planted at appropriate intervals to prevent or reduce wind erosion and crop losses caused by wind. Windbreaks will be discussed in more details in the section on agro-forestry.

18.2 Design

Tree species: Select erect tree species with a deep root system, exuberant off shoots, and with a trunk and branches capable of withstanding strong winds. Suitable local species include, Galba -*Calophyllumantillanum*, Mahogany - *Swietenia macrophylla*, Red Cedar - *Juniperus virginiana*, White cedar -, Kenip, Eucalyptus, Bamboo, Tamarind, Neem, etc

Grass species: Recommended grass species are Napier grass, Chrysopogonzizanioides - vertiver and Miscanthus.

18.2.1 Spacing

Windbreaks are usually spaced at a distance equal to 7 times the height of the shelter trees, shrubs or grass, although adjustments may be made on steep slopes to fit in with the topography of the land. The tops of dividing ridges, edges of fields and sides of roads should be utilized as much as possible for the planting of shelter trees, as long as the effectiveness of the windbreak is not affected.

18.2.2 Location and direction:

a. The windbreak should be set at right angles to the prevailing wind.

b. When windbreaks are planted across a hillside, they should follow the contour lines.

c. When grass strips are planted as windbreaks, they should be so arranged so as not to interfere with field work. Where hillside ditches exist, the strips should run along the side of the ditch in double rows.

d. At the time of setting up a tree windbreak, grass strips may be planted on the windward side of the trees in order to protect the tree seedlings and also to serve as temporary windbreaks before the trees are fully grown. The grass will remain as ground cover when the trees are grown.

18.3 Establishment

(1) Select the sites of the windbreaks and suitable tree or grass species.

(2) Planting pattern:

a. Acacia spp. may be established from either seeds or seedlings. Seeds may be sown in strips or hills. The spacing should be 0.5 to 1m within the row, and rows should be 1m apart.

b. Bamboos are usually planted in a single row. For thorny bamboo (Bambusasenostachya) and long branch bamboo Qi dolichoclada), a plant spacing of 1 to 1.5 m should be appropriate.

c. Napier grass may be planted by cuttings, with hills spaced 20 to 30 cm apart, and 30 to 50 cm between rows.

d. Vetiver and Miscanthus spp. may be planted by cuttings in hills 20 to 30 cm apart, with 30 to 50 cm between rows.

e. Windbreaks consisting of tall trees, e.g, Galba, Acacias and Tamarind, white cedar etc should be incorporated with suitable grass barriers or undergrowth shrubs.

(3) Planting season: Planting is usually done during the rainy season.

(4) Before planting, the land should be plowed and weeded. After planting, fertilizers should be applied. Good management should be maintained.

(5) Care should be taken to control pests and diseases which would cause damage to the main crops.

Agroforestry Systems

19. Agroforestry

19.1 Definition

Agroforestry is an integrated approach of deliberately using the interactive benefits from combining trees and shrubs with crops and/or livestock. It combines agricultural and forestry technologies to create more diverse, productive, profitable, healthy and sustainable land use systems. In agroforestry systems, trees or shrubs are intentionally used within agricultural systems, or non-timber forest resources are cultured in forest settings. It may include existing native forests and forests established by landholders

Agroforestry systems can display notable advantage over conventional agricultural and forest production methods through increased productivity, diversified economic benefits, social outcomes and the ecological goods and services provided. Agroforestry incorporates at least several plant species into a given land area and creates a more complex habitat that can support greater biodiversity to include a variety of birds, insects, and other animals.

The resulting biological interactions provide multiple benefits, including diversified income sources, increased biological production, better water quality, and improved habitat for both humans and wildlife.

Agroforestry also has the potential to help reduce climate change since trees take up and store carbon at a faster rate than many crop plants. (Ramesh U., Jain C.K, 2010)

19.2 Design

Design of an agroforestry system is the process of choosing and arranging components spatially and temporally. The design also needs to incorporate compatibility of components of the system. There is no substitute for good design A good agroforestry design should fulfil the following criteria:

A. Productivity:

There are many different ways to improve productivity with agroforestry: increased output of tree products, improved yields of associated crops, reduction of cropping system inputs, increased labour efficiency, diversification of production, satisfaction of basic needs, and other measures of economic efficiency or achievement of biological potential.

B. Sustainability:

By seeking improvements in the sustainability of production systems, agroforestry can achieve its conservation goals while appealing directly to the motivations of low-income farmers, who may not always be interested in conservation for its own sake.

C. Adoptability:

No matter how technically elegant or environmentally sound an agroforestry design may be, nothing practical is achieved unless it is adapted by its intended users. This means that the technology has to fit the social as well as the environmental characteristics of the land use system for which it is designed.

The ultimate aim of implementing agroforestry land management systems and technologies is to address land management issues in a sustainably manner. It therefore follows that diagnosis for the development of design is specific to the site. A basic procedure for diagnosis and design of an agroforestry system is summarized in table 16-1.

Table 191: Basic procedure of D&D (Diagnosis and Design) of Agroforestry system developed by ICRAF

D&D Stages	Basic Questions to answer	Key factors to consider	Mode of inquiry
Pre-diagnostic	Definition of the land use systems and site selection (which system to focus on?)	Distinctive combinations of resources, technology and land user objectives	Seeing and comparing the different land use systems
	How does the system work? (How is it organized; how does it function to achieve its objectives?)	Production objectives and strategies, arrangement of components	Analyzing and describing the system
Diagnostic	How well does the system work? (What are its problems, limiting constraints, problem-generating syndromes & intervention points?)	Problems in meeting system Objectives (production short-falls, sustainability problems Casual factors, constraints and interventions points	Diagnostic interviews and direct field observations Troubleshooting the problems, subsystems
Design & Evaluation	How to improve the system? (What is needed to improve system performance?)	Specifications for problem solving or performance enhancing interventions	Iterative design and evaluation of alternatives
Planning	What to do to develop and disseminate the improved system?	Research and development needs, extension needs	Research design project planning
Implementation	How to adjust to new information?	Feedback from on-station research, on-farm trials and special studies	Re-diagnosis and re-design in the light of new information

(Source: Modified from BOSTID, 1984.)

The choice of species of trees and other woody perennials should be based on: ·

- the goals and objectives of the farmer;
- the potential products/functions (e.g., fruits, nuts and nitrogen fixation);
- the environmental suitability of species for the site;
- the tree/shrub characteristics that influence their interactions with other components of the agroforestry system (e.g., growth rate, crown shape and rooting pattern);
- and · the origin (native/exotic) and availability of planting material.

Factors to be considered in the selection of crop and forage plants include their water and fertilizer needs, local dietary requirements, livestock needs (in the case of fodder), market potential, shade tolerance, competition with trees or other woody perennials, and the quality, price and availability of seed. If animals are to be a component of the agroforestry system, factors to be considered in choosing the kinds (and quantities) of animal include potential markets, desired products (e.g., Honey, meat and milk), interactions with other components of the system, price, and availability. (FAO, 2005)

The spatial and temporal arrangements of the various components of an agroforestry system (i.e., trees, crops and animals) are critical for its success; the aim is to minimize the competition for land, sunlight, water and nutrients among those components and to maximize their complementarity. Spatial arrangements refer to how system components are arranged in a landscape – such as the distance between trees in plots, and the configuration of such plots in relation to agricultural crops. Temporal arrangements may comprise the rotation lengths of trees and the seasonality of annual crops.

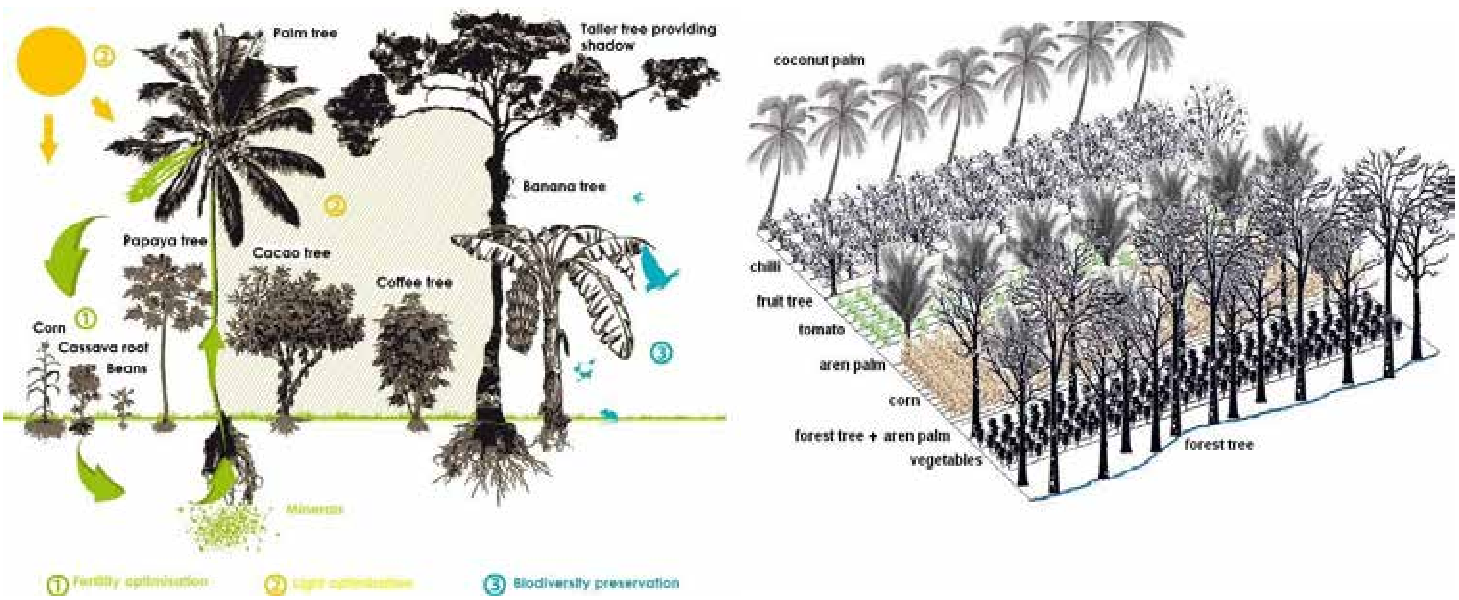


Figure 47: Typical agroforestry systems
(Source: http://pertaniandanmanusia2015.blogspot.com/2015/12/agroforestry.html)

Figure 48: Crop wind break illustration

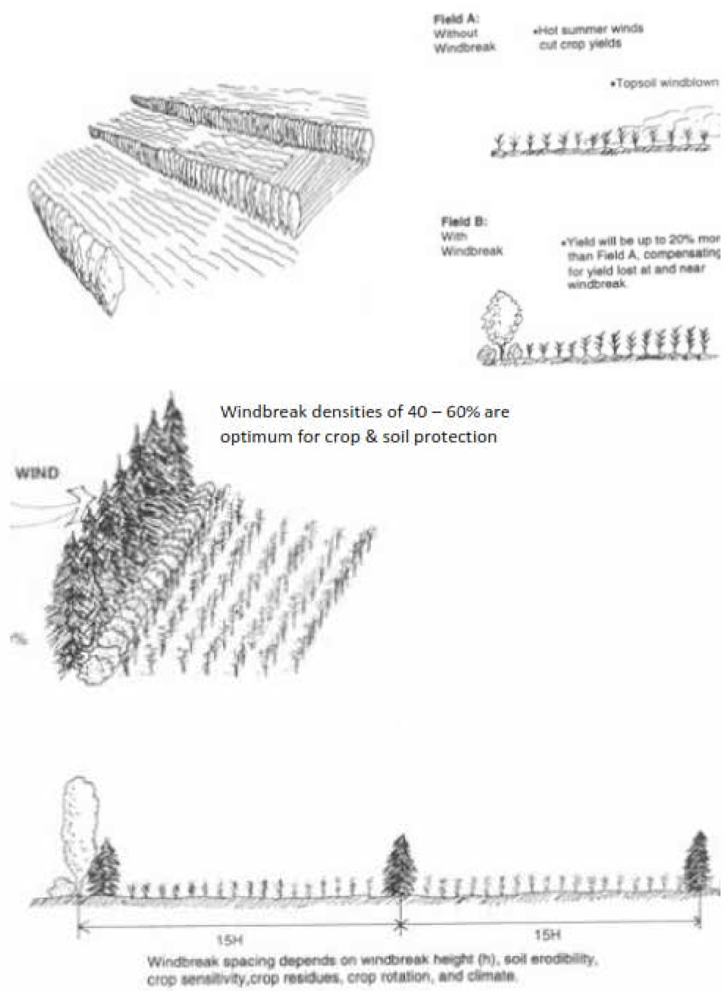


Figure 49: Livestock windbreak illustration

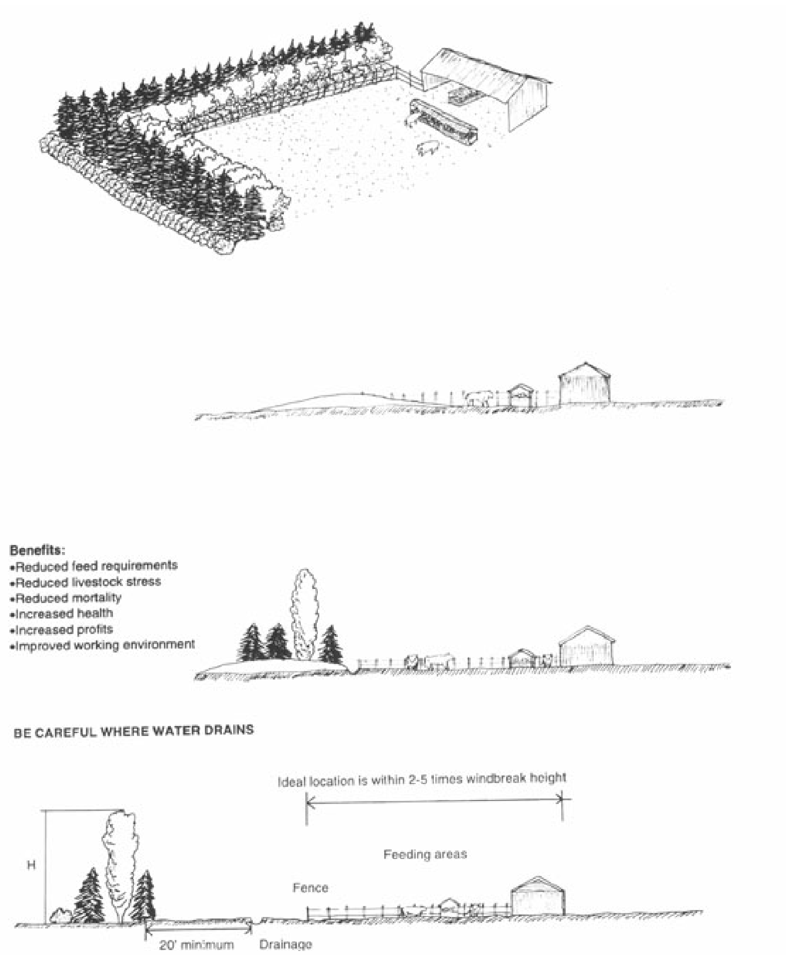
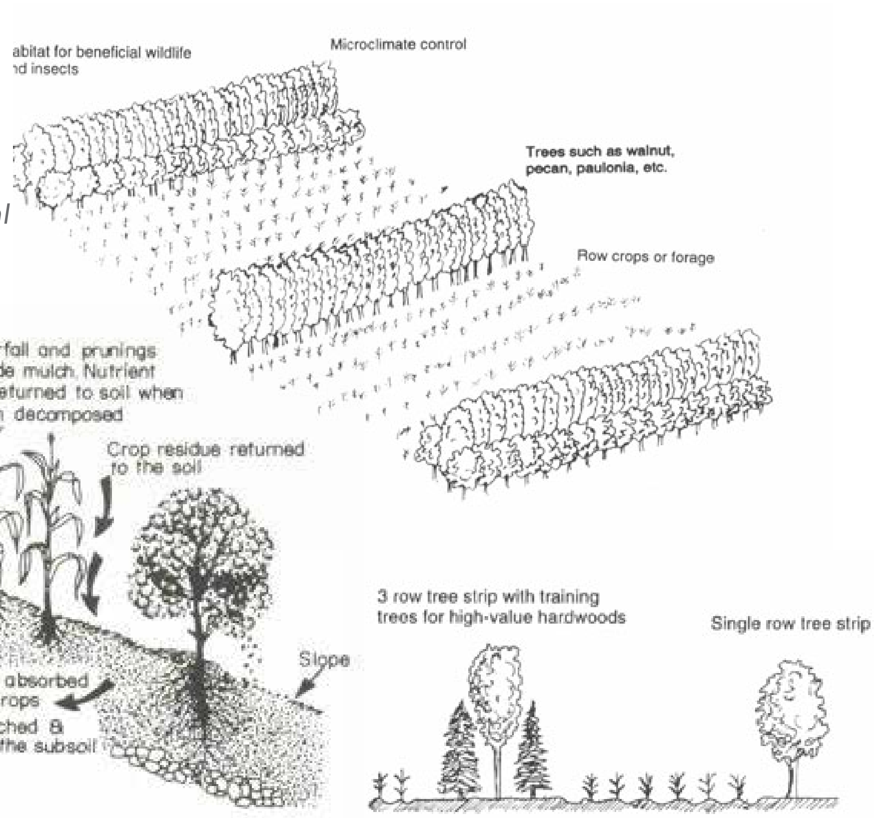


Figure 50: Alley cropping

Source : https://www.pantagraph.com/alley-cropping-demo-at-farm-progress-show/article_058ccf26-e235-586c-b329-776323849539.html



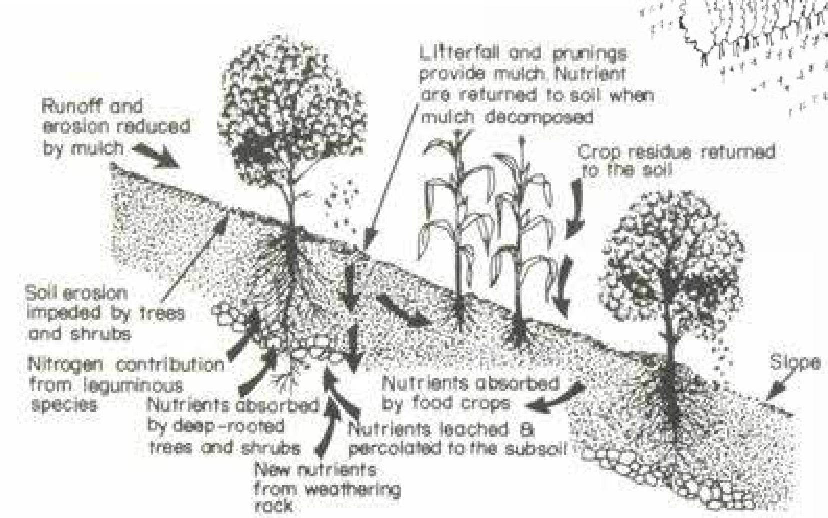


Figure 51: Contour buffer strips

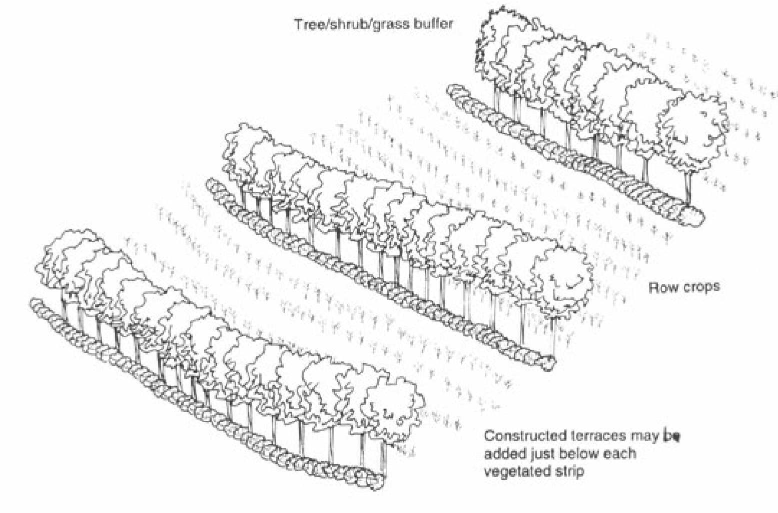


Figure 52: Riparian Forest buffer

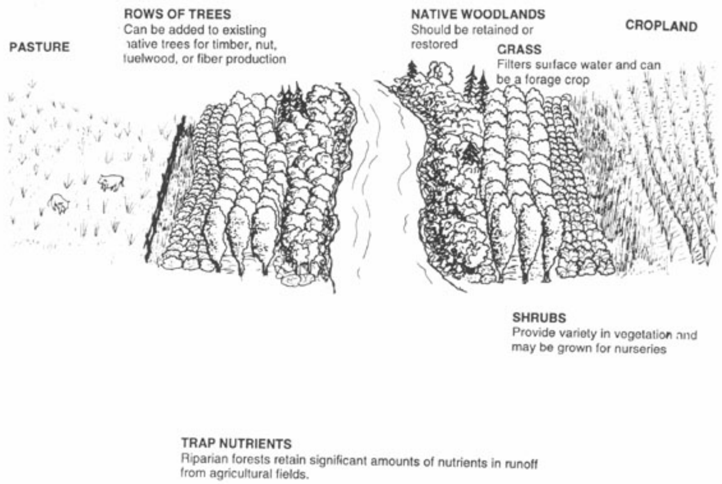


Figure 53: Filter strip

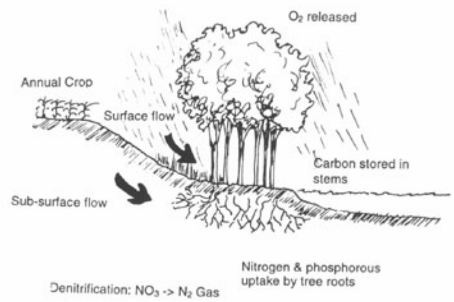
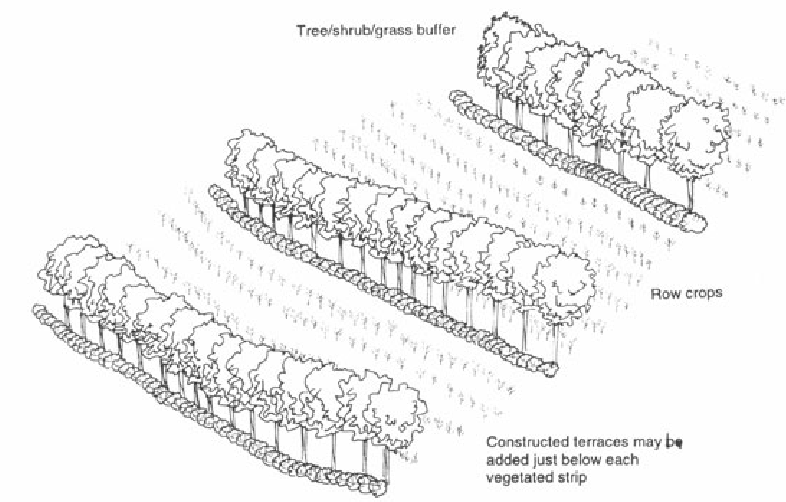
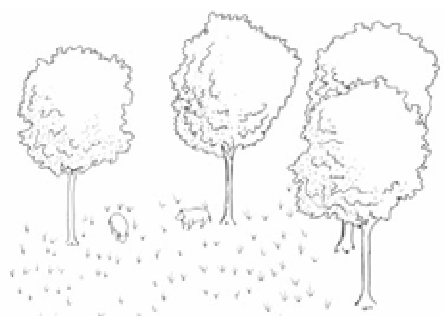


Figure 54: Multi-tier cropping

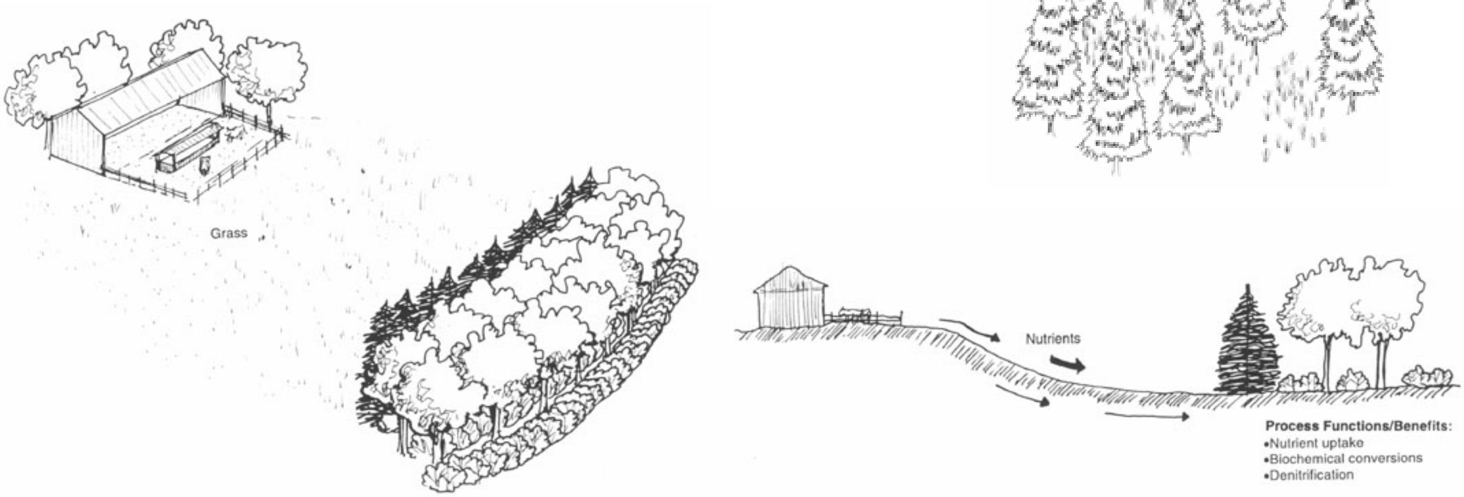


Trees and livestock (bees, small stock etc)



specialty crops

Figure 55: Wastewater management planting



Improved Crop Productivity

20. Crop Management

20.1 Definition

Application of selected crop management technologies and approaches are able to reduce soil loss and also benefit crop production e.g., by impacting on the availability of nutrients, regulation of various pest and disease vectors, providing shade and support etc.

These technologies and approaches are pursued with varying intensity within the local agricultural setting. Companion- and inter-cropping are practiced extensively on most small farms. Some common examples and the benefits accrued are listed below

Banana, plantain & Coconut

Also referred to as multistorey cropping, this approach ensures that soil surface is always shaded and protected from direct impact by the elements. The selected lower storied crop must be able to sustain some level of shading. The upper tier crop is usually a perennial crop and the lower tier an annual within this system. This system maximizes land use and output. The upper tier crop can also be substituted by other high value tree crop and forest species in an agroforestry system

Banana, plantain & pumpkin or potato

This system is pursued mainly for the purpose of effecting soil cover when crops with wider plant spacing are established. The primary purpose of the lower tier crop is for protecting the soil while offering some other benefit. The plants utilized are often vining rapidly growing plants that are established after the planting of the primary crop.

Plantain & Tannia, Cocoa

Shading of the lower tier crop is the primary objective in this system. The establishment of the lower tier is completed after the shading crop is well established, and is also established at high density.

Cucurbits & Corn

The objective of this system is two-fold in that it undertakes to provide soil protective cover and also reduce disease / pest pressure by inclusion of different plant species. The provision of an alternate income source that becomes available after the main crop and trellis support (e.g., corn stalk with runner beans and cucumber) is an added benefit.

Banana & Papaya

Reducing pest and disease pressure in sensitive crops such as papaya by limiting density of plants

Banana / plantain & coffee, Citrus, Cocoa, Cherry

Agro-forestry system of production

Vegetables Chives & Lettuce Beans

Limiting pest and disease pressure by adding varying plant species especially those (e.g., chives, onions, pepper, marigold) that are known to repel particular popular pest and vectors

20.2 Mixed cropping system in an already establish orchard

A decision to apply a mixed cropping system to an already establish orchard may occur at various stages of crop development. An example of possible mix cropping systems within an established coconut orchard is provided in table 17-1, with possible crop species that can be used. The crops selected for mixed-cropping should preferably have some level of shade tolerant since the incidence of sunlight under the coconut canopy may be limited based on planting density.

Table 201: Mixed cropping system with coconut

Coconut – Growth Period	Inter Crops
< 7 years of age	Annual Crops such as Groundnut, Arrowroot, Turmeric, Cassava, Sweet Potato, Yam, Ginger, Pineapple
7 to 20 years of age	Biennial crops such as Banana, plantain, pineapple.
Above 20 years of age	Perennials such as Cocoa or Coffee are suitable

21. Conservation tillage

21.1 Definition

Conservation tillage refers to any manual or mechanical tillage of the soil which aims to create a soil environment favourable to plant growth through physical, chemical or biological soil manipulation to optimize conditions for the various stages of plant growth; germination, seedling establishment and crop growth, Lal (1983). This manipulation to include physical loosening of the soil can occur through a range of cultivation operations (Ahn and Hintze, 1990).

Notwithstanding that a precise definition of conservation tillage is only possible within the context of known crop species, soil types and conditions, and climates, an operational definition of conservation tillage refers to tillage or tillage and planting combination that retains at least 30% or greater cover of crop residue on the soil surface to reduce erosion by water.

In cases where soil erosion by wind is the primary concern, at least 1000 lb/acre flat small grain residue is retained on the surface during the critical wind erosion period, (Bergtold and Sailus (eds), 2020).

Popular forms of conservation tillage utilized in small holder agriculture includes: Mulch, ridge, zone, and no tillage.

21.2 Mulch Tillage

Mulch tillage techniques are based on the principle of causing the total soil surface to be ploughed as per conventional tillage but leaving sufficient crop residue on the soil surface to significantly reduce erosion. A portion of the crop residue is incorporated into the top few inches of the soil.

21.2.1 Implementation

Utilized appropriate dead or chemically killed cover crop that have been established on field. Chop and mince residue to a minimum of 3 inches and distribute evenly over the surface to be planted. Area is then ploughed incorporating chopped residue into top 6 inches of the soil. In cases where previous crop residues forms part of the mulch being utilized, due attention must be given to the likelihood of increase pest and or disease pressure from infected residues. If residues are suspected to be infected, it is best that they are excluded entirely. This form of tillage is not recommended for soils that are predominantly wet.

21.3 Ridge Tillage

Ridge tillage, can be described as a hybrid between raised bed production and single row cropping, offering many of the benefits and advantages of both. Further, there is an added component of full-year cover cropping (i.e., the plot is taken out of vegetable or other short term crop production every second or third year). This system creates soil conditions that favour proper air and water movement, coupled with residue decay. This results in minimize soil damage or loss, break in weed cycles and depletion in the weed seed bank. The system also requires relatively low-intensive management by the farmer. There is also the potential for all other systems for crop production (weed control, pest control, fertility, irrigation, labour, etc.) to be incorporated within the overall scheme of the ridge tillage system.

21.3.1 Implementing a ridge tillage system

In this system, the soil is left undisturbed prior to planting but about one-third of the soil surface is tilled at planting. Farmers build ridges or raised beds, planting of row crops is done on preformed cultivated ridges, after the top of the ridge is scraped off into the furrows/pathway. This action flattens the ridge to receive plants and also removes weeds from having direct contact with the transplanted or germinating seedling (fig 55). Weeds controlled by herbicides or other methods away from the crop i.e. within the furrow is much easier, and because they are applied in bands reduces total application. Other cultivation practices such as soiling and hand weeding can be used during the crop cycle to control weeds within the crop and along the sides of the ridge.

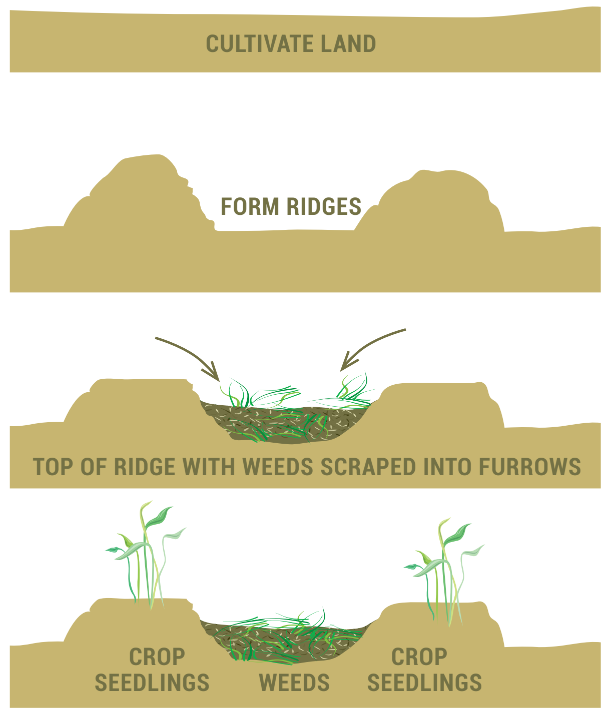


Figure 56: Ridge tillage illustration

21.4 Zone / strip tillage

This method describes a field tillage system that combines no till and full tillage to produce row crops. Narrow strips 6 to 12 inches wide are tilled within crop stubble, with the area between the rows left undisturbed.

21.4.1 Implementation

1. Perform weed control activity – brush cutting or application of herbicide. Allow stubble to remain in soil.
2. Demarcate area for crop establishment and area to be left undisturbed.
3. Till area to be cropped, burying approximately 50 % of the crop / grass residue.
4. Plant seedlings or sow seeds
5. Perform weed control and other cultural practices
6. Harvest crop.

Figure 57: Illustration of strip and traditional tillage cultivation of butternutsquash. (Note cover crop residue visible in strip tillage, protecting the soil; and soil splash on leaves in traditional tillage)

21.5 No Tillage

This method describes a system where no tillage is performed. Weed is controlled mainly through chemical means and drills are made into the undisturbed soil to sow seeds or introduce seedlings.

21.5.1 Implementation

1. Perform weed control activity – brush cutting or application of herbicide
2. Sow seed or plant seedlings into seed drills or holes
3. Perform weed control and other cultural practices during crop cycle.
4. Harvest crop.

Figure 58: Illustration of no till system with other conservation practices

Wet – Dry Season Technology

22. Slopeland irrigation

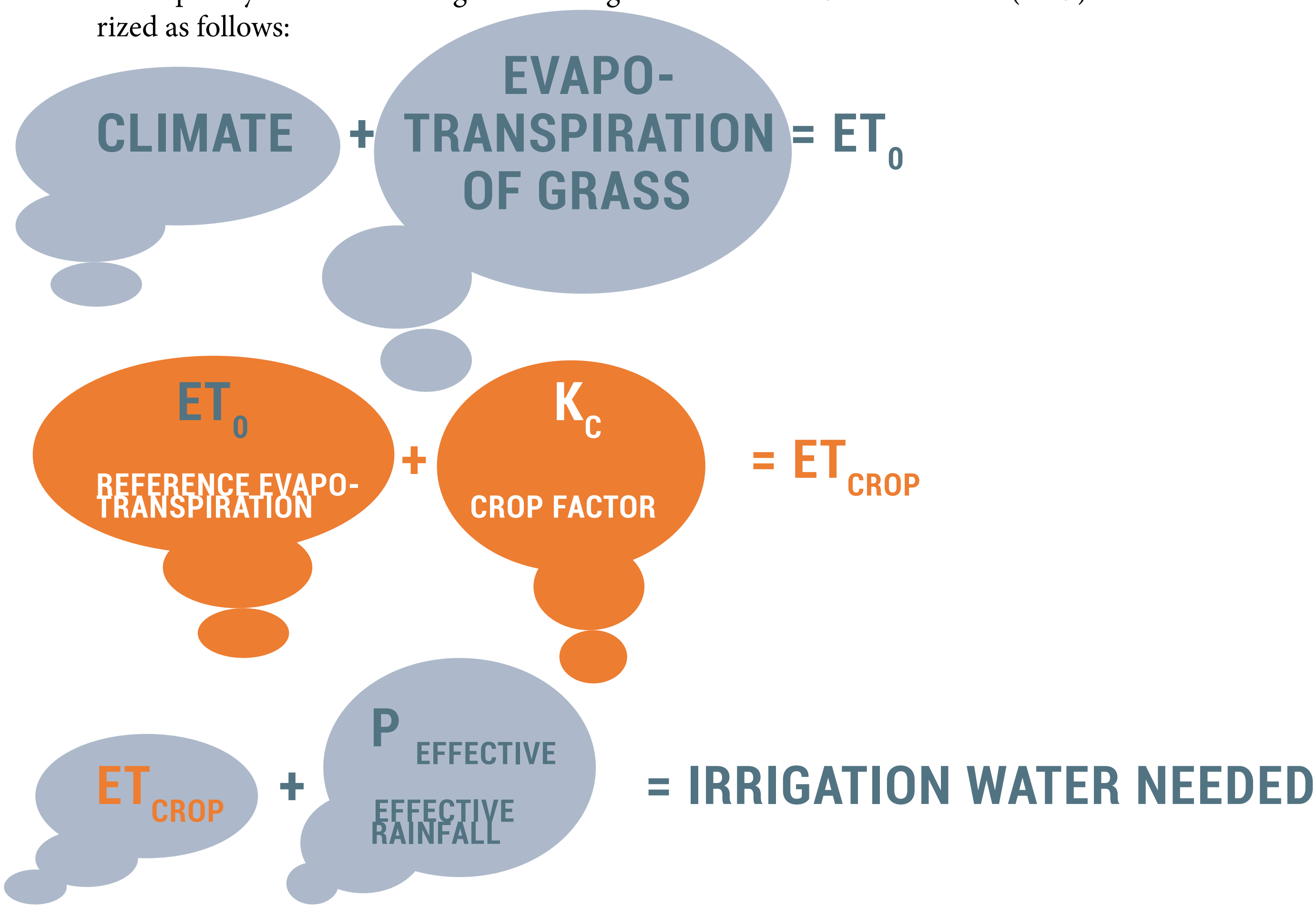
22.1 Definition

Slopeland irrigation supplies water by gravity or mechanical devices, to meet the needs of crops, livestock, and to improve the characteristics of the soil.

22.2 Planning and design

22.2.1 Water requirements

Water required by crops equals the total volume of water transpired/ evaporated from the plant and soil – Evapotranspiration. It varies with soil characteristics, crop types, crop development stage and weather conditions. Complete local records of water requirements of slopeland crops are generally not available in Dominica. A generally acceptable methodology for calculating crop water requirements have been developed by the Food and Agriculture organization of the United Nations (FAO) and can be summarized as follows:



Climate – Agrometeorology data: wind, rain, temperature, humidity, sunlight etc.

Evapotranspiration of grass – Measured evapotranspiration losses from grass that totally covers the soil; is 10 cm tall, actively growing and not short of water.

Reference evapotranspiration – Evapotranspiration value to which another crop evapotranspiration can be referenced.

Crop factor or coefficient–The most basic crop coefficient, K_c, is simply the ratio of ET observed for the crop studied over that observed for the well calibrated reference crop under the same conditions.

ETcrop – refers to the evapotranspiration of the crop being grown within the specific area relative to the reference evapotranspiration.

Peffective or effective rainfall- refers to that depth of rainfall that is not lost to deep percolation or runoff. It is the rainfall that is available for crop use.

FAO has also developed a computer program called CROPWAT to assist in determining crop water requirements. This program allows the user to input local agrometeorological data in order to estimate crop water requirements that is more specific to the location. Table 22-1 provides guidelines for determining seasonal crop water needs. A link to CROPWAT is also provided below:

https://cropwat.informer.com/8.0/

Table 221: Estimates of seasonal water needs for some crops

Crop	Crop water need (mm/total growing period)
Banana	1200-2200
Bean	300-500
Cabbage	350-500
Citrus	900-1200
Maize	500-800
Melon	400-600
Onion	350-550
Peanut	500-700
Pea	350-500
Pepper	600-900
Potato	500-700
Sugarcane	1500-2500
Sunflower	600-1000
Tomato	400-800

22.2.2 Effective irrigation depth per cycle

The depth of irrigation water applied should be determined with due consideration of variations in soil moisture at different parts of the slope, and the optimum water requirement of crops. The calculation of effective depth of irrigation at each application should be made with reference to 1) the availability of effective moisture within the root zone, and 2) absorption ratio in the root zone. The following equation may be used to find out normal consumption of water in any soil stratum:

$$dm = 1/100\ (Fc\text{-}Wp) * Sa * Ed$$

dm= Effective depth of irrigation (mm)

Fc = Field capacity in the stratum (by weight%)

Wp = Wilting point (by weight %)

Sa = Apparent specific gravity of soil in the stratum

d = Depth of the stratum

Normal water consumption in the stratum =

$$\frac{\text{Effective Depth Of Irrigation (Mm)}}{\text{Ration Of Water Absorption By Crops (\%)}} * 100$$

The stratum that renders the smallest value of water consumption, is the critical stratum. The amount of water consumption of this particular stratum is called Total Requirement Of Available Moisture (T.R.A.M.). This amount equals to water required for attaining effective irrigation depth at one application.

Table 222: Peak water requirements of some slopeland crops

Crops	Water requirement (mm/day)
Citrus	4.5
Mango	3.0
Avocado	4.0
Banana	5.0
Pineapple, Guava	3.0
Grassland	2.5
Papaya	3.5
Grapes	6.5

Table 223: Water requirements for livestock

Livestock	Water requirements (litres/day)
Cattle	30
Sheep & Goat	2
Pigs	6
Rabbit	0.7

Table 224: Reference values of field capacity, wilting point and effective moisture for various soil types

Soil Texture	Soil Characteristics		
	Field capacity (%)	*Wilting point (%)*	*Effective moisture (%)*
Sand	2.2 – 3.5	1.2 – 1.7	1.0 – 1.8
Sandy loam	3.5 – 8.5	1.5 – 3.5	2.0 – 5.0
Loamy sand	8.5 – 16.0	3.5 – 7.0	5.0 – 9.0
Loam	13.0 – 22.0	5.0 – 10.0	8.0 – 12.0
Sandy clay loam & clay loam	18.0 – 28.0	7.5 – 15.0	10.5 – 13.0
Silty clay loam & clay	25.0 – 36.0	14.0 – 22.0	11.0 – 14.0

22.2.3 Gross depth of irrigation

D = x 100%

D = Gross depth of irrigation per application

dm = Effective depth of irrigation per application

Ea = Irrigation efficiency

22.2.4 Watering period

N = or Nmin =

N = Irrigation interval (day)

dm = Effective depth of irrigation (mm)

U = Daily use of moisture by crops (mm/day)

Umax = Peak daily use of moisture by crops (mm/day)

Umin = Minimum irrigation intervals in days (day)

22.2.5 Irrigation efficiency

E = Ee*Ea

E = Irrigation efficiency

Ee = Water delivery efficiency (%), Ea = Water supply efficiency (%)

22.2.6 Irrigation water supply planning

V = * A * 10

V = Planned water supply

D = Gross irrigation depth per application (mm)

E = Irrigation efficiency

A = Area to be irrigated (Ha)

SECTION II - **APPROACHES FOR IMPLEMENTATION OF TECHNOLOGIES AND OTHER CONSIDERATIONS AND SUPPORTING INFORMATION ON SELECTED TECHNOLOGIES**

1 Introduction

1.1 SLM Approaches

Numerous approaches have been developed and proffered as being effective at sustainably managing agricultural lands. These approaches, when being implemented, should provide for the identification and addressing of the limiting factors to the achievement of production objectives established within the particular area. The common issue of resource limitation, that often only allow incremental implementation of recommendations must also be considered. The final approach selected should thus provide flexibility for prioritized implementation.

1.1.1 Recommended Approach

Fig 59 summarizes an SLM approach that is highly recommended for adoption in Dominica. It advocates for the mainstreaming of sustainable land management from the very inception of farm enterprise selection, by directing that all farm enterprises be established as a result of cost-effective demand. Incorporation of SLM concepts into the conduct of benefit analysis early, ensure that resource allocation is also adequately considered thus reducing the risk of its exclusion after enterprise establishment.

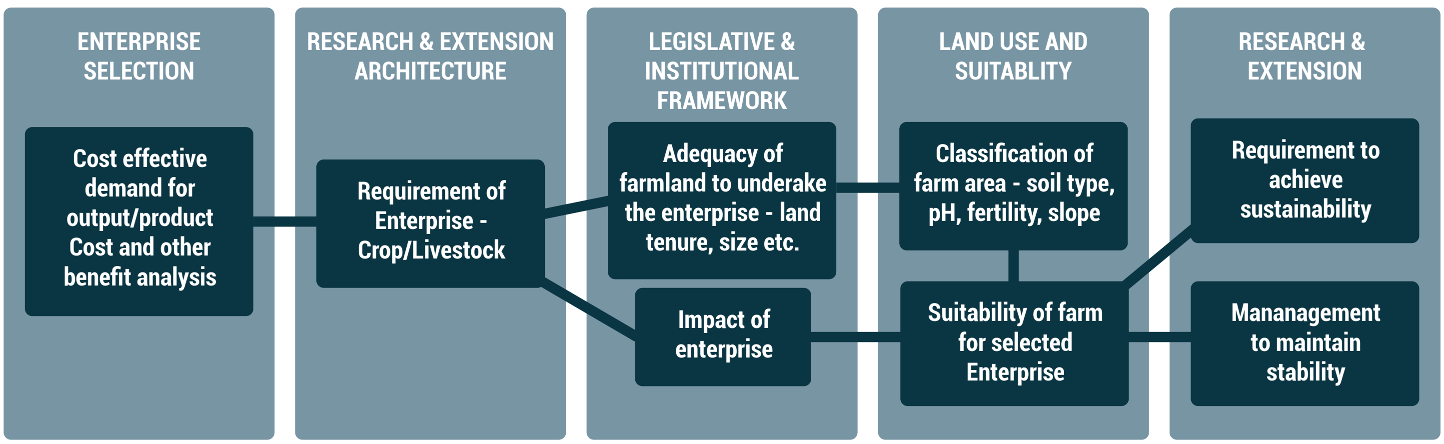


Figure 59: Summary of SLM approach for Dominica

The establishment and institutionalization of an effective research architecture that can be linked to an equally effective "extension" service to provide support for enterprise selection and determination of its requirements is crucial. This institution must be responsive to technological changes and must itself strive to be a change agent. Its operation must be based on a sound scientific approach, uncompromising in integrity.

Adequacy of the selected area to undertake the particular enterprise must be clearly established and guided via an appropriate technical, institutional and legislative framework. So too the impacts of the enterprise. It must be noted that potential impacts often do not just affect the immediate area of operation, but often has the potential to impact entire catchments with cross cutting implications.

The ability to determine the suitability of a given area to support a particular enterprise is an invaluable asset in effecting sustainable land management. This allows not only the saving of resources but also provide for the potential of maximizing returns on investments. The determination of suitability or otherwise also allows for consideration of other elements that can improve suitability if the site is accessed as deficient in the first instance. Management practices and other technologies that can encourage sustainability in suitable sites is also encouraged by this approach.

1.1.2 Participatory approaches

The sustainability of technology development and application is best achieved when there is early and continual engagement between the technology developers and beneficiaries. This observation was also documented by Bunch (1999), who was at the time looking at the adoption and sustainability of soil conservation technologies in Africa and India. The early exposure of the final beneficiaries to the technology allows for opportunities for adaptation to suit local conditions and immediate needs. It may also lead to the total rejection of the technology by beneficiaries opting instead to develop or adopt alternatives. In the same way, farmer participatory approaches have proven to be very successful in introducing new technologies to farmers, who learn by doing and interacting with their peers. Adaptation of new technology during these interactions often lead to greater sustainability and application. These approaches to include farmer field schools, Farmer demonstrations etc., are recommended to introduce the identified SLM technologies to farmers.

2 Understanding slope land cultivation

2.1 Concept of farmland sustainable land management

The primary purpose of sustainable land management is to ensure sustained productivity of land, through conservation of water resources and prevention, reduction or reversal of degradation - soil erosion, landslides debris flows, soil nutrition depletion, biodiversity reduction, organic matter depletion. This objective is to be achieved with the help of agronomic, vegetative and engineering methods.

All soft top soils, when exposed to rains or storms, are subject to erosion. Washed off soil, when carried away by runoff water, will bring pollution and damage upon downstream area. In addition to the maintenance of land fertility, soil conservation should be a major priority of slope land cultivation techniques.

The overall objectives of soil conservation should aim at the following:

(1) promotion of proper land use

(2) Prevention of soil erosion and restoration of the fertility of eroded land

(3) Maintenance of soil fertility

(4) Reduction of water runoff and regulation of water resource

(5) Prevention of water and land pollution caused by carried off soil and debris

(6) Enforcement of safe drainage and irrigation on slope land

(7) Prevention of wind erosion

2.2 What is soil erosion

Soil erosion is a naturally occurring process that affects all landforms. In agriculture, soil erosion refers to the wearing off of a field's topsoil by the natural physical forces of water and wind or through forces associated with farming activities such as tillage. Issues of wind erosion is not currently a serious factor within the local agricultural landscape and is therefore not discussed in details.

2.2.1 Factors affecting the rate of soil erosion

Vegetation, rainfall, soil, wind and topography are the primary factors influencing soil erosion, although other factors may be involved. The kinetic impact of rain hitting the soil causes water erosion. (Laburda T, Zumr D, Kavka P, Neumann M, Devaty J, Balenovic N, et al. 2019). Water erosion will occur when rainfall exceeds a certain value in a single rainfall event.

Vegetation type and coverage can reduce the soil erosion index, the effectiveness of rainfall, and the kinetic energy of raindrops and runoff and lead to different soil bulk densities (Ning Ai, Qingke Zhu, Guangquan Liu and Tianxing Wei, 2020). Splash from raindrops falling on the soil surface may destroy the structure of soil by causing the displacement of soil particles (splash erosion), allowing soil movement and transportation with runoff. Therefore, particle size, bulk density, initial water content, and infiltration properties of soils have important roles in water erosion and soil loss. Topography restricts the types and configuration of vegetation and affects soil moisture, runoff production, and runoff pathways, thus affecting water erosion and soil loss (Ning Ai, Qingke Zhu, Guangquan Liu and Tianxing Wei, 2020).

2.3 Forms of Water Erosion

Rain droplets striking and breaking up soil aggregates followed by the dislodging of the smaller peds can be seen as the commencement of the other forms of water erosion.

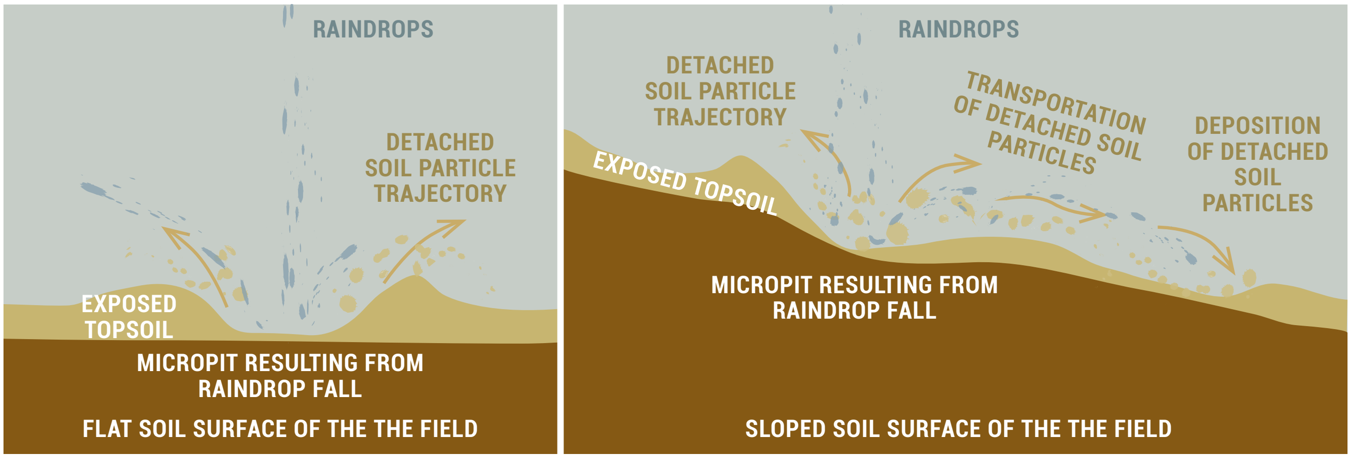


Figure 60: Model of rain splash erosion on flat and sloping soil

2.3.1 Sheet Erosion

Sheet erosion is the movement of soil from raindrop splash and runoff water. It typically occurs evenly over a uniform slope and goes unnoticed until most of the productive topsoil has been lost. Deposition of the eroded soil occurs at the bottom of the slope or in low areas. Lighter-coloured soils on knolls, changes in soil horizon thickness and low crop yields on shoulder slopes and knolls are other indicators. Sheet erosion removes fine particles and organic matter from the soil without leaving any clear traces, although the soil will be deprived of its fertility. It is extremely difficult to rehabilitate soil which has deteriorated in this way.

Figure 61: Sheet erosion in mineral soils
uploaded by **Les Basher**

2.3.2 Rill Erosion

The signs of rill erosion appear mainly on hills, and appears as a 0.3- to 3.9-inch-deep set of channels that run parallel but may converge at some points. Runoff water forms these channels as it concentrates and then flows down a slope, (Roundy 2019)

There is a distinct flow pattern to rill erosion which means that the water runs through these predictable, if disconnected, parallel channels. When water has accumulated on the ground, the film of water becomes runoff. At first, runoff will etch on the ground numerous wrinkles. The wrinkles will deepen into grooves and then gutters. Over time, the soil profile wears down and becomes increasingly thinner with each rainfall. Once the slope tapers off and flattens at the base, soil particles sit there, deposited into a terrace or are carried further into water channels.

Once the channels formed by rill erosion reach four inches, they become gullies. The width, depth, and flow strength of gullies are much more significant. At this point in their development, rill eroded channels displace soil and nutrients, and the sediment carried along can cause some clogging. However, these channels are not yet wide enough to be a significant issue.

Figure 62: Rill erosion

Source: www.Alamy.com

Factors that trigger rill erosion include:

- **Poorly structured soils** — are prone to break up during through the impact of rainfall
- **Nature of the soil itself** — Clay soils, for example, vary in how well they can withstand aggregate raindrop impact
- **Rainfall intensity** — The higher and more frequent rainfall, the greater the risk for soil to seal, preventing water from penetrating below the surface
- **Slope length** — On long slopes, water has more time to collect momentum and soil particles
- **Slope angle** — The angle affects the speed of the runoff, which then increases the power of the water to break of soil particles and carry them through the rills

The most compelling reason to address and curb rill erosion is that it's the first stage of a more severe issue called gully erosion. Once channels reach a depth of four inches, thanks to water flows carving a track in the same place, there's no going back — you've officially entered gully erosion.

2.3.3 Gully erosion

Gully erosion is a highly visible form of soil erosion which can indicate an imbalance in regular watercourse flow. Larger (and faster) than normal water flows cause steep-sided watercourses which then widen further during periods of heavy rainfall. The energy of the water scours away the soil, undermining the vegetation. Once the vegetation and topsoil are removed, gullies spread rapidly up and down drainage lines until there is insufficient runoff to continue the erosion. This type of erosion affects soil productivity, restricts land use, and can damage roads, fences and buildings.

Figure 63: Gully erosion
Photo by Craig Allen - Nardoo Hills in Victoria.

As the water flows with full force through these gullies, the cycle of degradation continues. Soil particles are picked up and deposited elsewhere, causing blockage and siltation in waterways, dams, and reservoirs.

Suspended sediments also include all-important nutrients and pesticides, which then reduce water quality. Once these fine deposits of soil clog groundwater aquifers, they can pollute main watercourses and negatively affect the breathing patterns of aquatic life.

Besides these issues, the harmful effects of gully erosion also include restricted land use, reduced soil productivity, damage to roads, fences, and buildings.

The causes of gully erosion are numerous and includes:

- Cultivating or grazing on soils that previously identified as vulnerable to gully erosion
- Runoff from events like tree clearing in a catchment or construction of new residential areas
- The building of structures like waterways, contour banks, tracks, or roads
- Poorly designed construction or maintenance waterways in cropping areas
- Poor vegetative cover because of issues like brush fires, salinity, and overgrazing
- Diversion of an established drainage line to soils that already have a high risk of erosion, for example, up a steep creek bank or highly erodible soils

Once a gully becomes wide and deep enough, they're a hard problem to fix and heal. If you can catch and repair the land during the early stages of a newly formed gully, you may be able to stop it from spiraling to the point of no return.

3 Characteristics of major soil type

The type of soil on your farm will determine the management practices required to limit soil degradation through erosion and also increase productivity.

3.1 Sand

This soil type contains more than 80 percent sand. In addition to its gritty feel, sand is typically prone to dryness. Grab a handful, and you'll be able to feel the loose single grains. Squeeze a handful of wet sand, and it will take shape, but crumble apart when touched; this is evidence of its large pores. The large size and rounded shape of sand particles allow for fast water absorption and drainage, as well as effective aeration. It's also easy to work with and dig through sandy soil. However, because of the air pockets that exist between sand particles, water rushes through sand, washing away vital nutrients. It is also very highly susceptible to erosion from both water and wind. It therefore requires diligent management to ensure that it remains constantly protected from the external elements.

3.2 Loamy sand

Loamy sand feels gritty; and contains a range from as low as 70 to 85 percent sand, to as much as 85 to 90 percent sand, with the remaining mineral composition silt and clay. About a quarter of the sand is a mix of very coarse, coarse, and medium sand, and less than half is very fine or fine sand. This combination results in soil that is highly permeable to water and air. However, because it doesn't hold very much water or nutrients, loamy sand tends to need frequent irrigation and fertilization and is also very prone to erosion. Addition of organic manure improves fertility and also the water holding capacity of loamy sand. It is necessary to maintain permanent cover and other water diversion measures to control erosion

3.3 Sandy loam

Defined by a composition that's at least 50 percent sand particles, sandy loam is balanced by varying concentrations of clay and silt. It has a somewhat gritty texture, depending on the ratio of sand to clay and silt, and should form a one- to two-inch-long ribbon that breaks easily when mixed with water and squeezed between two fingers. Because of the comparatively large size of sand particles, water and air can usually move freely through sandy loam. This helps ensure good drainage without too much nutrient runoff, though it also means that sandy loam soils with less clay can struggle to hold enough water or nutrients and so benefits significantly from organic matter addition.

3.4 Silt loam

This texture consists mostly of silt size particles (.05 to. 002 mm), and when the moist soil is rubbed between the thumb and forefinger, it is loamy to the feel, thus the term silt loam. When it is dry, clods are moderately difficult to break and rupture suddenly to a floury powder that clings to fingers; shows fingerprint. When moist it has a smooth, slick, velvety, or buttery feel; forms firm ball; may ribbon slightly before breaking; shows good fingerprint. Silt-sized grains also contain nutrients and help make a soil workable.

3.5 Loam

Loam soils have a mixture of sand, silt and clay in relatively equal amounts, and generally contain more nutrients, moisture, and humus than sandy soils, have better drainage and infiltration of water and air than silt and clay-rich soils, and are easier to till than clay soils.

3.6 Clay loam

Clay loam combines about 20 to 40 percent clay with near equal parts sand and silt. It has a medium texture, and it feels somewhat smoother and more powdery than sandier soils. Clay is the smallest of the three soil textures, measuring under .002 millimetres in diameter, and has numerous small pores, which slows down water movement and can lead to oversaturation if not irrigated carefully. Additionally, dry clay has a tendency to form solid chunks or layers, called pans, that are tough to break apart. As a result, clay loam soil can suffer from lack of aeration and root growth. However, clay's high surface area helps it retain nutrients, so clay loam may need less fertilizer than other types.

3.7 The effects of soil type on soil management

Managing soil differs from type to type, because of the qualities elaborated above, which is why it's useful to take soil type into account when looking at readings and data from soil probes. Each snapshot of the soil can be qualified with information about porosity, water-holding capacity, nutrient-holding capacity, erodibility, and root penetration. This can lead to decisions about soil management that wouldn't be obvious without the combination of knowledge of soil type and individual data from a farm.

For example, in sandy loam, loamy sand, and sandy soils, low-nutrient readings could mean that the soil needs a boost from organic matter like compost. In sandy soils, the organic matter can change the nature of the particles so that they can hold more nutrients, improving soil fertility.

Sandy soils are also at risk of becoming acidic. This can happen slowly, simply because of irrigation that causes nutrients to leach out of the root zone. Or, it can happen more quickly because of the use of certain fertilizers. The chemistry of acidic soils puts them at risk for aluminum toxicity, and so farmers with acidic soils use lime additions to raise the pH.

3.8 Contour farming

Contour farming refers to the practice of tilling (the preparation of soil for planting and the cultivation of soil after planting) sloped land along lines of consistent elevation in order to conserve rainwater and to reduce soil losses from surface erosion. This farming method consists of row patterns nearly level around a hill – not up and down hill. The rows form small dams that slow water flow and increase infiltration to reduce erosion. These objectives are achieved by means of furrows, crop rows, and wheel tracks across slopes, all of which act as reservoirs to catch and retain rainwater, thus permitting increased infiltration and more uniform distribution of the water.

This method replaces the practice of Straight-line planting in rows parallel to field boundaries regardless of slopes that was imported from Europe and long remained the prevalent method utilized in our early agriculture. Efforts by the colonial estates managers to introduce erosion control measures coincided with the promotion of contour farming by the US Soil Conservation Service in the 1930s as an essential part of erosion control. (Eds. of Encyclopaedia Britannica, 2019).

Contour farming practice has been proven to reduce fertilizer loss, power and time consumption, and wear on machines, as well as to increase crop yields and reduce erosion. Contour farming can help absorb the impact of heavy rains, which in straight-line planting often wash away topsoil. Contour farming is most effective when used in conjunction with such practices as strip cropping, terracing - step formation along the contour to reduce water velocity down slope, water diversion – drainage, mulching and other crop cover.

3.8.1 Establishment of contours

The "how to" of various low-cost methods of establishing contours have been presented in section 1. Other methods of establishment are also available. Table below highlights some of the more common methods that can be used and compare and contrast some of the characteristics of each method.

Table 31: Comparison of recommended contour levelling methods

Method	Distance (m)	Accuracy	Remarks	People, equipment
A-frame	4	Medium	Awkward to transport	1 or 2 people, mason's level
A-frame, plumb line	4	medium to high	Fast to use	1 or 2 people, plumb line
Flexible tube water level	10 to 15	High to very high	Awkward to transport Very quick Avoid water loss	2 people, 2 measuring scales
Line level	20	Medium	Very easy to transport Quick to operate Useful on rough ground	3 people, mason's level 2 measuring scales
Surveyor's level	more than 100	Very high	Expensive, delicate	2 people, 1 levelling staff
Abney level	100	Low - medium	Quick, rather good estimate Direct reading in degrees and percent	2 people, target levelling staff
Semi-circular level	100	Medium to high	Faster for longer distance	2 people, target levelling staff
Optical Clinometer	10 to 15	medium to high	Quick, rather good estimate Direct reading in degrees and percent	2 people, levelling staff

4 Soil erosion management strategies

4.1 Agronomic management strategies

Suitable strategies for agronomic soil conservation include agronomic management measures designed to prevent the loss of soil through erosion, or from becoming physically or chemically altered through abuse. Examples of such measures include mulching and other crop management that utilized the effect of surface covers to reduce erosion by water and wind. It is generally recommended that technologies are so selected to provide maximum complementary benefits such as improvement in soil structure, nutrition, shading, support etc. Further, selected technologies must be easily adapted to suit local conditions and fulfil the characteristics established in report 1 to include:

a) Have the potential to increase land productivity in the short-term

b) Have a relatively short establishment time

c) Highly cost effective

d) Easy to learn

e) Reliant on locally-available and inexpensive inputs

The approaches that enable and empower people to:

- implement, adopt, spread and adapt best practices.
- Priority will be given to approaches that can be readily adapted to local conditions
- Characterized as inclusive and people-centered.
- Foster multi-stakeholder involvement, be gender considerate, multi-sectoral, oriented to capacity building and organized promotion of the SLM agenda.

4.1.1 Mulching

Objective

The main objective of this technology is protecting the soil from the negative impacts of water and wind, while providing complementary benefits of reduction in weed growth, water loss, increasing microbial action, and increasing organic matter and nutrition content in some cases. Mulching also aids in the management of soil temperature.

Application of mulching

Mulching is applied in situations where:

- Runoff and soil losses are high
- An increase in soil organic matter, reduction of evaporation is required
- Suppression of weeds is required
- Management of soil temperature is required.

The use of plastic or polyethylene material as mulch, results in only some of the benefits listed above. Particularly, these materials result in reduction in organic matter and an increase in runoff. This translates into the need to provide for adequate drainage measures.

Cover crops and other grasses planted to protect terraces or to serve as live barriers are ready sources of organic mulch. So, to are various crop residues left over after harvesting. All large crop residues or plant parts should be cut into smaller pieces before application. Due attention must be directed to pest and disease control and also to the suppression of mulch becoming a fire hazard.

The table below highlights some of the common organic mulching materials that can be used and their benefits.

Table 41: Beneficial effects of various Organic Mulches

Types of mulch	Beneficial effects
Straw mulch, **C.**zizanioides or Vetiver, Residues of Zea mays (corn)	Reduction of splash effect of rain, Decrease of runoff velocity, Reduction of soil loss
Straw of *Oryza sativa* (rice), Straw mulch, Leaves of *Phyllostachys bambusoides* (bamboo), Residues of Z. *mays*	Decrease of soil bulk resistance, Penetration resistance
Grass & Wood shavings	Increase of size + stability of soil aggregates, increase of infiltration capacity, hydraulic conductivity
Straw of O. sativa, Straw mulch, Leaves of P. bambusoides, Vetiver, Residues of Z. mays,Cenchrus purpureus-elephant grass (non- flowering stage)	Increase of soil moisture, Decrease of soil temperature
Gliricidia sepium, Leucaena leucocephala, stover of Zea mays, straw of O. sativa	Increase of activity and species, diversity of soil flora and fauna
Straw of O. sativa, Vetiver	Suppression of weeds
Stover of Z. *mays*	Increase of organic matter + nutrient content, increase crop yield

Both methods (organic and inorganic) of mulching are practiced locally. Plastic mulches and other synthetic weed barriers are widely applied in pineapple and protected vegetable production primarily to prevent or retard weed growth. Organic mulching is also practiced in banana, plantain and other field vegetable production particularly during the dry season to reduce moisture and soil lost, reduce weed growth, and improve microbial hence organic matter availability. Appropriate pest control strategies especially relating to snails, slugs and rodents must be evaluated for incorporation into production systems when mulches are used.

4.1.2 Crop Management systems

The common practice of intercropping e.g., planting tannia (*X.sagittifolium*) or pumpkins (*Cucurbita pepo*) with bananas and plantains is one such example where the lower tier crop benefits from the shading provided by the taller plant, whereas the cultivation of the tannia/ pumpkin benefits the banana or plantain. Plantain and Banana has also become the shade crop of choice (due to ease of establishment) for the establishment of Cocoa crop which requires shading during its early stage of growth. The supply of sufficient nutrients to meet the crop requirements within these systems is often a point of concern. The total quantity of nutrients that ought to be provided must be the sum of that required for each crop independently.

Intercropping & Mix cropping

Coconut and or Citrus interplanted with bananas / plantain and other annuals and perennials are also popular combinations locally. Coconut /citrus seedlings are planted 20 to 30 feet apart. The wider spacing between the crops gives grower an opportunity for raising other crops, either annuals as intercrop or perennials as mixed crop as a source of additional income. When annuals are grown in the interspaces of coconut palms, it is designated as *inter-cropping* and when perennials are grown, it is called *mixed-cropping.*

Advantages of Intercropping or mixed cropping

1. Reduction in soil erosion and controls pests and weeds;
2. Intercropping with cash crops affords higher profitable;
3. It acts as an insurance against failure of crops in abnormal year;
4. Inter-crops maintain the soil fertility as the nutrient uptake is made from both layers of soil;
5. Inter-cropping gives additional yield income/unit area than sole cropping;
6. It helps to avoid inter-crop competition and thus a higher number of crop plants are grown per unit area;
7. Inter cropping system utilizes resources efficiently and increases the productivity
8. Intercrops provide shade and support to the other crop.

Cover crops

The system of using cover crops is generally not practiced locally though a number of the plant species that are recognized as cover crops in other jurisdictions are available locally. The benefits of this system are invaluable, especially in situations where land degradation reversal is intended. Cover crops selection are primarily based on the main crop that is being grown and the objectives of using the cover crop.

Fallows

The practice of allowing land to lie fallow as a planned strategy for addressing land degradation has proven to be quite challenging locally. This is particularly due to small farm acreages that characterize the majority of farmers. Generally, varying systems of crop rotations are practiced with relatively short fallow periods. Two possible approaches that can be adopted in improve fallows include the planting of plants species considered to be green manures, and the planting of species with other specific plant protection characteristics.

Improved Fallows – Green manure

Objectives

The main objective of utilizing this technology is to increase organic matter and nutrients in the soil, and also to improve the physical and chemical characteristics of soil, increasing resistance of soil to degradation.

Why utilize green manure?

Long fallow periods that were part of the traditional shifting cultivation system practiced by the forebears for encouraging soil regeneration are no longer possible. Land availability is generally a constraint to this practice and thus the practice of improved fallows of short periods with selected plant species as green manure is recommended as an alternative to benefit soil regeneration. Green manure crops may be grown to improve sandy soils, heavy clay, and every type of unproductive soil. They may also be grown between rows of existing crops.

Some examples of plant species that can be utilized in improved fallows and their benefit includes:

Guinea grass (*Megathyrsus maximus*)

Previouslycalled (*Urochloa maxima* and *Panicum maximum)*. It was moved to the genus *Megathyrsus* in 2003. It is fast growing and produces a large volume of organic matter that can be applied to the soil thereby encouraging increase soil microbial biodiversity. It's a high-quality ruminant feed source being suited to both grazing and cut and carry system; It's also drought tolerant.

It does not perform well on severely degraded soils and is intolerant of waterlogging

Shrubs of woody plants such as pigeon pea (*Cajanus cajan*)

Advantageous in improving the physical soil conditions due to the penetration of their roots into deeper soil layers

It has deep tap roots hence it can tolerate drought and poor soil conditions. It is an efficient nitrogen-fixing species when growing conditions are favourable.

Leucaena leucocephala

Increase the N content and change the quantity of available P fractions in the soil. it can be planted and managed in a variety of systems, such as in balanced pasture-forage systems, or in hedgerows to control erosion in fields, or as a windbreak, fence or boundary marker around the house or field. Leaves can be applied as nutrient rich fertilizer.

Macuna pruriens

Referred to as "cow-itch" or velvet beans (*M. pruriens)* is an annual shrub that grows long vines. Velvet bean display some drought tolerance and is an excellent green manure or cover crop with ability to suppress weeds and provide generous amounts of organic matter and nitrogen for the soil.

Pueraria phaseoloides

It is known tropical kudzu in most tropical regions. It Increases the N content and change the quantity of available P fractions in the soil. It is a forage crop and a leguminous cover crop used in the tropics.

The possibility exists for some of these plant species to become invasive as such careful assessment must be undertaken prior to their introduction to include management strategy.

Planting time and pattern

The manipulation of planting time and pattern, while practiced, is not primarily done for the purpose of soil conservation, but as a response to environmental conditions and plant requirements. It can however be utilized as an effective soil and water conservation method. Cropscan be planted at close spacing or at a time to provide a higher canopy during periods with high rainfall intensities. These actions can help protect the soil from erosion.

Multiple Cropping

Multiple cropping involves different kinds of systems depending on the temporal and spatial arrangement of different crops on the same field.

Agroforestry is a collective name for the land use system in which woody perennials are integrated with crops and/or animals on the same land management unit. Alley cropping – Trees & Shrubs usually planted along cropped plot boundaries as in fig. 63is a form of agroforestry. Agroforestry technologies will be examined in more details in chapter 5 under the section alternate SLM technologies.

Figure 64: Example of Alley cropping – Pineapples and Mangoes (Layou Park Dominica)

4.1.3 Conservation tillage

Tillage operations impacts soil properties through pulverization, crushing or compacting, altering bulk density, pore size distribution and composition of the soil atmosphere that affect plant growth. Appropriate tillage practices however, are those that avoid the degradation of soil properties but maintain crop yields as well as ecosystem stability. Lal 1983 and Parr *et al*. 1990 concludes that conservation tillage provides an opportunity for addressing land degradation and improving soil productivity.

No tillage, minimum tillage, reduced tillage and direct drilling are terms synonymous with conservation tillage. The main characteristic of conservation tillage incorporates crop production systems involving the management of surface residues (Carter, 2005).

The main characteristics of the four main types of conservation tillage namely: mulch tillage, ridge tillage, zone tillage, and no-tillage are listed in table 4-2.Conservation tillage can provide several benefits for agricultural systems such as soil conservation, economic advantages associated with reductions in crop establishment time and energy use, reduction in soil sheet erosion and nonpoint pollution, and enhanced storage or retention of soil organic matter and improvement of soil quality at the soil surface.

Table 42: The dominant types of conservation tillage used in agricultural systems

Form of tillage system	Some other terminology used	Main characteristics of the tillage system
Mulch tillage	Stubble mulching, trash farming, sod farming, live mulch system	Some form of full-width shallow primary tillage used prior to crop planting. High percentage of crop residues retained at the soil surface
Ridge tillage		Primary tillage confined to formation of raised ridges or beds in rows often on a contour. Planting occurs on the ridges
Zone tillage	Strip	Primary partial-width tillage for row crops confined to bands, separated by bands of undisturbed soil, to form a seedbed for each row
No-tillage	Direct seeding, zero tillage	Soil undisturbed with no primary or secondary tillage. Crop seeded/planted directly into the soil

The no-till system of cultivation with crop residue mulches forms a basis for conservation farming because it conserves water, prevents erosion, maintains organic matter content at a high level, and sustains economic productivity. Antap and Angen (1990) reported that retaining crop residues on the soil surface with conservation tillage reduces evapotranspiration, increases infiltration rates, and suppresses weed growth.

Emphasis will now be placed on the conservation tillage methods that are more applicable to agriculture within the local context, characterized by relatively small farm size and high dependence on manual labour for accomplishment of tillage and cultivation practices.

4.1.3.1 Mulch Tillage

This technique is useful on many different soil types inclusive of poorly drained soils. The increased surface roughness of this method reduces erosion and benefits greater infiltration than that in conventional tillage.

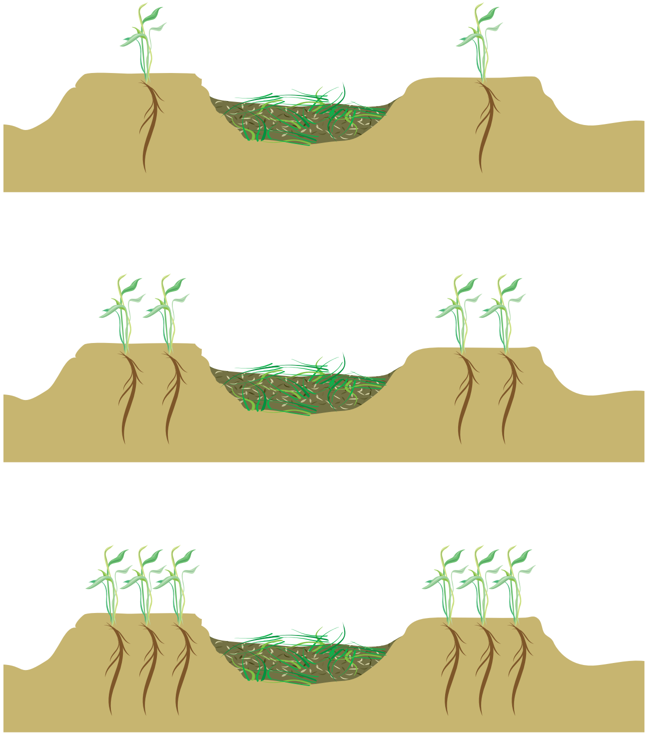
Mulch tillage is the conservation tillage method that is considered to be most similar to conventional tillage. The labour / equipment requirements are similar and so it is usually the method selected by farmers moving away from conventional tillage.

Figure 65: Mulch tilled field with the incorporation of chemically killed cover crop
Source: Ohio State University

Crop residues must be inspected to ensure that they are free from pests and diseases before being incorporated. In cases where the residues are or may be diseased it is advisable to exclude these residues. Residues must first be chopped/minced into smaller bits prior to incorporation. Mulch tillage must be appropriately managed or wholly excluded from soils that are traditional wet as the crop residues tend to conserve additional moisture and encourage fungal and bacterial infection.

Figure 66: Mulch tillage utilizing corn residue

4.1.3.2 Ridge Tillage



Ridge tillage works well with row crops such as corn, vegetables and other grains.

Figure 67: Illustration of crop establishment with ridge tillage

Advantages

Controlled Traffic:

After ridges are established, all field traffic is confined to the furrows between the ridges. Restricting traffic to the same middles each year may prevent soil compaction from occurring in the area of root growth. However, if previous traffic or tillage operations ‘have created a compacted zone severe enough to reduce root growth, measures should be taken to eliminate the compaction before ridges are constructed.

Crop Residue Management.:

Ridge-till is considered to be a form of conservation tillage since over 30% of the residues remain on the surface after planting. By the time cultivation is necessary, the crop canopy is able to buffer the impact of intense rainfall. After harvest, all crop residues remain on the surface until the following planting.

Water management:

Planting on ridges with the crop residue removed only over the seed allows the soil to retain more moisture during dry season and also encourages drainage from around the root zone especially of vegetable crops during the rainy season.

Improved weed control:

Herbicide and other mechanical means can be utilized with greater ease. Scraping of the top of the ridge removes weeds and deposits it into the furrows away from the crop. Chemical weed control and other methods can then be utilized with greater ease to effect weed control. Cultivations are relied upon to control weeds that emerge between the rows.

Disadvantages

Specialized Equipment Needs:

Converting to ridge-till planting involves adapting or replacing conventional tillage equipment if mechanical means are being used. These translates into high upfront cost. High initial labour cost for initial establishment of the ridges also occurs for manual operations. These when amortized over the 2- 3 years that the ridges are expected to be cultivated without a fallow period, is not limiting.

Permanent Row Width:

Once ridges are established, the row width for all future crops are locked in. Farmers that prefer to plant crops in narrow rows have found it difficult to construct and maintain ridges on less than 30 inches spacing. Ridges may also limit the practicality of crop rotation that involves the seeding of particular crops.

Potential Erosion Problems:

Properly managed, ridge-tillage should provide adequate soil erosion control on gentle slopes - 0-4% (Ditsch, 1986) As the slope increases in steepness, the potential for water to concentrate in the furrow and develop into gullies is greater, see fig 68. To prevent gully erosion from taking place, ridges would have to be built following the natural contour. This may limit the total area that can be cultivated. Improper construction of ridges and furrows and non-inclusion of appropriate drainage structures such as lined step drains can also lead to convergence of water to one area leading to overtopping and flooding (fig 67 B) and severe erosion at the edge of ridged farmland fig 68.

Figure 68:Gullying within ridge farmland &overtopping and flooding of ridges

Figure 69:Severe erosion on tail end of ridged farm land

4.1.3.3 No-till

No-till farming (also known as zero tillage or direct drilling) is an agricultural technique for growing crops or pasture without disturbing the soil through tillage – the turning over of the top 6 inches of the soil. No-till farming decreases the amount of soil erosion tillage causes in certain soils, especially in sandy and dry soils on sloping terrain.

Spears (2018), explains that from a soil perspective, the benefits of no-till farming far outnumber those of tillage-based systems. No-till practices allow the soil structure to stay intact and also protect the soil by leaving crop residue on the soil surface. Improved soil structure and soil cover increase the soil's ability to absorb and infiltrate water, which in turn reduces soil erosion and runoff and prevents pollution from entering nearby water sources.

The rate of moisture evaporation is significantly reduced in no-till systems, which not only improves infiltration and storage of rainwater, but also increases irrigation efficiency, ultimately leading to higher yields, especially during hot and dry weather.

Soil microorganisms, fungi and bacteria, critical to soil health, also benefit from no-till practices. When soil is left undisturbed, beneficial soil organisms can establish their communities and feed off of the soil's organic matter. A healthy soil biome is important for nutrient cycling and suppressing plant diseases. As soil organic matter improves, so does the soil's internal structure—increasing the soil's capacity to grow more nutrient-dense crops.

Benefits:

- No-till dramatically reduces soil erosion.
- Crop residue remains on the soil surface and thus protects the soil from most of the damages caused by wind and rain.
- Crop residue on the soil surface reduces runoff and retains moisture.
- No-till helps build organic matter and thus a encourages healthy soil biome.
- Using existing row and planting patterns for controlled traffic through the plot helps eliminate compaction within cropped areas.

Considerations:

- No-till requires skillful management.
- No-till restricts the farmer to surface-applied herbicides.
- For best results, fertilizers should be injected or banded. This is particularly true for nitrogen, especially for those forms that are volatile.
- Weed control is primarily dependent upon herbicides. And manual control

4.1.3.4 Strip or Zone till

For the establishment of certain crops especially root tubers and rhizomes e.g., Root crops tillage may be necessary within the areas where the plants are established. Strip or Zone till, is recommended.

Strip till is a field tillage system that combines no till and full tillage to produce row crops. Narrow strips 6 to 12 inches wide are tilled within crop stubble, with the area between the rows left undisturbed.

Benefits:

- Herbicides are often applied in a band or strip, reducing the total amount applied.
- The clean strip may provide better seed-soil contact for small seeds.
- Strip-till requires a significantly reduced effort to prepare the field compared to conventional tillage.
- Controlled traffic means reduced compaction in the growing area.
- Considerations:
- The clean strips are more erodible than soil that is covered with residue; contour farming is recommended on slopes.
- Specialized equipment may be needed to provide the clean strips.
- Soil moisture requirement at planting time may be more critical, and soil structure may be damaged by improper operations.

5 Windbreaks

5.1 Objectives

- To control wind erosion on exposed land.
- To reduce physiological or mechanical damage to crops caused by strong winds.
- To reduce evapotranspiration and thus irrigation requirement.
- To reduce salt damage especially on the Atlantic side of Dominica.

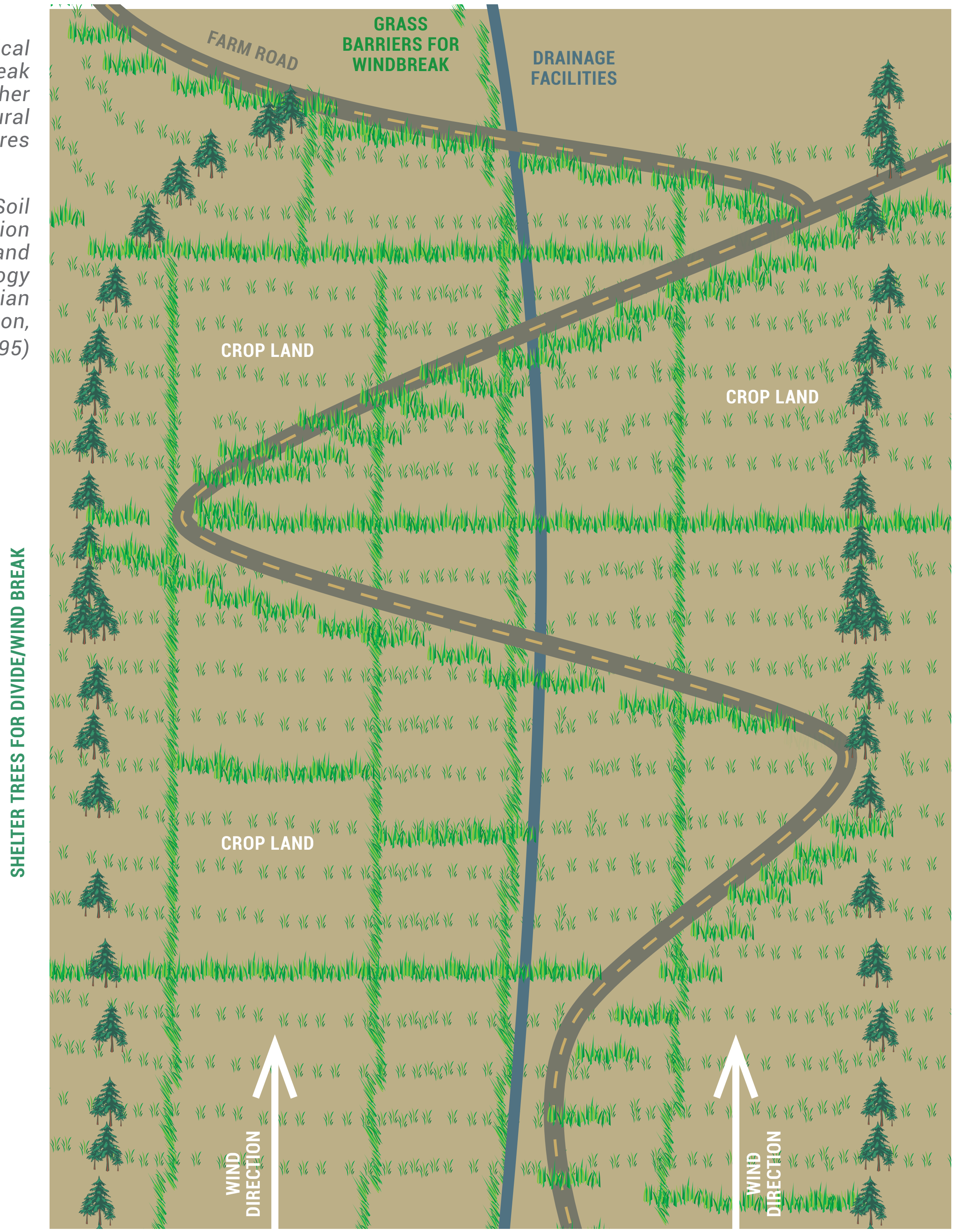


Figure 70: Typical on-farm wind break layout with other infrastructural features

Source: Soil conservation handbook, Food and fertilizer technology center for the Asian and Pacific region, 1995)

5.2 Application

Wind breaks are typically applied on slopes affected by wind erosion or where strong wind prevails. It is particularly useful when farm enterprises with crops or livestock that are particularly susceptible to wind damage – physiological or mechanical, are being produced, e.g., vegetables. Apiaries and flowers.

5.3 Maintenance

Fresh seedlings should be planted to replace any dead plants. Pruning to attain optimized shape and rapid initial growth should be done specific to the plant characteristics. For bamboo windbreaks, unnecessary branches or stalks should be removed in order to encourage the growth of small, dense twigs which will give better protection against the wind.

For grass windbreaks, additional shrub screens can be erected to provide additional resistance to wind.

The roots of shelter trees must not be allowed to interfere with the growth of crops. A ditch should be dug between the shelter and the crop, to prevent the roots of the barrier trees from spreading. The branches of the shelter trees should be pruned if they adversely affect the growth of crop.

6 Agroforestry

Agroforestry is an integrated approach of deliberately using the interactive benefits from combining trees and shrubs with crops and/or livestock. It combines agricultural and forestry technologies to create more diverse, productive, profitable, healthy and sustainable land use systems. In agroforestry systems, trees or shrubs are intentionally used within agricultural systems, or non-timber forest resources are cultured in forest settings. It may include existing native forests and forests established by landholders

Agroforestry systems can display notable advantage over conventional agricultural and forest production methods through increased productivity, diversified economic benefits, social outcomes and the ecological goods and services provided. Agroforestry incorporates at least several plant species into a given land area and creates a more complex habitat that can support greater biodiversity to include a variety of birds, insects, and other animals.

The resulting biological interactions provide multiple benefits, including diversified income sources, increased biological production, better water quality, and improved habitat for both humans and wildlife.

Agroforestry also has the potential to help reduce climate change since trees take up and store carbon at a faster rate than many crop plants. (Ramesh & Jain, 2010)

6.1 Objective

to increase the productivity of associated crop and livestock systems, leading to more diverse and sustainable production systems and better income, while protecting the environment.

To manage land efficiently so that its productivity is increased or restored.

To address soil erosion, conserve soil moisture and increase soil fertility

To conserve or improve biodiversity, including the genetic diversity of plant and animal species, through sustainable management and conservation of forests and trees; thus, ensuring the continuation of ecological services.

6.2 Benefits of agroforestry

1. Control runoff and soil erosion, thereby reducing losses of water, soil material, organic matter and nutrients.
2. They can maintain soil organic matter and biological activity at levels satisfactory for soil fertility. This depends on an adequate proportion of trees in the system- normally at least 20% crown cover of trees to maintain organic matter over systems as a whole.
3. They can maintain more favourable soil physical properties than agriculture, through organic matter maintenance and the effects of tree roots.
4. They can lead to more closed nutrient cycling than agriculture and hence to more efficient use of nutrients. This is true to an impressive degree for forest garden/farming systems.
5. They can check the development of soil toxicities, or reduce exiting toxicities-both soil acidification and salinization can be checked and trees can be employed in the reclamation of polluted soils.
6. They utilize solar energy more efficiently than monocultural systems different height plants, leaf shapes and alignments all contribute.
7. They can lead to reduced insect pests and associated diseases.
8. They can be employed to reclaim eroded and degraded land.
9. Agro forestry can augment soil water availability to land use systems. In dry regions, though, competition between trees and crops is a major problem.
10. Nitrogen-fixing trees and shrubs can substantially increase nitrogen inputs to agro forestry systems.
11. Trees can probably increase nutrient inputs to agro forestry systems by retrieval from lower soil horizons and weathering rock.
12. The decomposition of tree and pruning can substantially contribute to maintenance of soil fertility. The addition of high-quality tree prunings leads to large increase in crop yields.
13. The release of nutrients from the decomposition of tree residues can be synchronized with the requirements for nutrient uptake of associated crops. While different trees and crops will all have different requirement, and there will always be some imbalance, the addition of high quality prunings to the soil at the time of crop planting usually leads to a good degree of synchrony between nutrient release and demand.
14. In the maintenance of soil fertility under agro forestry, the role of roots is at least as important as that of above-ground biomass.
15. Agro forestry can provide a more diverse farm economy and stimulate the whole rural economy, leading to more stable farms and communities. Economics risks are reduced when systems produce multiple products.

6.3 Applicability

The application of Agro-forestry systems will become relevant in the following situations within the local agricultural landscape;

Degraded land reclamation: Soils that have been degraded after years of misuse can be reclaimed by the establishment of appropriate plant species, to include plants that are tolerant to the particular limiting factor within the area.

Slopes with high susceptibility to erosion: The systematic spatial establishment of particular types of plant species can serve as physical barrier to downslope movement of water, reducing its velocity and so its erosive power. Multi-level plants also act to intercept raindrops and so its impact on the surface of the soil.

Wind swept production area with high exposure: Plants with upright growth patterns and dense canopy strategically positioned are able to serve as wind breaks and shelter for cash crops, livestock and other farm enterprises.

Low fertility production area: Planting plant species with high generation of organic material that can be applied to the soil to improve soil fertility. The establishment of specific legumes with nitrogen fixing bacteria nodules to fix nitrogen in the soil. There are also some plants that are able to cause nutrients in the soil to become more available, reaching deep into the profile to recycle nutrients that would otherwise be unavailable.

Production areas with low soil permeability, high water table: The roots of plant species with particular characteristics are able to break through restrictive soil layer to access nutrient stores

Diversification of farm income: Agroforestry advocates for the establishment of different plant species with varying production cycle, maturity and output. This allows for effective utilization of space (vertical and horizontal) and income from various sources thereby protecting against income loss from failure from one crop.

Diversification of bio-diversity: Varied plant species with different complementary characteristics are usually part of this system. This encourages a more complex varied ecological system usually with reduced pest and disease pressures.

6.4 Common agroforestry systems

1. Agri silvicultural system (crops – e.g., annual crops and vines – plus trees)

The system is the planting of trees among crops known practices such as dispersed interplanting, trees with perennial crops and alley cropping.

a. Alley cropping

Alley cropping is the growing of annual crops or forage between rows of trees or shrubs to form hedgerows. This practice improves soil characteristics and fertility, alley cropping can be done in areas with flat to gently rolling terrain.

Examples of shrubs to be grown with crops include *Sesbania sesban, Gliricidia sepium*or

Calliandra species.

The benefits of alley cropping include:

- Controls soil erosion
- Trees shelter crops from wind damage
- Trees sequester carbon dioxide

b. Trees with perennial crops

Trees can be grown in combination with other perennial crops such as coffee, sugarcane and tea. This system provides land use with strong build up soil, organic matter, multiple or intercropping, mulch and extended rotation, because crops are permanent there is little replanting. Hence there is minimal disturbance of soil and thereby, more carbon is sequestered in the soil.

c. Wind breaks

Wind breaks or shelter, are planted to slow down wind speed. The trees should be of different heights, and should be planted alongside bushes and grasses. Wind trees should not have gaps as wind can be channeled through the gaps creating a destructive tunnel of high winds.

A good knowledge of your farm wind direction is important so that you can plan your windbreaks to make sure you protect fruit trees, vegetables and other areas.

Other agroforestry technologies listed below inter alia:

- multipurpose trees in croplands,
- plantation–crop combinations,
- home gardens,
- trees for soil conservation and reclamation,
- and improved fallows are all represented and examined within other sections of this manual and will not be here repeated.

2. Agro-silvopastoral systems (trees plus crops plus pasture and animals)

    a. apiculture with trees

This agroforestry technology holds tremendous potential for further expansion within the context of local agriculture. The existence of extreme sloping land with high sensitivity to continued access and or further cultivation, can be developed with appropriate flowering species that provide food forest to foraging bees. Given that bees can forage up to an average distance of 6.1 km or 3.8 miles, (Beekman, & Ratnieks, 2000), these food forest need not be in the immediate vicinity of the bee farm.

Establishing and managing an Agro-silvopastoral system

The establishment of an agroforestry system involves, among other things, site preparation, plant and animal material selection, planting, cultivating, and marketing. The availability of suitable materials and adequate financial and technical inputs is crucial. The nature of site preparation varies according to the characteristics of the selected plot and agroforestry system. It will generally include some form of land preparation (e.g., land clearing, preparing holes for planting seedlings, or weeding around and protecting naturally regenerated seedlings), and also more extensive works, such as terracing or other soil conservation measures, fencing against stray animals, and general cultivation – weeding, fertilizer application, pest and disease management etc. Such more extensive works may require specific machinery and tools, which centrally procured from private operators or central government.

The selection of plants and animal inputs are also significant elements in the success of agroforestry establishment.

1. Tree seedlings can be purchased from commercial nurseries (Forestry and Division of agriculture) or produced by the land owners/managers themselves, depending on needs and situations. Smallholders may be able to purchase tree seedlings at competitive rates from local nurseries. In some cases, it may be possible to transplant seedlings from nearby natural forests, after seeking the requisite permission, although survival rates may be relatively low because of the associated stress of uprooting and replanting of seedlings. Every effort should be made to select high-quality seedlings to improve tree survival rates. The establishment of a community forestry nursery – in which community members share costs and provide inputs – has been shown to be an efficient way of producing low-cost seedlings.

2. Livestock component especially bees can be bought from registered members of the bee association; hive health is critical and should be the determinant factor for purchase. The area selected for the apiary must be well sited with adequate protection. In any given agroforestry system, it should be clear who has primary responsibility for the care and security of the livestock. Assistance from individuals who is experienced and technically competent – such as an early

adopter in the area or a governmental or non-governmental extension service is recommended for new entrants. The planting of trees and annual crops should be timed to coincide with favourable climatic conditions (e.g., the onset of the rainy season). A detailed workplan should be prepared to ensure that planting proceeds efficiently and that any follow-up work, such as weeding, is carried out effectively.

Marketing is another essential element of agroforestry, in which the products generated by the system are converted into actual income. It involves the following steps: selecting target markets; adding value to products; getting products to prospective buyers; setting the price; and promoting the products.

Maintenance

Maintenance is needed to ensure that an agroforestry system functions effectively. Common maintenance practices include: seedling protection, weed control, pest control, animal browsing, fertilization, irrigation, thinning, pruning, coppicing, harvesting and post-harvesting operations.

Agroforestry systems are dynamic; their performance, and the impacts of outside factors, should be carefully monitored. A management plan must be developed and should be adapted to changing circumstances and in achieving production goals. Management changes may be required when, for example: trees start competing with crops for space, sunlight and nutrients; markets for products change; and there are changes in labour requirements or availability. Effective monitoring requires good baseline information, record keeping and a set of relevant and measurable criteria.

7 Crops requiring trellising - Yams, passion fruit & Christophine

The rapid increase in yam and passion fruit production has significantly increase the number of trellis poles that are required. Wooden poles are harvested on both private and public lands with very little concern with sustainability of harvest. This situation has become even more urgent since the passage of Hurricane Maria, which impacted a significant number of the trees around the country. Replanted and sprouting from existing in situ seed stock are under tremendous pressure, and are harvested as stakes for yam and passionfruit production. Some of these are also harvested for housing development.

7.1 Objectives of technology application

To reduce or eliminate the harvesting of saplings and other young trees for trellising vining crops, thereby increasing the success rate of reafforestation programs.

7.2 Application

To be applied wherever trellis poles are required.

The variety of the yam being cultivated must be considered when selecting trellising options or even determining whether to trellis at all. Varieties with larger vegetative patterns such as the rotundatas' will require a sturdier trellis system if trellising is determined to be necessary.

Some of the known varieties of yams in the humid tropics under Dioscorea are rotundata, alata, polystachya, bulbifera,cayenensis, esculenta, dumetorum and trifida.

D. rotundata and D. cayenensis, also called white and yellow yam respectively are the most prevalent yam locally. White yam's tuber is cylindrical in shape and has a brown skin and white flesh. Yellow yam has yellow flesh and colour caused by the presence of carotenoids. Yellow has a longer period of vegetation compared to white yam.

D. alata also called winged yam and purple yam is the next important variety grown locally. Varieties like Costarican and Kenabayo falls within this grouping.

Cush- Cush variety falls within D. Trifida.

The implications of not trellising the crop and the impact on yields and other cultural management needs to be more fully investigated. It may well be that varieties with a tougher more robust canopy and leaf structure do not require trellis in specific AEZ zones, thereby reducing the overall number of trellis stakes required.

Substituting metal or recycled PVC post for the wooden post provides the most effective way of reducing the reliance on wooden trellis post. A source for the recycled PVC post is currently being sourced.

The initial capital cost implications for replacing wood post with 5/8-inch steel rods was estimated at $7,938.00 per acre (567 poles per acre, $42.00 / 5/8 steel rod, 3 poles per 20 feet rod). Whereas for wooded post it was estimated as $2,835.00 (5.00 / pole) per acre. The steel rod however has an average lifespan of 8-10 years compared to 2-3 years for the wood stakes. This translates to an average annual direct cost of $945.00 and $794.00 for wood and metal poles respectively.

8 Soil nutrition management

8.1 Improving soil fertility

The goal of soil fertility management is to create soil chemical conditions that encourage plant growth and supply required nutrients in the amounts and at the times they are most needed. To achieve this most effectively, the following information must be known about the soil/ land being managed:

- Land characteristics, potentials and limitations
- Likely impacts of change in management on their productivity
- How can they be made more resilient - minimize the impacts of climatic events;
- Systems of management that can be adopted to maintain their productivity and usefulness in terms of quality and quantity of output in a given time
- The active and central role of the farmer as steward, or manager of the resource.

Five mechanisms to improving land husbandry within most small-scale farming systems include:

- Continuous soil cover of living plants, which together with the soil structure facilitate the infiltration of water;
- A litter layer of decomposing leaves or residues providing a continuous energy source for macro and micro-organisms;
- Roots of different plants distributed throughout the soil at different depths, which permit an effective uptake of nutrients and an active interaction with micro-organisms
- The major period of nutrient release by micro-organisms coinciding with the major period of nutrient demand by plants;
- Nutrients recycled by deep-rooting plants and soil microbes (bacteria etc.).

It must be noted, that adequate soil fertility is only one of the many soil-related growth / production factors. The addition or improvement of soil fertility by the addition of chemical or organic additives will increase desirable plant growth only if the plant is deficient in the nutrient applied and other growth factors are not also significantly limiting plant growth. The ways in which crops respond to these applications often are different because some soils have inherent physical limitations to plant growth. Soil testing is the best guide to soil fertility. Plant tissue analysis may also be helpful when used in conjunction with soil testing.

8.1.1 Soil Testing

Refer to chapter 1, for taking samples for soil testing.

Test for:

- Texture (estimated by the hand-feel method)
- Organic matter (reported as a percent of the total soil)
  - Each percent of organic matter in the soil releases 20 to 30 pounds of nitrogen, given an acre of soil measured to a depth of 6 inches weighs approximately 2,000,000 pounds, which means that 1 percent organic matter in the soil would weigh about 20,000 pounds per acre. (Funderburg E., 2001)
- pH
- Soluble salts
- Nutrients

- Major Nutrients
  - Nitrate nitrogen (available)
  - Phosphorus
  - Potassium
- Secondary Nutrients
  - Calcium
  - Magnesium
  - Sulfur
- Micronutrients
  - Boron, chlorine, cobalt, copper, Iron, Manganese, Molybdenum, Zinc

- Soil Tests interpretation
- Soil pH, from the 1:1 soil: water method, indicates the acidity or alkalinity of soil based on a scale of 0 to 14.
- **Soluble salts** are measured by the electrical conductivity of a soil extract
- **Organic matter** (O.M.), reported as percent of total soil, contains about 95 percent of all soil nitrogen (N).
- Nutrients (major and minor) - Nitrate nitrogen, reported in ppm.

Organic fertilizers such as manures, compost or bone meal are derived directly from plant or animal sources. Inorganic fertilizers such as ammonium nitrate, urea or other NPK formulations are often called commercial or synthetic fertilizers because they go through a manufacturing process, although many of them come from naturally occurring mineral deposits.

The primary difference between manufactured / synthetic / inorganic and organic - soil amendments/organic fertilizers is the speed at which nutrients become available for plant use. If only a certain element such as nitrogen is quickly needed to be available to plants, an inorganic fertilizer such as ammonium nitrate might be in preferred. Many of the nutrients contained in organic fertilizer first must be converted into inorganic forms by soil bacteria and fungi before plants can use them, so they typically are more slowly released.

Organic fertilizers and soil amendments promote improvements in soil tilth (suitability of the soil to support plant growth) and also are typically lower in nutrient content.

8.1.2 Soil pH

Soil pH is a characteristic that describes the relative acidity or alkalinity of the soil**.** Pure water will be close to a neutral pH, that is 10 to the minus 7 concentration of H^+ ions (10^{-7} [H^+]). This concentration is expressed as 7. Any value above 7 means the solution is alkaline. Values below 7 indicate that the solution is acidic. Soils are considered acidic below a pH of 5, and very acidic below a pH of 4. Conversely, soils are considered alkaline above a pH of 7.5 and very alkaline above a pH of 8. (Jensen, Thomas L., 2010)

8.1.2.1 pH and plant nutrition

The availability of some plant nutrients is greatly affected by soil pH.Plants have different pH requirements but the “ideal” soil pH for most is close to neutral. Neutral soils are considered to fall within a range from a slightly acidic pH of 6.5 to slightly alkaline pH of 7.5. It has been determined that most plant nutrients are optimally available to plants within this 6.5 to 7.5 pH range, plus this range of pH is generally very compatible to plant root growth. Nitrogen, K, and S are major plant nutrients that appear to be less affected directly by soil pH than many others, but still are to some extent. Phosphorus, however, is directly affected. At alkaline pH values, greater than pH 7.5 for example, phosphate ions tend to react quickly with calcium (Ca) and magnesium (Mg) to form less soluble compounds that are less available to the plant. At acidic pH values, the phosphate ions react with aluminum (Al) and iron (Fe) to again form less soluble compounds, again not readily available to the plant. Most of the other nutrients (micronutrients especially) tend to be less available when soil pH is above 7.5, and in fact are optimally available at a slightly acidic pH, e.g., 6.5 to 6.8. The exception is molybdenum (Mo), which appears to be less available under acidic pH and more available at moderately alkaline pH values. In general, heavy metal availability is highest at low pH.

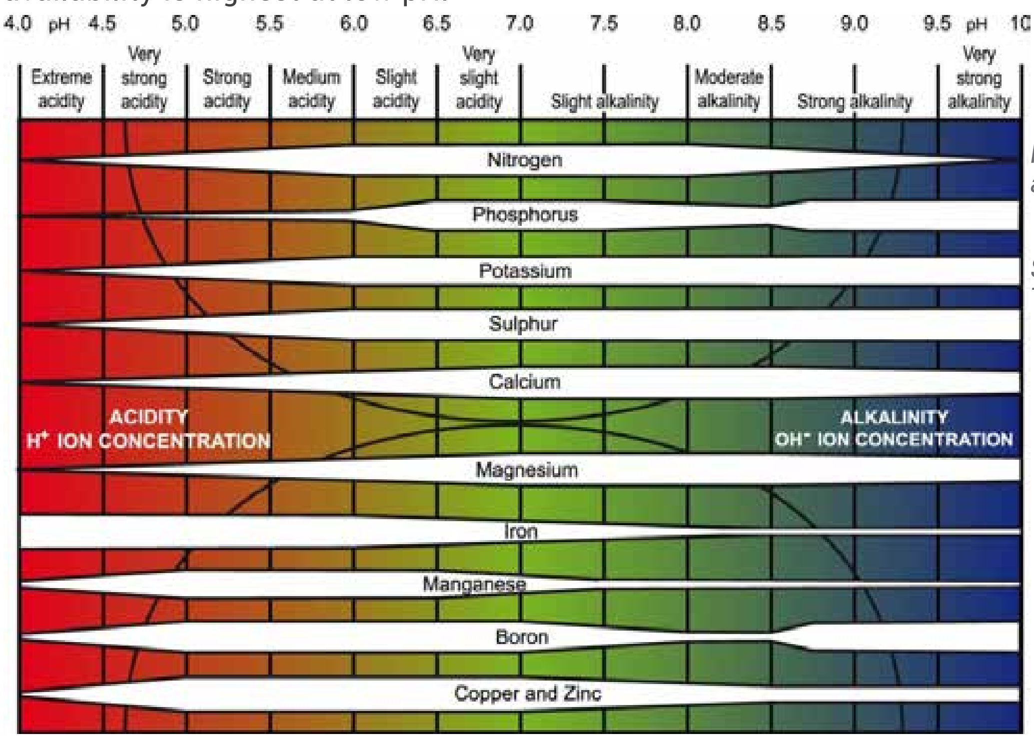


Figure 71: pH nutrient availability chart

Source: Redrawn from Truog, (1946).

8.1.2.2 Altering soil pH

Exchangeable acidity is a measure of the soil's ability to withstand a change in pH upon lime addition. The higher the exchangeable acidity of a soil, the more lime is needed for a particular pH change.

In some cases, soil ameliorates are added to the soil to adjust the pH. In on-farm applications, this is more commonly attempted for acidic soils to raise the pH from a range of 4.5 - 5.5 up to 6.5 or approaching neutrality. This is usually done by applying and incorporating a liming material, often finely ground calcitic ($CaCO_3$) limestone, or dolomitic [$CaMg (CO_3)_2$] limestone. Many other liming materials are available commercially. The speed and strength of these materials can be calculated using Fineness Values (FV), Calcium Carbonate Equivalents (CCE), and Effective Neutralizing Value (ENV). These calculations are also essential to determining the rate of application.

It is also possible to lower the pH of a soil using a liquid acid solution. It is also important to note that most on-going crop production, especially where ammonium based, or ammonium releasing N fertilizers (e.g., anhydrous ammonia, ammonium sulphate, and urea) is applied will gradually lower the soil pH.

Nitrification or the conversion of ammonium N to nitrate N produces acidity:

$2\ NH_4^+ + 4\ O_2 \quad 2\ NO_3^- + 4\ H^+ + H_2O$

2 H^+ are produced for every N in the ammonium-N form (NH_4^+). This reaction occurs regardless of the source of the NH_4^+. This acidity is often the largest single source of acidity in fertilized agricultural soils. The net amount of acidity created when N fertilizer is applied depends on other

reactions that occur with the fertilizer. The acidity created by different fertilizer materials is summarized below, as well as the lb. $CaCO_3$ required to neutralize the acid.

Table 81: Acidity from common ammonium-based fertilizer and equivalent neutralizing volume of lime

N Source	Theoretical lb CaCO3/lb N	Official (AOAC) lb CaCO3/b N
anhydrous ammonia	3.6	1.8
urea	3.6	1.8
ammonium nitrate	3.6	1.8
ammonium sulfate	7.2	5.4
monoammonium phosphate	7.2	5.4
diammonium phosphate	5.4	3.6

Lime requirements increase with cation exchange capacity (CEC), and a soil's CEC increases with organic matter and clay content. Thus, clay soils with high organic matter content require more lime for a similar pH change than sandy soils with low organic matter. In other words, high CEC soils tend to be well-buffered, requiring more lime to change the pH; while sandy soils are poorly-buffered, requiring less lime per unit pH change. Also, because of the greater buffering, the soil pH will decrease slower on high CEC soils than on poorly-buffered sandy soils.

Calcium Carbonate Equivalent (CCE) is the neutralizing value of a liming material compared to pure calcium carbonate. A CCE of 100% indicates that a material will neutralize the same amount of acidity per pound as pure calcium carbonate. Commonly used liming products and their CCE is listed in table 7-2 below.

Lime recommendations are given in 100% effective neutralizing value (ENV). To convert to lime recommendation for a particular liming material;

Lime rate (tons/acre) = 100 x lime rate for 100% ENV (tons/acre) / ENV of material

$$\text{Actual Lime Required} = \frac{\text{Recommendation}}{\text{Env Of Limestone}} * 100$$

- For example: soil test recommendation is 1.5 tons/acre of 100% ENV; limestone material has ENV = 70.3. Thus: Lime rate (tons/acre) = 100 x 1.5 / 70.3 = 2.1 tons limestone/acre

Table 82: CCE of common liming products

Common Name	Chemical Formula	CCE
Calcitic Limestone	$CaCO_3$	100
	$MgCO_3$	119
Burned Lime, Quick Lime	CaO	179
Hydrated Lime, Slaked Lime	$Ca(OH)_2$	136
Dolomitic Limestone	$(Ca,Mg)CO_3$	109
	$CaSiO_3$	86

Source : https://www.smart-fertilizer.com/articles/liming-materials/

Given the basic understanding of the mechanism by which pH affects the availability of some major nutrients, it is also possible to deduce alternative ways besides changing of pH to increase the availability and use of added nutrients. For the nutrients mentioned above that are adversely affected by extremes in soil pH, acidic or alkaline:

- P-containing fertilizer can be applied in or close to the seed-row at planting to facilitate early season uptake of phosphate ions by crop roots before allowing it to react with soil cations dominating under acidic (e.g., Al^{3+} or Fe^{3+}) or alkaline (e.g., Ca^{2+} or Mg^{2+}) soil pH conditions.
- Under alkaline soil pH values, the phosphate fertilizer can be applied in bands with fertilizer which generates NH_4^+ as noted above. That will allow slight acidification of the soil adjacent to the fertilizer band. Another method is to manufacture compound nutrient fertilizer granules that contain the N, P, and even elemental S-containing fertilizers, for application to alkaline soils so the soil adjacent to the granule will also be acidified slightly and allow enhanced P uptake when the crop roots intercept the granules.
- The foliar application of soluble Fe fertilizer compounds to Fe-deficient crops grown in high pH soils where the Fe^{3+} ions of the Fe fertilizer react so fast with soil that the nutrient is tied up and unavailable to plants. By avoiding the soil and applying the Fe to the leaves, the small amount of Fe ions is successfully introduced into the crop.

8.2 Role of Major and Minor Essential Nutrients in Crop Development

pH – Potential Hydrogen – Key to unlocking soil nutrients

Nitrogen – Vigorous vegetative growth

Phosphorous – Flowers, fruits and roots

Potassium – Vigor and disease resistance

Calcium - Cell division and formation, fruit set and use of Nitrogen

Magnesium – Photosynthesis, utilization and mobility of phosphorus and iron Influence's earliness and uniformity of maturity

Sulphur - helps develop enzymes and vitamins, promotes nodule formation on legumes, seed production

Table 7-3 provides a list of essential plant nutrients and the ionic form absorbed by plants.

TABLE 1: Form, source, mode of uptake and major functions of the 16 plant essential nutrients.

Nutrient family	Nutrient	Percentage of plant	Form taken up by plants (ion)	Mode of uptake	Major functions in plants
Primary	Carbon	45	Carbon dioxide (CO_2), bicarbonate (HCO_3^-)	Open somates	Plant structures
	Oxygen	45	Water (H_2O)	Mass flow	Respiration, energy production, plant structures
	Hydrogen	6.0	Water (H_2O)	Mass flow	pH regulation, water retention, synthesis of carbohydrates
	Nitrogen	1.75	Nitrate (NO_3^-), ammonium (NH_4^+)	Mass flow	Protein/amino acids, chlorophyll, cell formation
	Phosphorus	0.25	Dihydrogen phosphate ($H_2PO_4^-$, HPO_4^{2-}), phosphate (PO_4^{3-})	Root interception	Cell formation, protein syntheses, fat and carbohydrate metabolism
	Potassium	1.5	Potassium ion (K+)	Mass flow	Water regulation, enzyme activity
Secondary	Calcium	0.50	Calcium ion (Ca^{2+})	Mass flow	Root permeability, enzyme acitivity
	Magnesium	0.20	Magnesium ion (Mg^{2+})	Mass flow	Chlorophyll, fat formation and metabolism
	Sulfur	0.03	Sulfate (SO_4^{2-})	Mass flow	Protein, amino acid, vitamin and oil formation
Micro	Chlorine	0.01	Chloride (Cl^-)	Root interception	Chlorophyll formation, enzyme activity, cellular development
	Iron	0.01	Iron ion (Fe^{2+}, Fe^{3+})	Root interception	Enzyme development and activity
	Zinc	0.002	Zinc ion (Zn^{2+})	Root interception	Enzyme activity
	Manganese	0.005	Manganese ion (Mn^{2+})	Root interception	Enzyme activity and pigmentation
	Boron	0.0001	Boric acid (H_3BO_3), borate (BO_3^{3-}), tetraborate (B_4O_7)	Root interception	Enzyme activity
	Copper	0.0001	Copper ion (Cu^{2+})	Mass flow	Enzyme activity
	Molybdenum	0.00001	Molybdenum ions ($HMoO^{4-}$, MoO_4^{2-})	Mass flow	Enzyme activity and nitrogen fixation in legumes

Table 83: Essential Plant Nutrients- form, source, mode of uptake and major functions

Source : https://cdn-ext.agnet.tamu.edu/wp-content/uploads/2018/11/ESC-009-essential-nutrients-for-plants.pdf

9 Understanding Fertilizers

Fertilizers refer to Soil amendment that guarantees the minimum percentages of nutrients (at least the minimum percentage of nitrogen, phosphate, and potash). An organic fertilizer refers to a soil amendment derived from natural sources that guarantees the minimum percentages of nitrogen, phosphate, and potash. (Master gardener program: WSU)

Fertilizer Facts:

- The three-number combination (fertilizer *grade* or *analysis*) on the product identifies percentages of nitrogen (N), phosphate (P2O5), and potash (K2O), respectively. The product may also identify other nutrients, such as sulfur, iron, and zinc, if the manufacturer wants to guarantee the amount.
- Time release or slow-release fertilizers contain coating materials or are otherwise formulated to release the nutrients over a period of time as water, heat, and/or microorganisms break down the material.

Some examples of the availability of nitrogen are provided in Table 8-1.

Table 91: Some examples of availability of Nitrogen

Examples of Quickly and Slowly Available Nitrogen	
Quickly available nitrogen Lasts 4-6 weeks	Ammonium sulfate Ammonium nitrate Calcium nitrate Potassium nitrate Urea
Slowly available nitrogen Available over weeks to months Regulated by solubility or microorganism activity	Resin-coated urea Sulfur-coated urea Isobutylidenediurea (IBDU) Methylene urea Urea formaldehyde Manure Poultry wastes Blood meal

10 Composting

Tropical soils are generally low in organic material partly due to the high temperatures and the rapid rate of decomposition. Composting is one method of effectively adding organic material and limited volumes of nutrients to the soil. The practice of adding compost to the soil is well entrenched into production methodology locally in Dominica, with many producers utilizing tea compost and feeding through irrigation system. The main method of making tea compost locally involves the combination of farmyard manure and other minced leguminous crops such as *Glyricidiasepium* and allowing it to steep in a set volume of water for 3 months. A combination ratio of 2 bags of manure/minced gliricidia to 45 gallons of water is usually used. The resulting tea is diluted with 2 parts of water being applied to the plant.

Figure 71 depicts the process of composting. Materials to be used in moderation during composting process includes:

- Large amounts of grass clippings
  - Small particle size and high nitrogen, produces smell unless mixed with brown materials.
  - Manure
  - May contain strains of *Escherichia coli* and other bacteria that cause human illness. If manure is composted for food gardens, a 4-month curing process following composting is necessary to reduce pathogens.
- Large amounts of plants/weeds treated with pesticides (herbicides, insecticides, and fungicides)
  - Most pesticides readily break down in the composting process and present no threat as long the decomposition process had been completed.
- Large amounts of high tannin-containing leaves
  - Slow to decompose, but can be used in small quantities if chopped well and mixed with other materials.
- Large amounts of paper products
  - If paper is composted due to a shortage of dry materials, add no more than 10% of the total weight of the material being composted.
  - Higher amounts create imbalances in the carbon to nitrogen ratio.
  - Do not use color printed glossy magazines as inks may not be safe as a soil additive.
- Large amounts of soil
  - Large amounts of soil increase weight, decrease oxygen infiltration and can suffocate microorganisms.
  - Soilless composting is often practiced.

What is the Carbon to Nitrogen Ratio Talked About in Composting Literature?

The ratio of carbon to nitrogen in the pile needs to be around 30 to 1. This is typically found with the combination of two parts green materials with one-part brown materials (Table 9-1). Compost piles too high in carbon will be slow to process or even not decompose. Piles too high in nitrogen develop strong ammonia odors.

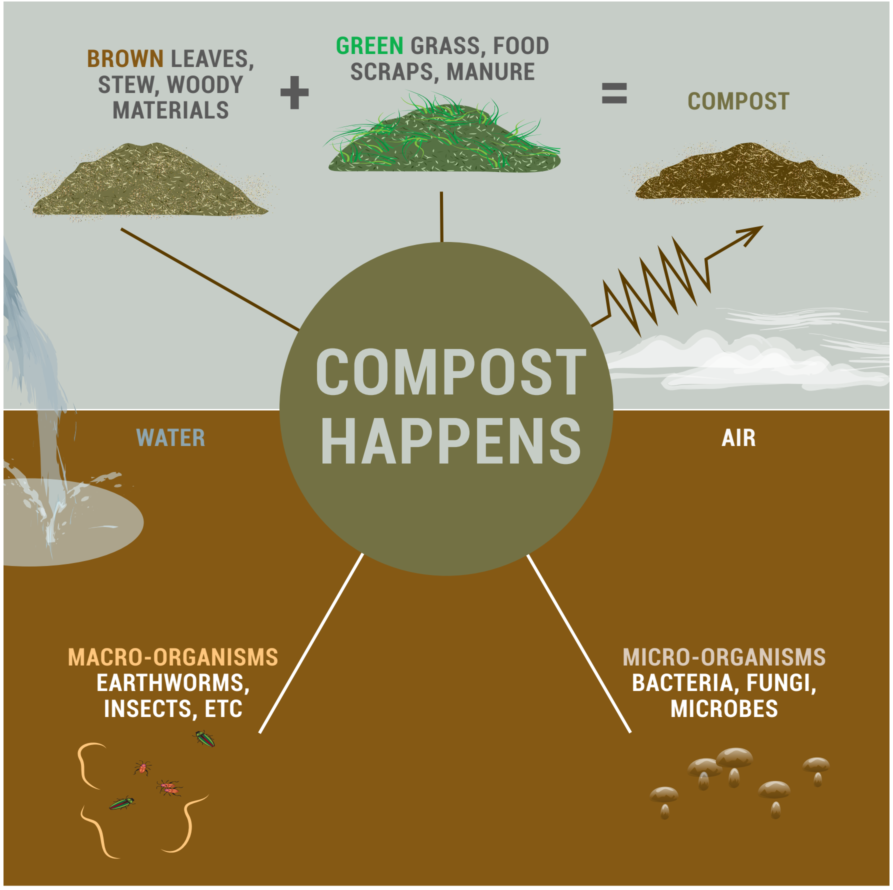


Figure 72: Process of Composting

Source : http://www.yorkton.ca/livinghere/garbage/composting.asp

Location of the Compost Bin / Structure

Structures are not necessary for composting but do help prevent excess water from rainfall, wind and marauding animals from carrying away plant wastes. Open compost piles can be used in less-populated rural locales, but structures are highly recommended near or within urban areas. Generally composting requires:

- Partial shade
  - Avoids baking and drying by sun but provides some solar heating to start the composting action.
- Wind protection
  - Prevents too much moisture loss.
- Water source
  - Needs to keep the pile moist but not soggy.
- Convenience
  - For loading and unloading of materials, but away from yard activities.

Size

A minimum volume of material is necessary to build up the heat necessary for efficient composting. When composting materials are heavy in green constituents, keep the bin smaller to allow for better aeration. Three feet by three feet by three feet is considered minimum size to allow for heating. If composting materials high in brown materials, a larger bin (5 feet by 5 feet) may be required.

Routine Care of a Compost Pile

The breakdown of organic yard wastes is a biological process dependent on microorganism activity. Like most living things, these microbes require favorable temperatures, moisture, oxygen, and nutrients.

- Temperature
  - Plant-digesting microbes operate in a temperature range of 21°C to 60°C
  - Breakdown occurs slowly at the lower temperatures.
  - Well-managed compost rapidly breaks down in warmer conditions when compost temperatures quickly reach 49°C to 54°C.
  - If temperature of the plant mass exceeds 71°C, the microbes will die.
- Moisture and oxygen
  - Essential to microbial activity.
  - In a region of limited rainfall or if under shelter, add moisture regularly to maintain composting. Microorganisms in the dry areas will die. Even after moisture is added to a dried-out pile, the microbes that remain require time to multiply and resume plant digestion. The net result is slower composting.
  - Excess moisture displaces air and slows breakdown.
  - Surplus water creates low oxygen conditions where certain microbes multiply and produce foul odors.
  - The best description of the proper moisture level is moist or damp but not soggy.
  - Size of material to be composted also affects aeration (0.5 – 1.5 inches)
- Nutrients
  - The microbes that break down plants use the plants for food.
  - Nitrogen is the most important food nutrient,
  - Nitrogen shortage drastically slows the composting process.
  - Woody and dried plant materials tend to contain little nitrogen in comparison to the total mass of the material.
  - Green plant material, however, contains a high percentage of nitrogen.
  - A mix of two parts green to one-part brown material generally gives the best nitrogen balance.
  - Add a plant fertilizer high in nitrogen when green materials are scarce

Some of the problems anticipated during composting, their causes and solutions are provided in Table 9-2.

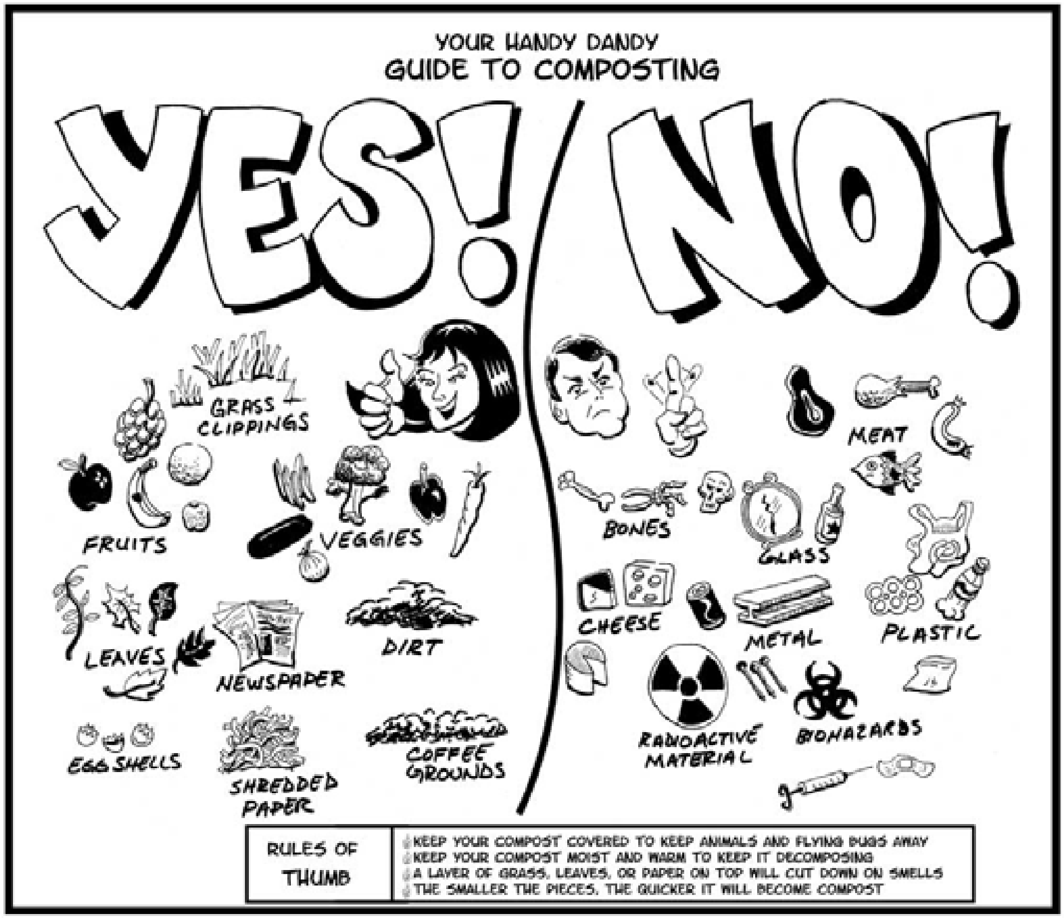


Figure 73: Pictorial guide for materials to be used in composting

Source: http://armzrace.com/2010/08/20/your-handy-dandy-guide-to-composting/.

Table 101: Some examples of Green and Brown Materials in composting

Examples of Green and Brown Materials	
Green Materials	**Brown Materials**
Vegetable wastes (12–20:1) Coffee grounds (20:1) Grass clippings (12-25:1) Cow manure (20:1) Horse manure (25:1) Poultry manure, fresh (10:1) Poultry manure, with litter (13–18:1)	Dry leaves (30–80:1) Corn stalks (60:1) Straw (40–100:1) Bark (100–130:1) Paper (150–200:1) Wood chips and sawdust (100–500:1)

Table 102: Composting Troubleshooting

Problem	Cause	Solution
Rotten odor	Anaerobic conditions Excess moisture • Compaction • Small particle size	• Turn the pile • Make smaller pile • Add dry porous materials
Ammonia odor	• Too much nitrogen (low C:N ratio)	• Mix in brown materials • Note: If compost high in ammonia is used as mulch, it may burn tender foliage. If mixed into soil as an amendment, it can burn roots.
Outside couple of inches is dry	• Dry air	• Water regularly and cover outer edge with tarp.
Low temperature	• Pile too small • Insufficient moisture • Poor aeration • Lack of nitrogen	• Make larger pile • Add water when turning pile • Turn pile to aerate • Mix in green materials or add N fertilizer
Pests (rats, insects)	• Presence of meat, dairy, or fatty wastes	• Do not compost kitchen scraps with meat, dairy, fats, oils, or grease.

References

Antapa, P.L. and Angen, T.V. 1990. Tillage practices and residue management in Tanzania. In: Organic-matter Management and Tillage in Humid and Sub-humid Africa. p. 49-57. IBSRAM Proceedings No.10. Bangkok: IBSRAM.

Beekman, M., &Ratnieks, F. (2000). Long-Range Foraging by the Honey-Bee, Apis mellifera L. Functional Ecology, 14(4), 490-496. Retrieved July 22, 2021, from http://www.jstor.org/stable/2656543

BOSTID, 1984. Methodology for Diagnosis and Design of Agroforestry and Management Systems.

The Editors of Encyclopaedia Britannica (15 Mar. 2019). "Contour farming"., https://www.britannica.com/topic/contour-farming. Accessed 21 July 2021.

Carter M.R. (2005). Conservation tillage; in Encyclopaedia of Soils in the Environment. pgs. 306-311

Roundy D. September 30th, 2019. what-is-the-difference-between-rill-and-gully-erosion. https://graniteseed.com/blog/

Ditsch D.C. (1986). Ridge-Tillage: Advantages and Disadvantages. uknowledge.uky.edu

Funderburg E., (August 2001). What does organic matter do In Soil? In Noble Research Institute Ag news and views

Bergtold J. and Sailus M. (eds) (2020). Conservation tillage system in the Southeast. SARE Handbook 15.

https://extension.oregonstate.edu/news/heres-scoop-chemical-organic-fertilizers

https://www.noble.org/news/publications/2001/august/what-does-organic-matter-do-in-soil/

https://www.pantagraph.com/alley-cropping-demo-at-farm-progress-show/article_058ccf26-e235-586c-b329-776323849539.html

Isaiah I.C. Wakindiki, B.O. Mochoge, Meni Ben-Hur, 2007. Assessment of indigenous soil and water conservation technology for smallholder farms in semi-arid areas in Africa and close spaced trash lines effect on erosion and crop yield – in report on Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities, 2007

J.L. Richardson & M.J Veprakas eds. 2001 "Wetland Soils Genesis Hydrology, Landscape Classification".

Jensen T. L. (2010) Soil pH and the availability of plant nutrients. International Plant Nutrition Institute (IPNI) Today, No. 2.

Laburda T, Zumr D, Kavka P, Neumann M, Devaty J, Balenovic N, et al., 2019. The effects of rain drop impact on soil surface microtopography. In: 11th International Workshop on Precipitation in Urban Areas (Urban Rain 18).

Lal, R. 1980. Crop residue management in relation to tillage techniques for soil and water conservation. In: Organic recycling in Africa 74-79. Soils Bulletin 43. FAO, Rome.

Lal, R. 1983. No-till farming: Soil and water conservation and management in the humid and sub-humid tropics. IITA Monograph No. 2, Ibadan, Nigeria

Lancaster Brad (2016). Rainwater harvesting for drylands and beyond - https://www.permaculturenews.org/2016/06/13/bunyip-water-level-measure-contour-lines-swales/

M.R. Carter (2005). Conservation Tillage in Encyclopaedia of Soils in the Environment, pg. 306 -311

WSU Master gardener program – C180 (6/21) factsheet: Organic fertilizer, wsu.edu

https://s3.wp.wsu.edu/uploads/sites/2076/2021/06/C180-Organic-Fertilizers-21.pdf. Accessed 15/ 6/21

Natural Resources Conservation Service Des Moines, Iowa, May 2001. Terraces. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_006954.pdf

Ning Ai, Qingke Zhu, Guangquan Liu and Tianxing Wei, 2020. Soil-moisture-importance/soil-erosion-influencing-factors-in-the-semiarid-area-of-northern-shaanxi-province-china: https://www.intechopen.com/books/ #B11

Peace Corp information collection and exchange, 1986. Soil conservation techniques for hillside farm

Penhallegon R. 2015. Here's the scoop on chemical and organic fertilizers

Ramesh U.& Jain C.K, 2010. Agroforestry Systems and Practices.

Richardson J.L. &Veprakas M.J. (eds.) 2001. Wetland Soils Genesis Hydrology, Landscape Classification.

Stefanie Spears (2018). What is no-till Farming. In Regeneration International newsletter, 06/24/2018.

Truog, E. (1946). Soil reaction influence on availability of plant nutrients. Soil Science Society of America Proceedings 11, 305-308

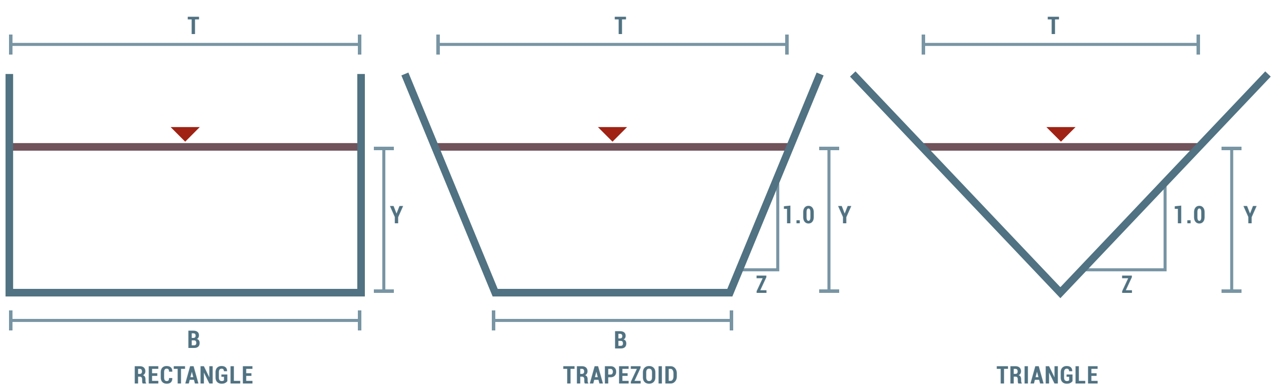
Xu, Ximeng& Zheng, Fenli& He, Chao & Lu, Jia &Bian, Feng. (2018). Comparison of runoff and soil loss in different tillage systems in the Mollisol region of Northeast China. Soil and Tillage Research. 177. 1-11. 10.1016/j.still.2017.10.005. f

ANNEX

Annex 1: Common nitrogen fixing plant species

1.	Acacia albida	21.	Bauhinia variegate
2.	Acacia auriculiformis	22.	Butea monosperma
3.	Acacia catechu	23.	Cassia fistula
4.	Acacia aneura	24.	Cassia siamea
5.	Acacia dealbata	25.	Casuarina equisetifolia
6.	Acacia decurrens	26.	Dalbergia latifolia
7.	Acacia farnesiana	27.	Dalbergia sissoo
8.	Acacia implexa	28.	Delonix regia
9.	Acacia leucophloea	29.	Gliricidia sepium
10.	Acacia mearnsii	30.	Hardwickia binate
11.	Acacia melanoxylon	31.	Leucaena leucocephala
12.	Acacia mollissima	32.	Moringa oleifera
13.	Acacia nilotica	33.	Oogeiniaoojeinensis
14.	Acacia planifrons	34.	Parkinsonia aculeata
15.	Acacia Senegal	35.	Peltophorumferrugineum
16.	Albizia chinensis	36.	Pithecellobium dulce
17.	Albizia lebbek	37.	Prosopis alba
18.	Albizia procera	38.	Prosopis chilensis
19.	Alnus nepalensis	39.	Prosopis cineraria
20.	Alnus nitida	40.	Robiniapseudoacacia
41.	Samanea saman	44.	Sesbania bispinosa
42.	Saraca indica	45.	Sesbania grandiflora
43.	Sesbania aegyptica	46.	Tamarindus indica

Annex 2 Open Channel Diagram and Equations:



In open channel, z is side slope of trapezoidal and triangular channels, defined as horizontal to vertical ratio. Both sides of the open channel are assumed to have the same side slope.

Open Channel Equations (note that $R=A/P$):

Rectangle: Aby $P = b+2y$ $T=b$

Trapezoid: $A=y(b+yz)$ $P=b+2y\sqrt{(1+z^2)}$ $T=b+2yz$

Triangle: $A = zy^2$ $P = 2y\sqrt{(1+z^2)}$ $T= 2yz$