(3) The following items should be evaluated for consideration of proper mitigation measures:

a) Magnitude of damage to farmlands and agricultural facilities,
b) Major causes of damage,
c) Necessity of physical conservation measures,
d) Areas to be protected, and
e) Necessity of permanent and/or temporary conservation measures.

3. Planning

3.1 Basic Concept of Planning

(1) A plan of farmland conservation should be rationally established by considering the existing and future land use plan and drainage of runoff water from upstream and project areas without any damage in the downstream area.

(2) To prevent soil erosion by runoff water, a drainage system with intercepting drains, collecting drains, and main drains, should be properly arranged, and also some mitigation measures, such as gully erosion prevention works should be taken in the project area.

(3) A plan of farmland conservation should be formulated by an appropriate combination of physical and agronomic prevention measures of soil erosion.

3.2 Selection of the Project Area

(1) The project area should be determined by careful consideration of the topographic, geological, and soil conditions, drainage system, boundary of the catchment area, damage by erosion, intention of local people, and other regional development plans in and around the project area.

(2) The beneficial area of the farmland conservation plan is the area to be protected by the physical and agronomic prevention measures.

3.3 Items to be Considered in Planning

(1) The following items are to be considered for formulation of the farmland conservation plan:

- Drainage system,
- Prevention of sheet and rill erosion,
- Prevention of gully erosion and its conservation measures,
- Improvement of farm roads, and
- Agronomic measures for prevention of soil erosion.

(2) Intercepting and collecting drains should be systematically arranged to drain the surface water.

(3) In order to prevent rill and sheet erosion, contour cultivation, the cropping pattern, mulching, and the greenbelt should be effectively arranged in the project area.

(4) Preparation of the drainage network and construction of gully erosion control weirs should be planned to prevent gully erosion in the project area.

(5) In the areas with steep slopes, farm roads should be provided and improved appropriately from the viewpoint of farmland conservation.

(6) The farmland conservation plan should properly include both physical measures and agronomic measures.

3.4 Principles of Soil Erosion Control

Soil conservation measures can be broadly classified into two types: i) physical methods and ii) agronomic methods. Physical methods are mainly followed to control the discharge and velocity of runoff water, enable rain to seep into soil, and improve the drainage network. Agronomic methods prevent the soil particles from being dispersed by the action of rain drops and the erosion that follows it. It is very advantageous to use these two methods together in the field.

(1) A farmland conservation plan should be established with careful consideration of the following principles of soil erosion prevention:

- Reduction of surface runoff by enhancing water permeability of the land,
- Control of the velocity of runoff water,
- Improvement of drains, and
- Strengthening of the tolerance capacity of land against soil erosion.

(2) The following agronomic measures should be considered for planning of farmland conservation:

- Contour cultivation,
- Planting of grass,
- Mulching,
- Application of organic matter,
- Improvement of soil structure (granulating),
- Introduction of proper crop rotation and mixture cropping,
- Improvement of the permeability of soil by deep tillage,
- Ridging for drainage,
- Greening of slopes of terrace works,
- Improvement of drains under the errace structure,

- Maintenance of the drainage network, and
- Dredging of sediments in the grid chamber.

(3) The following items should be considered for planning of the physical measures of farmland conservation:

- Maintenance of a proper gradient of farmland for prevention of soil erosion,
- Control of runoff water by proper arrangement of the drainage system,
- Planting of grasses on the slopes of the terracing facilities,
- Maintenance of the gentle gradient of intercepting drains,
- Proper arrangement of grid chambers and check dams,
- Avoidance of the implementation of physical works during the flood season,
- To precede implementation of drainage and sediment control works, and
- Conducting of regreening works quickly.

3.5 *Planning for Runoff Water*

(1) The planned runoff volume should be determined by the peak discharge of 10-year probability for main and collecting drains, and 5-year probability for intercepting drains, in principle.

(2) The peak runoff volume should be calculated by the Rational Method shown below. the flood discharge should be calculated based on the specific discharge in the project area.

$$Q_p = 1/3.6 \times r_e \times A$$

Where

Q_p : peak discharge (m^3/sec),

A : catchment area of a drain (km^2),

r_e : average effective rainfall intensity during the concentration or lag time (mm/hr) to be givenin the probability year.

(3) The Probable rainfall intensity should be estimated by statistical methods based on the collected rain fall records.

(4) The effective rainfall intensity should be estimated by the following methods:

a) Permeability test method

$$r_c = r - f_c$$

Where

r_e : effective rainfall intensity (mm/hr),
r : rainfall intensity (mm/hr),
f_c : Ultimate permeability capacity (mm/hr).

b) Peak discharge coefficiency method

$$re = fp \times r$$

Where

r_e : effective rainfall intensity (mm/hr),
r : rainfall intensity (mm/hr),
f_p : peak discharge coefficiency, given by $f_p = 3.6Q_p/(r \times A)$,
Q_p : actual peak discharge (m^3/sec),
A : catchment area (km^2).

(5) The concentration or lag time of flood should be determined by consideration of the results obtained by field survey and data analysis. The probable effective rainfall intensity curve (r_e-curve) is to be prepared based on the obtained data mentioned above. The probable effective rainfall intensity should be determined by careful integration of these data.

3.6 Agronomic Measures for Erosion Control

(1) The agronomic conservation measures are, in essence, the proven techniques of soil and crop and livestock management, closely related to normal farming practices, but specially designed or selected to be beneficial in terms of conservation. They are usually inexpensive and can be adopted relatively easily by small farmers. However, before such measures are introduced to a new locality, their compatibility with existing farming methods and cropping systems should be carefully considered, together with their likely effectiveness in erosion control under the prevailing conditions.

(2) On steep farmlands in the up-country area, agronomic conservation measures should be used in conjunction with physical measures for, used alone, they may not be totally effective. They have proven most effective in gentle slopes below 12 or 15 %, but when used in conjunction with discontinuous types of terrace, for example, they allow safe cultivation of steeper slopes than would be possible in their absence.

(3) The detailed description of the principal agronomic control measures is summarized in Appendix E.3.

4. Design

4.1 Drainage Works

4.1.1 Types of Drains

Drains can be classified into the following four types and these are commonly arranged as shown in Figure E.1:

a)	Intercepting drain	:	being arranged along the contour line to drain runoff water to the collecting drains,
b)	Collecting drain	:	being arranged at a right angle to the contour line at 200-300m intervals to collect runoff water from the intercepting drains and flash it to out the drainage channels,
c)	Drainage channel	:	receives runoff water from the project area and connects to natural waterways to drain it, and
d)	Natural waterways	:	transport the runoff water to the downstream area.

4.1.2 Basic Concept for Planning of the Drainage Network

(1) Networking of the drainage system

The planning of the drainage network is to be the basis of farmland conservation. Thus, it should be planned based on the following concepts:

a) Surface water coming from the upstream of the project area should be collected by the intercepting drains constructed in the upper reaches of the project area and drained to the downstream area directly, in principle,
b) The collecting drains should be reinforced to avoid further erosion in cases where the surface water from the upstream area is not collected by the intercepting drains,
c) The conditions of the natural waterways which would receive discharge from the project area, such as the flow capacity, cross section, revetment, and necessity of sediment or grid chambers, should be carefully examined in order to avoid any damage to farmlands and buildings in the downstream area.

(2) Arrangement of the intercepting drains

The intercepting drains with trapezoidal shaped should be arranged along the contour line, and the distance between the intercepting drains is normally set at 60-100 m though it depends on the slope conditions. The length of an intercepting drain, or the distance between the collecting drains, is normally set at 200-300 m, but should not exceed 500 m.

(3) Arrangement of the collecting drains

There are two types of collecting drains, namely the valley type and ridge type. For the valley type, a collecting drain is arranged in the bottom of the valley, and an intercepting drain is arranged from the ridge toward the valley with a slope of 1/30-1/50. This type is usually applied in the area with a strict water use system because it does not change the existing drainage regime. With the ridge type, a collecting drain is arranged in the ridge part of the area, and an intercepting drain is arranged from the valley toward the ridge with a slope of 1/30-1/50. Because of the stable foundation of the ridge area, the ridge type has highly stabille facilities. However, the ridge type has disadvantages as it would change the existing drainage regime, and the overflow from the intercepting drains would easily cause gully erosion in the project area. The distance between the collecting drains should be set at 200-300 m maximum, and they should be arranged at a right angle to the contour line with a slope of less than 170 % (60°).

4.1.3 Structure of the Drains and Appurtenant Facilities

(1) Lock and spill drains

This physical method of soil conservation is in much use and can be seen practiced in tea, rubber, and coconut cultivation, which are all commercial crops. This could be practiced with other annual crops as a successful conservation method. These drains should be 1 ft (0.3 m) wide and 1.5 ft (0.5 m) deep. At 10 ft (3 m) intervals 3 ft (1 m) x 1 ft (0.3 m) trunks should be placed inside the drain. Soil removed from the drains must be deposited along the lower bund of the drain. The trunks left at intervals in the drain will control the velocity of the water. Excavation of the drains will start from the upper end of the land.

(2) Graded drains

Graded drains are designed for transporting the discharge water from the side drains and contour drains. They are paved with stone and look like staircases. As the drains are paved with stone, no erosion is caused by the drain flow.

(3) Intercepting drains

Intercepting drains are normally unlined or grass-covered, but they must be u-shaped concrete ditches in the steep slope area. The drain bed should have a proper cline which would not cause a flow velocity of over 1.0 m/s in unlined drains, and 1.5 m/s in grass-covered drains. Several inlets should be installed in the intercepting drains with proper measures to prevent the inflow of sediments. The backfill of the sidewall and foundation of the the bottom slab concrete of the lined drain should not use sand and gravel for prevention of scoring.

(4) Collecting drains

Collecting drains should be designed with careful consideration of the stability of drains, such as preparation of a stilling basin and energy dissipation works at bends and connections, especially in the steep slope area causing a supercritical flow. The stilling basin should be installed at the joint portion of the intercepting drains. (See Figure E.2)

(5) Drainage channels

Drainage channels should be designed with careful consideration of the control of the flow velocity and channel erosion at the joint portion. Planning and design of the drainage channel must follow the data given below:

a) Drops with a water-cushion should be prepared in the area with high water head and the joint portion of the drainage channel and collecting drain,
b) Sediments in the channel should be dredged periodically in the farmland conservation area,
c) Channels should be lined up to the elevation level of 10 years probability and should be reinforced concrete structures,
d) Proper tail bay works should be implemented at the joint portion of the drainage channel, and
e) Channels should be aligned to keep an appropriate distance from the slope, at least 50 cm.

(6) Stilling basin works

This stilling basin works with a proper distance between the intercepting drains and/or collecting drains should be prepared for prevention of sediment inflow to drains and channels. The dredged sediments should be sent back to the farmlands for conservation of the fertility of the land.

4.2 Gully Erosion Prevention Works

(1) Gullies are formed when water accumulates in low-lying areas of the land and flows downhill. By the action of soil erosion, the gully deepens gradually, as there is no grass a cover in the area around the drain. In lands with mild slopes (15-20 % or less), the eroded gullies could be partially filled with soil and grass could grow as a soil cover. This can be converted into a lead-away drain to convey water for extensive gully erosion in very steep slopes.

(2) A series of gully controls should be erected. These bunds will control the velocity of the flow and retain the soil particles usually carried away with the water. The number of bunds to be constructed will depend on their the dimensions, the size of the gully slope of the land, and soilstability. To control the gully erosion of over 4 m, it is recommended to get suggestions from

qualified engineers. Follow the instructions given below to control the smaller gullies.

(3) To prevent gully erosion two types of bunds need to be erected, namely: i) Bunds paved lightly with stones and ii) Bunds with poles or sticks. Stone gullies are prepared if stones can be found near by and the width of the gully is less than one meter.

(4) Boulders must be used to pave the gully bed and stones must be laid after deepening the gully by 1/3 of its height. If the bund is 1.5 m high, the gully must be excavated by 50 cm. The bund must be erected towards the upper section of the slope and the spaces between bigger stones must be filled with smaller pieces of stone. The center of the bund must be 50 cm higher than the sides. Erosion by the spilling over of excess water from the bund can be prevented by paving large sized stones on the bottom of the water exit side of the bund. Similarly, the upper section of the bund also should be paved with stone. Grass should be planted when the gully is filled up. (See Figure E.3)

(5) If stones cannot be found on the land, poles and twigs may be used to erect bunds where the gully has formed. A few poles should be fixed at intervals of 20 cm across the gully. Stack some twigs should be stacked from the bottom up and the larger ends of the twigs must be placed in between the poles and the smaller ends laid on the gully slope downward. The longer twigs must be stacked at the bottom and shorter ones on top to allow for compact stacking. Twigs or branches of the Bovitiya, Acacia, Dekerdens, and pandered plants could be used for stacking and the upper section of the bund erected with sticks and poles can then be filled with gravel. (See Figure E.4).

4.3 Farm Road Construction

(1) Farm roads constructed in the erosion prone areas have a close relationship with other facilities related to farmland conservation. Farm roads in such areas are apt to be waterways of runoff water, so that some farm roads are severely damaged by erosion. Thus, the farm road construction plan should be prepared in line with the overall conservation plan of farmland.

(2) One of the effective methods is to design a farm road which functions as a drainage channel during the rainy season. The layout and structure of this farm road should be determined by careful consideration of the discharge control by the cutting walls, construction of drains and structural design without clogging by sediments, twigs, and leaves.

(3) The following points should be considered. When planning a farm road in sloping areas:

- Drain age of the runoff water through a stilling basin to avoid soil loss,
- Maintenance of the drainage conditions of the roadside drains, and

- Conducting of slope protection works with a waterpipe system and the greening of slopes.

4.4 Physical Measures for Erosion Control

(1) Since cultivation and runoff are both inevitable, physical measures for control are needed in the up-country area. With some structures, such as bench terraces, erosion will not be increased significantly even when soils are loosened by tillage.

(2) The most important physical measures for soil conservation are the land treatments e.g. terraces, hillside ditches, and contour dikes all of which are built along the contours or on a grade. Their main function are:

a) to change a steep slope into a gentle slope by a series of flat or small gradient strips along the contours across a slope to facilitate cultivation and for erosion control, and
b) to change a long slope into a series of shorter slopes by the use of bunds or ditches to intercept and divert runoff for safe disposal, hence minimizing erosion.

(3) Detailed description of the principal physical control measures are summarized in Appendix E.2.

FIGURES

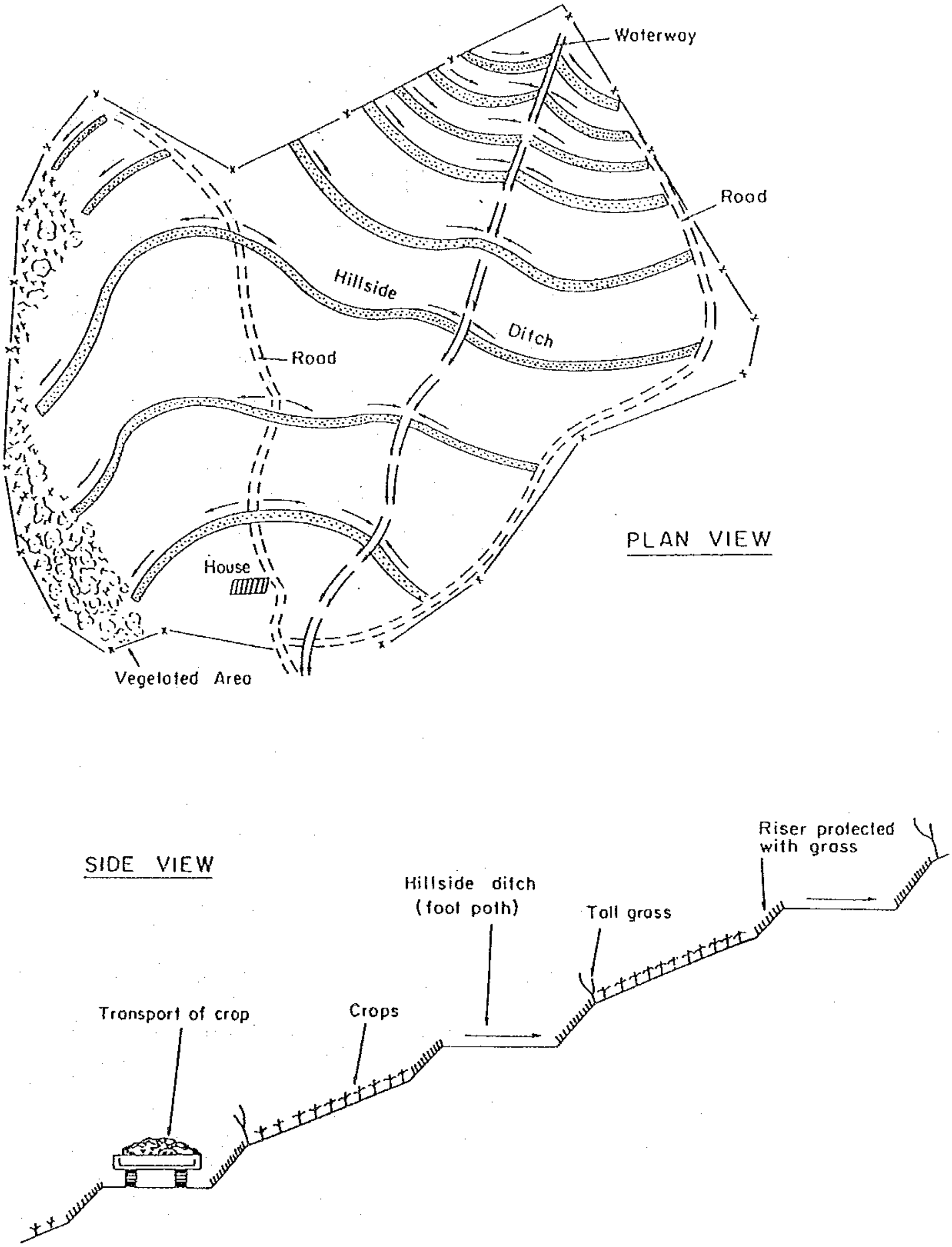
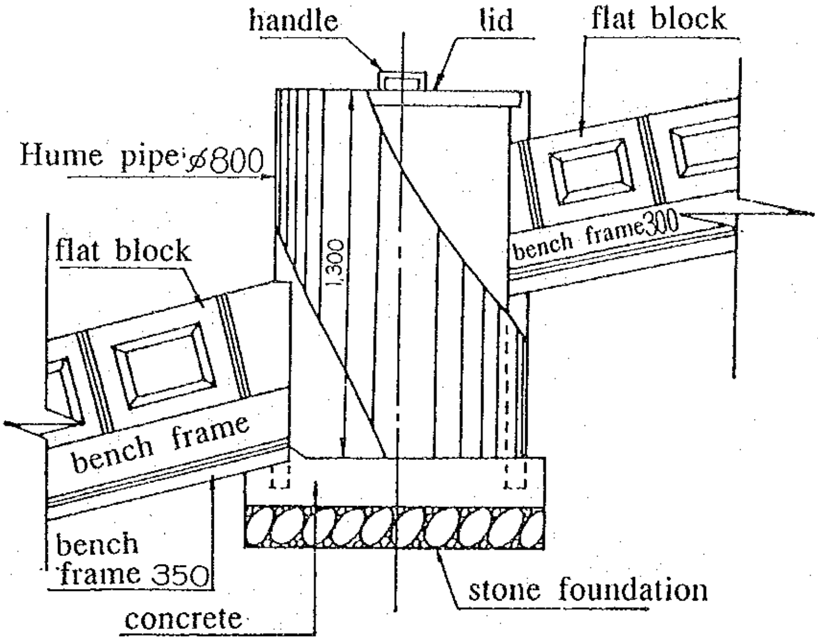


Figure E.1 Usual Layout of Drains

Side View



Plan View

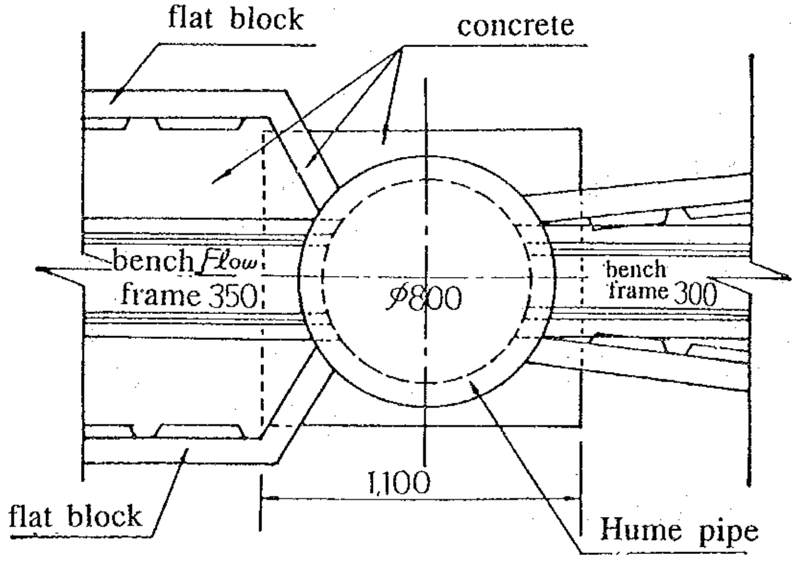


Figure E.2 Stilling Basin

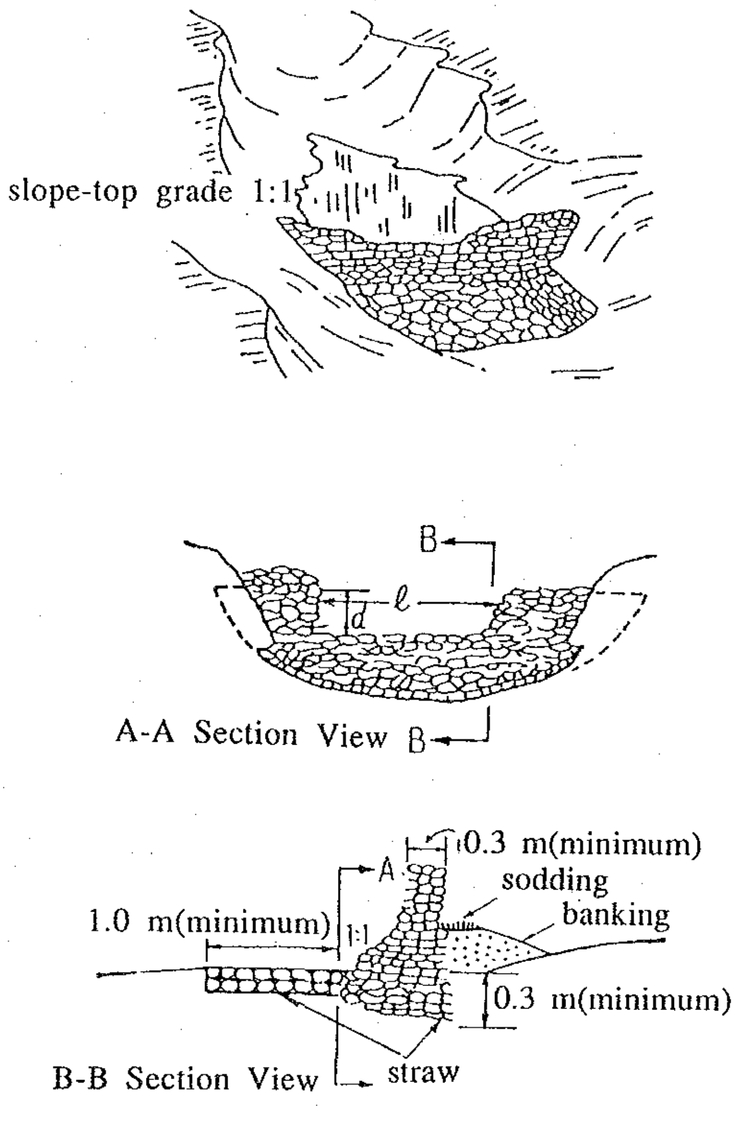


Figure E.3 Prevention of Gully Erosion by Stone Paving

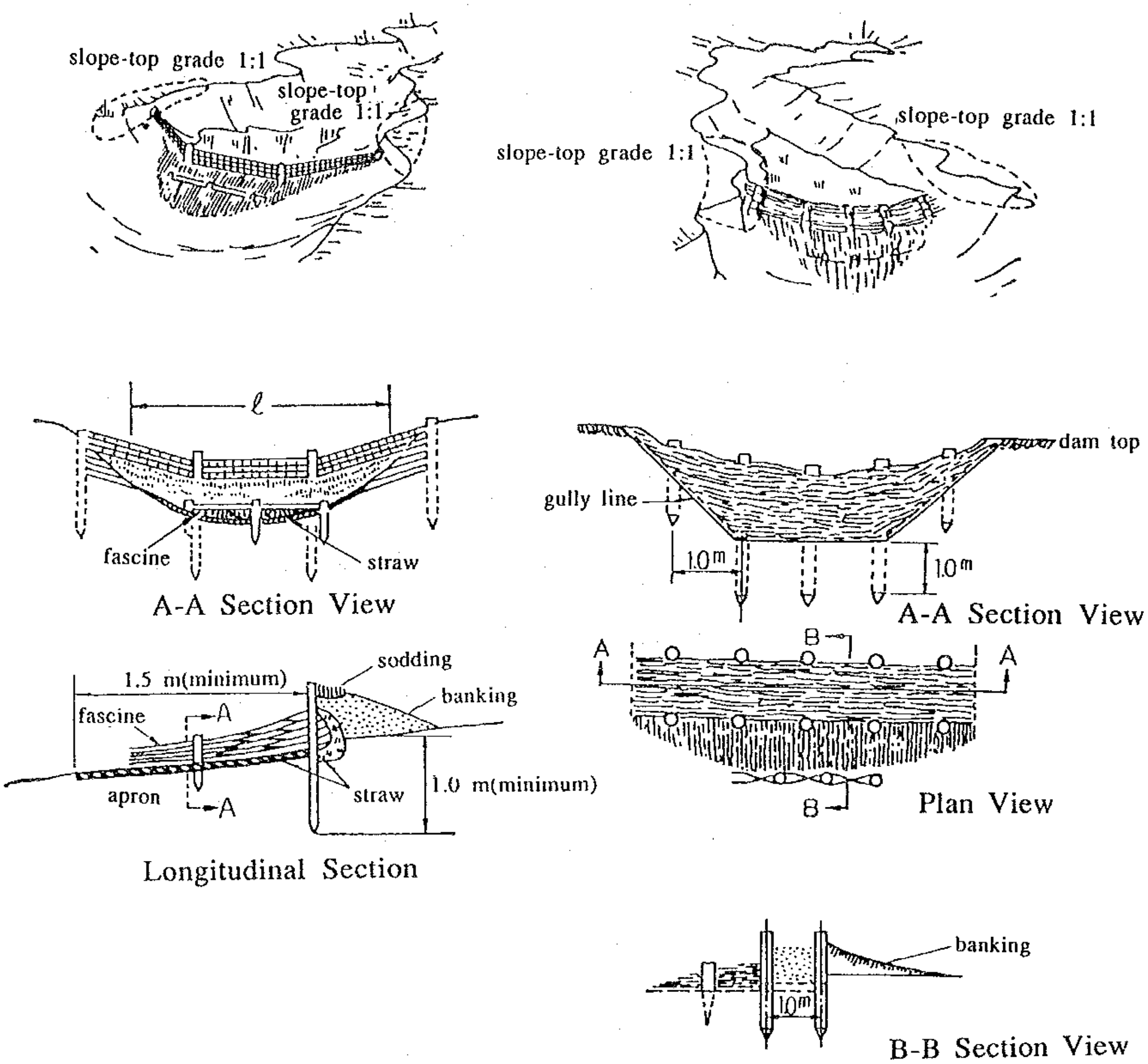


Figure E.4 Control of Gully Erosion by Using Poles and Twigs

APPENDIX

APPENDIX E.1

APPENDIX E.1

"A-FRAME": A SIMPLE TOOL FOR ESTABLISHING CONTOUR LINES

1. General

One problem faced by farmers is how to draw the contour lines first so that they can establish the tree rows or hedges along these contours and make sure that all trees along each row are planted at the same elevation. There are accurate instruments for leveling, such as hand held levels or tripodmounted levels used in surveys by engineers. There is also the carpenter's level. However, these are generally unavailable and too complicated for the common farmer. What is needed is a simple instrument that can be easily built and conveniently and accurately used by the farmers themselves. The A-frame is such a tool. The following is an outline of the instructions for building and using an A-frame:

2. How to Build an A-Frame

(1) Procure the materials needed

a) Two poles 1-1.3 m long; one pole 1m long (if available, 3 cm by 3 cm lumber may be used).
b) Sufficient length of twine or string or wire (or nails) for fastening the poles together.
c) A rock of about 5 cm in diameter to be used as a weight or plumb bob.
d) A piece of string 2 m long to hold the plumb bob.

(2) Build an A-frame

a) Lay three poles (or pieces of lumber) on the ground.
b) Tie (or nail) the poles firmly together.
c) Attach the rock firmly to one end of the string.
d) Tie the other end of the plumb bob string to the top of the A-frame so that when the A is standing, the hanging rock or plumb bob is below the horizontal bar but not touching the ground.

(3) Prepare the A-frame for use

a) Hold the A-frame erect on nearly level ground so that leg-A is on point-1, while leg-B is on point-2.
b) Mark the point where the plumb bob string touches or crosses the horizontal bar.
c) Reverse the position of the A-frame so that leg-A is placed on point-2 while leg-B is on point-1.

d) Mark the point where the plumb bob string crosses the horizontal bar.

e) Measure the distance between the first and second marks on the horizontal bar and mark the third or middle exactly between them.

f) The A-frame is now ready for use. If it is held erect so that the plumb bob string touches the middle mark, the points where leg-A and leg-B are standing are at the same level or elevation.

3. How to Use the A-frame

(1) Mark point-1 (where you want to start the row of trees) on the slope. Place leg-A of the A-frame on the point.

(2) By trial and error, find the proper location of leg-B (without moving leg-A from point-1). When the plumb bob string coincides with the middle mark on the horizontal bar, mark the location of leg-B as point-2. This is on the same level as point-1 (Caution: When the wind is strong, it may push the plumb bob string from the vertical line and the A-frame may give wrong results. To avoid errors, shelter the plumb bob from the wind or avoid using the frame on windy days).

(3) Continue the process until a series of points are established on the slope. All these points have the same elevation, and a line connecting these points is a contour. A row of trees planted along this contour line is a contour hedge.

(4) Establish the next contour line (either above or below the first one) by following the same procedure mentioned above.

APPENDIX E.2

APPENDIX E.2

PHYSICAL EROSION CONTROL MEASURES

1. Introduction

A physical measure is a type of soil conservation technique which usually requires ground works and materials other than the plant species which are grown for controlling erosion. It is usually applied to sloping farmlands primarily to prevent the washing out of soil caused by rain water. The materials are rocks, stones, parts of plant species, and earth from canals and ditches. The application of a structural measure is advantageous in small sloping farmlands. The growing of plant species on this type of farmlot, a vegetative measure, may reduce the productive space for agricultural crops due to close shading and the wider area to be used for growing trees. Although vegetative or agronomic control measures are very efficient and productive, they are not completely appropriate for all types of erosion. Physical structures are generally used in places where vegetation cannot be immediately established and in gullies, channels, or river and road banks that have to be stabilized and protected. Physical structures are erected for the following purposes:

- to divert runoff to where it can be safely disposed,
- to reduce the velocity of runoff and prevent souring of the land, and
- to provide an effective barrier for sieve moving of soil and reclamation of eroded areas for vegetation to grow.

2. Gully Control

2.1 General

Gullies are formed by excessive surface runoff which flows with a high velocity and force that is sufficient to detach and carry away soil particles. In controlling gully erosion, the following considerations are important:

a) Improvement of the catchment area of the gully to reduce and regulate runoff water,
b) Stabilization of gully head to prevent further scouring in the gully,
c) Safe drainage of water through the gully, if it is part of the natural drainage, and
d) Reclamation of the gully area if it is not a part of the natural drainage system.

2.2 Improvement of the Catchment Area

Experience shows that complete gully control cannot be achieved without proper treatment of the drainage area, as well as the gully itself. No gully, caused by a poor watershed, can be properly controlled without proper treatment or protection of the upper catchment area. If gully formation is caused by a denuded watershed with excessive runoff, the vegetative cover should be reestablished. Grasses, shrubs, and trees increase infiltration and the water absorbing capacity of the soil. In critical conditions, surface runoff can be reduced by contour bands made from intercepting drains that run along the contour, behind which surface runoff can be retained and gradually absorbed into the soil.

2.3 Stabilization of Gully Head

Before gully control measures are applied, runoff should be diverted from the head of the gully. This principle generally applies to all gullies, except for those with a small drainage area with negligible runoff. A diversion canal is a ditch like combination with the ditch on the upper side. The ditch can be a "V" or "U" shaped. The U or flat bottom ditch has better flow characteristics and carries water at a low velocity. Diversions steer runoff away from gully heads, serve as spillways to lead water from small earth dams, protect critically planted areas from washing, and flood irrigated dry sites. The canal should be located on stable slopes, far enough away to prevent sloughing into the gully overfall. The diversion ditch is dug above the gully head at a distance of once or twice the depth of the gully.

Diversion ditches should be large enough to carry all the water that will discharge from contributing drainage areas during periods of maximum runoff from the 5-10 year highest rainfall, but large flows of more than 0.5 m^3/s should be avoided. The ditch should empty its flow onto spreading areas which are or can be made resistant to erosion, like rock cropping out of the soil surface, sod, or brush areas. Water spreaders made of wire, rock, brush, or a combination of these materials may be prepared for this purpose.

2.4 Stabilization of Gullies

To check the gully from scouring backward, the gradient of the gully needs to be reduced to less than 45°. The surface of the gully is then stabilized by either sodding, brush cover, riprap interplanted with cuttings, a pole structure or solid structure of rip-rap, gabion or concrete, depending on their availability. After treating and improving the watershed and stabilizing the gully head, the gully beds have to be treated for prevention of further erosion. This is primarily achieved by: i) Earth plugs, ii) Brush fills, and iii) Check dams of available materials.

Earth plugs are a series of small earth fills placed across small or medium gullies. The spacing is determined by running a line from the water level of the earth dam upstream to the channel bottom where another plug should be placed. The earth fills are raised above the ground level and short diversion ditches are sometimes used to lead overflow away from the ends of the fill to prevent erosion damage and to spread water.

Brush fills comprise brush packed into small gullies not exceeding 1 m x 1 m in size starting at the very head. Shrubs, brush, and small trees need to be trimmed to permit compost placement. The gully should be lined first with small branches to prevent soil erosion. The objective is to obliterate the gully with soil held by the brush. Live branches or limbs that may grow later are preferred.

2.5 Check Dams

Check dams are constructed in small or medium gullies by either infiltration in soil or by diversions. Check dams can be temporary or permanent. If the volume of runoff conveyed through gullies is not greater than what can be controlled by well established vegetation, a temporary check dam may be used during vegetation establishment. Permanent structures should be resorted to only if the runoff volume cannot be controlled by vegetation.

(1) Temporary Check Dams

The main purpose of temporary check dams is hold soil and moisture at the bottom of gullies until vegetation can be established. Low check dams are less likely to fail and after they silt up and rot away, the vegetation can control the low overfalls much more easily than in high dams. The average effective height of temporary check dams is about 30 cm, and should not exceed 0.5 m. The effective height is the vertical distance from the original gully bed to the spillway crest of the structure. This type of dam is more successful in gullies with small drainage areas. The location and spacing of check dams are determined at strategic places where plant growth can be protected and facilitated.

Check dams should be well anchored into the ground to prevent washout underneath or sound ends of the structure. They should have a sufficient spillway capacity to convey runoff at the maximum expected rate during the life of the structure. A spillway apron will be necessary to prevent undermining of the structure. It is desirable to have the notch at a greater depth. There are several methods of check dam construction as described below. The selection of a method primarily depends on the available material, size, and characteristics of the gully.

a) Brushwood dams are temporarily constructed in areas where stones are not available. These are best suited to gullies with small drainage areas and soil conditions where posts can be driven. Several types of brushwood dams are in use. Sprouting or non-sprouting brushwoods are placed between two rows of pegs or posts driven into the soil 40 cm apart across the gully bed with the foundation dug well into the banks. The distance between the rows of pegs or posts is about 1 m for a 5 m gully. The brushwood is packed firmly between the two rows and tied by a wire. Any type in use should have a spillway at the center, lower than the end. On the lower side of the dam, branchwood is placed lengthwise to form an apron to prevent scouring by overflow.

b) Log or pole dams are constructed by using two rows of vertical poles which are driven into the bed of the gully, extend to the sides above the flood level and which are spaced at 60 cm to keep the horizontal poles in place. In a wide shallow stream, it is best to leave all posts more than 0.5 m above the ground, so that the top of the posts follows the surface of the stream bed. If the gully has steep sides, it is better to make a rectangular notch at the center that is big enough to allow flood passage. The second method is a structure in the form of a single row of posts driven side by side to form a wall of logs secured by horizontal poles. Some of the poles are placed lengthwise below the check dams to serve as an apron.

c) Stone or loose-rock dams are commonly used in gully control as dry-rock walls. The construction of a loose-rock dam starts with the smothering of the gully banks of the dam site with a slope of 45°. Then, the foundation of 30-50 cm deep, extending into the banks, is dug and the excavated soil is piled upstream to be used for refills. The largest rocks are laid at the bottom. This is followed by another layer, in rows, across the gully with sufficient overlap to produce a shingle effect until the dam is built to the required height. Periodic inspections, repair and maintenance of these erosioncontrol structures must be carried out, particularly after heavy rains to ensure proper functioning.

(2) Permanent Check Dams

Gully control should be achieved as much as possible by vegetation and the use of simple structures, but there are cases where only permanent structures solve the problem. Permanent dams are constructed from durable materials, such as reinforced concrete, masonry, and earth with permanent spillways. Permanent dams may be recommended when the following gully control conditions exist:

- Volume of runoff cannot be controlled by vegetation,
- Soil is very unstable,
- Area is remote and regular maintenance is difficult; and
- Temporary dams are inadequate (cannot withstand floods) or impractical (have a short life span).

Permanent check dams are located in such a way that the line of discharge from the spillway is parallel to the centerline of the gully immediately below the dam. This will prevent side-cutting of the drainage channel below the surface. These check dams are named according to their use or the materials for construction.

a) Silt Trap Dam

When excessive sediment load threatens the water supply to the downstream area and trapping of silt by vegetation is not sufficient, a silt trap dam is necessary. A fast and positive reduction of sediment movement can be achieved by constructing permanent silt trap dams. The requirements and design of such dams are similar to those of water storage dams. The maximum storage capacity at minimum cost should be considered and storing water in a few large dams is usually more economic.

b) Gully Head Check Dam

To check the advance of gully head scoring, a permanent check dam will be necessary to stop the active head moving upstream. This dam is used to elevate a silting gradient up to 0.5 to 3 % from the spillway crest to the rim of the gully head.

c) Masonry Check Dam

This dam is used in gullies or small stream channels with high rates of runoff or where vegetation cannot be established and rocks or stones are available. Hollow concrete blocks, tiles, or any hard and durable material are also used. The minimum thickness of all walls should be 30 cm. The slope of the downstream side of the dam below the spillway should be at least 1 : 2. The thickness of the base must not be less than three-fourths of the height of the dam. (See Figure AE.1)

d) Concrete Check Dam

A concrete dam is recommended where materials for masonry check dams are not available or inadequate. The same general specifications for masonry and concrete structures can be used for concrete dams. One of the disadvantages of masonry and concrete structures is that they are very inflexible and not easy to repair when damaged.

e) Gabions

A gabion, which is a large rectangular wire crate filled with stones, is a very common erosion control technique which originated in Italy. It is flexible, permeable, and economic in places where stones are abundant. Besides stabilizing gullies, gabions can also be used in flowing water for land reclamation along shores and retaining walls. Gabions may be constructed from locally available wire mesh with a diameter of not less than 2.5 mm. A gabion 2 m x 1 m x 0.5 m in size requires 10 m^2 of mesh wire, 12 m of iron rod 7 mm in diameter and 10 m of tie wire. The mesh wire is formed into a rectangular basket by tying its edges. The iron rods are tied around the basket for reinforcement.and cross ties are made to keep the gabion in shape during filling.

Before being filled with stones, it is placed in position to form a check dam or retaining wall. Stones larger than the mesh should be riprapped in front of the gabion while it is being filled. The bank or inner side can be roughly filled. After filling, the cover of the gabion is sewn along the front edge and sides. Gabions placed side by side or on top of one another are connected with a strong galvanized wire.

3. Riverbank or Stream Bank Erosion Control

Stream bank erosion is frequently associated with gully erosion because it is essentially a process of lateral cutting. Gullies often begin at the banks of natural water courses and by waterfall erosion, and move back into adjacent lands. In addition, portions of the bottom land are frequently damaged by bank erosion that occurs along many of the streams. This is particularly noticeable at the bends of winding channels.

In controlling bank erosion, temporary jetties, wing dams, fences, trees and cable revetments, or other types of deflectors are usually necessary along the eroded bank before vegetation can be established. In large channels, bank protection works should always incorporate vegetative measures with structures. Conservation measures in watersheds have a direct bearing on the success of protection of channels and banks. Channel stabilization works can never give the maximum protection if abnormal floods rip out or clog the channel.

Before selecting the type and design of bank protection, the technical feasibility should be determined. Causes of instability should be determined early and removed or treated. Bank protection and channel stabilization works are accompanied by mechanical control devices. Plantings should be as carefully planned as the mechanical structures used in river control works. Several methods have been developed to reclaim or prevent erosion damage along river banks.

4. Terracing Works

On steeper slopes, where simple conservation practices are insufficient to prevent erosion, bench terracing is considered the most effective practice. Well laid out bench terraces, even on slopes of up to 35 %, can prevent erosion and increase water infiltration. Generally, slopes of up to 25 % should be the limit for land leveling by bench terracing. Bench terracing is also applicable in reducing current steep slopes to stable ones. The degree of stable slope depends on the site-specific conditions. Possible stable slope is tentatively set at less than 15 %, but it must be revised based on the data obtained by actual projects and surveys. On steeper slopes, plantations on small contour benches and the permanent cover crop on the slopes are safer and no losses of land occur through terrace risers.

4.1 Contour Bunds

Erosion is generally severe in the cultivated uplands and a variety of practices can be applied to prevent erosion and restore and improve productivity. On small plots and gentle slopes, contour cultivation, contour ridges, and grass strips are more feasible. Cooperation between farmers is essential, especially for surplus water drainage systems, such as intercepting and collecting drains. Land consolidation is certainly very important. The contour bund method is considered the simplest physical method. Construction of simple earth bunds along the contours or land slopes can control the velocity of runoff and facilitate the permeability of soil. Runoff water controlled by contour earth bunds is to be diverted to a natural waterway by graded drains. It is important to cover the slope of the bunds with grass.

4.2 Bund Terrace

This method commonly seen in hilly areas is considered one of the effective physical methods. Bunds are arranged like a leveled flight of steps and are made by cutting a section of the slope inward and filling the adjacent section. Before cutting the terrace, 1ft (0.3 m) of fertile topsoil should be removed and kept aside. After cutting and preparing the terrace, the cut topsoil should be spread on the terrace surface for an enhanced harvest. (See Figure AE.2)

4.3 Broad Base Terrace

This has broad bunds of about 40ft (12 m) with drains cut above them and in some instances the height is between 0.1-0.3ft (0.03-0.09 m). Since this method is more advantageous for lands with mild slopes less of than 24 %, it is not preferable for the up-country area. (See Figure AE.3)

4.4 Ridge and Furrow System

Crops like potato and cabbage are grown in terraces, especially in lands with mild slopes where ridges and furrows are erected parallel to the contours of the land. As the ridges and furrows are erected across the slope, the velocity of water is reduced and this makes for better drainage round the root system of the crops since they are cultivated on the terraces. In this system, drains in the terraces and furrows can be considered as side drains connected to the collecting drains that convey water.

4.5 Bench Terraces with Soil Risers

Bench terracing is probably the most effective soil conservation practice on sloping land. It is also the only possible practice that can reclaim land for cultivation on slopes of over 8-10 % and up to 35 %, sometimes even up to 55 %, for the production of sustained yields of agricultural products. This is a major method of conserving soils where cultivation is carried out on steep and eroding slopes or on lands which are now under less intensive use, such as grazing, but have sufficiently deep soils to be permanently converted into agricultural land.

The most important step in successful land conversion from badly eroding or under-used lands to highly productive crop lands is the selection of sites. The following factors have to be considered:

a) Good soil texture with sufficient depth

Sandy and coarse soils should be avoided. Conversion should be started in good loamy sands to heavier textured soils. The minimum depth of the section to be replaced should not be less than 30 cm for annual crops. Plantations need deeper soils for the development of root systems. Therefore trees should always be planted on the fill section near the riser, where the soil is the deepest and most fertile.

b) Topographic features and crop adaptation

Areas with a greatly undulating topography should be excluded. Depending on the intended cropping pattern, annual crops should be planted on terraces with 5-25 % slope. Orchards may be planted in areas with over 35 % slope and very narrow bench strips.

c) Participation of farmers

Bench terracing without the participation of farmers has been unsuccessful. Many cases have been observed in which farmers have agreed to conversion under pressure from officials. These areas are, in most cases, poorly farmed or not cultivated at all.

(1) Design and layout

In designing terraces, natural features should be used, where possible, in siting waterways and paths. A base line at a right angle to the contours (directly up and down the slope) should be established near their center and on a line of approximately average slope for the area to be terraced. Using a level, pegs should be placed at 1m vertical intervals on the baseline. The level will have to be set up several times if the land is steep (See Figure AE.4). These pegs form the base from which the "contour lines" are pegged out on the ground. Once again using the level, pegs are placed at the same elevation, about 10m apart (or closer if the terrain is irregular) and then joined with a rope. After the setting out, the pegs are realigned, to smooth out the contour lines for easier construction and subsequent cultivation between them.

Collecting drains should possibly be sited in small natural depressions, but they should not be more than 100 m apart . The width of a collecting drain varies from 0.5 m to 4 m at the bottom depending on the catchment areas and slopes. The bed of the waterway has to be nearly level and well sodded or seeded with grass, in order to reduce water velocity. Also it is necessary to construct drop structures to reduce velocity. These should be constructed of stone, but as an alternative, well sodded drops may be used.

When the area to be terraced does not extend to the top of the watershed, the runoff from above must be diverted into waterways passing through or around the terrace area. Therefore, it is necessary to construct intercepting drains. The maximum length of the ditches should be half the distance between the waterways and their grade should be 0.5 to 2.0 %.

(2) Construction

Since each individual terrace is formed by the balancing of the cut and fill volume, construction of bench terraces may start at any point after the setting out has been completed. However, it is recommended that the works should commence with the construction of intercepting drains and should then proceed downhill. Thus, there should be no problem with runoff during construction. Furthermore, the risers should be sodded or seeded with grass as soon as they are completed.

The surplus of backfill soil should be placed on the fill side of the center line of the bench. In normal circumstances this makes the outside of the bench 10 cm higher than the center at the time of construction. This fill material soon settles to form an almost level terrace. To prevent water spilling down the riser, a ridge of 10 cm in height and 20 cm in width is built along the lip of the riser. This material is obtained from the excavated drains at the bottom of each riser (See Figure AE.5). It is recommended that the terrace needs a slight back-slope, if possible.

Collecting drains and their sides should be constructed with a series of drops, to reduce the velocity of runoff water and if possible, the drops should be made of stone or equivalent materials. The elevation of the top of the drops should be near the original ground level, between the center of the bench and the top of the riser. Moreover, the drain at the bottom of each riser should run into the waterway at the same level (See Figure AE.6). On completion of the earth moving works, the risers should be trimmed to 2 : 1 slope and sodded. Sodding should be carried out in continuous strips of not more than 20 cm apart. Risers may be protected from erosion by seeding, this method requires much less labor than sodding.

As an example, Table AE.1 summarizes the physical characteristics of bench terracing with a standard vertical interval (VI) of 1 m. On slopes of up to 10 % a lower VI should be used depending on the crops or rotation and farm machinery to be used. On slopes of over 25 % no bench terracing with 1 m VI should be carried out. In fact, such slopes should not be normally used for arable crops. It is evident that the width of the cultivable benches on a slope of 25 % is only 2.5 m out of a total width of 4.0 m of terrace, 1.5 m are lost on the riser. On a slope of 35 % the width of the bench is only 1.36 m and 1.5 m are occupied by the riser. A 25 % slope should be the maximum of bench terracing for arable crops if animal or mechanical power tools are used. Preferably the limit should be set at 20 %.

On steeper slopes, narrow benches may be cut, but only for tree plantations. The VI to be used between these benches depends on the space required for the specific tree crop. There is no loss of land for risers as the root and air space is provided by the horizontal distance between the benches. For each tree a wider basin should be constructed, by cutting into the slope and filling the material on the downhill side. A permanent and dense cover crop is essential. As for the trees, an individual basin weeded around each tree is very effective against erosion, and the cost is much lower. On a slope of 30 %, the risers would be only 0.3 m high and the total earth movement would be about 750 m^3/ha. The standard bench terrace with a 1 m VI on a 30 % slope would require 1,642 m^3/ha of benches.

4.6 Bench Terraces with Stone Walls

This method is justified where stone can be found in adequate quantities close to the site and the potential productivity of the land pays the expense. Its construction at intervals on the contour not only protects the land from erosion, but simultaneously reduces the number of stones, which facilitates cultivation and increases crop production. To justify the relatively high cost, intensive land use is necessary.

The building of stone terraces is preferred in stony lands where the cutting of drains is difficult. Stone terraces can control the velocity of runoff. Also the eroded soil is retained by them whilst the water escapes through the stones. The base of stone terraces must be about 3ft (0.9 m) wide and made of large stones or boulders. The terrace must be anchored by the existing natural rocks to strengthen its structure. The top of the terrace should be about 1ft (0.3 m) wide and the side towards the hill should be 1.5ft (0.5 m) high. Also the upper section of the terrace should be of a uniform level. The lower slope section of the terrace must slope towards the hill.

(1) Determination of intervals between bench terraces of level cross section

The horizontal distance is determined by the height of the retaining wall and a slope of the land. Thus, it can be expressed as follows:

$$HD = H/S$$

where
HD : horizontal distance (m),
H : height of the retaining wall (m),
S : slope (m/m)

This formula only applies to those bench terraces where a retaining wall is provided and back filling is carried out (See Figure AE.7). This method is the most expensive and is only used when there is insufficient soil depth on site to be reclaimed. Usually, bench terraces of level cross section are constructed by moving soil from the upper part down to lower part (See Figure AE.8). In this case, the horizontal distance can be expressed as follows:

$$HD = (H1 + H2)/S$$

where
H1 : depth of excavation in the upper part of the terrace (m),
H2 : height of fill in the lower part of the terrace (m)

Although this method is cheaper than the previous one, it is still fairly expensive. Level bench terraces have many advantages, but suffer from the following drawbacks:

a) They are too narrow for machinery to be easily used,
b) Many high retaining walls are needed. Thus, the cost increases for reclamation and tillage due to difficulties of access to the benches.
c) After construction, the soil depth in the upper part is often too shallow for plantation.

(2) Determination of intervals in the presumed stable slope

The disadvantages mentioned above may be largely overcome by designing bench terraces on the principle of stable slope. This design is practical for steep slopes to gentle ones. However, stable slope changes for different soils, local observations and experiences. Thus, it is recommended to reach fairly exact conclusions from reviewing the conditions of a given cultivated soil and comparing its stability against erosion seen in different slopes. The interval can be calculated as follows:

$$HD = 2(D1 - D2)/(S1 - S2)$$

where

D1 : present depth of the soil (m),
D2 : minimum soil depth required by crops (m),
S1 : present slope (m/m),
S2 : presumed stable slope (natural or artificial) (m/m).

The stable slope may be achieved in two ways, namely: i) by transporting soil from the upper part of the terrace to the lower part using earth moving equipment, and ii) by leaving it to be done by cultivation and nature over a period of years. When an area is being reclaimed for orchards, it may sometimes be worthwhile to subbench the individual rows before planting. With rotation crops, it is advisable to let nature and cultivation do the job of benching. The cost is thereby reduced and it is easier to build up and maintain soil fertility (See Figure AE.9).

(3) Retaining walls

Walls are constructed from stones collected on the spot. As a rule, close and low retaining walls are preferable to high walls set far apart. The height of a stone retaining wall is given as follows:

$$H = (H1 + X1) + (H2 + X2)$$

where

H	:	height of the wall,
H1	:	depth of the soil (presumed to be lost by creep, at the foot of the wall),
H2	:	depth of the soil (presumed to be deposited near the wall),
X1 and X2	:	safety factor (usually 30 cm and 10 cm).

The formula is readily understood when it is considered that the wall on the lower side must be sunk into the ground by an amount equal to the depth of soil which is expected to be removed by creep (plus 20 cm safety factor), and that on the upper side must rise above the ground surface by an amount of equal to the depth of deposition expected (plus 10 cm safety factor) (See Figure AE.10).

(4) Drainage of gravitational water

It is frequently observed that great amounts of water percolating through the retaining wall wets the terrace below it after rainfall. In order to drain this water, weep holes are provided at the foot of every retaining wall. These furrows need not have a large capacity, since they only conduct small quantities of water, but they need a continuos longitudinal grade. For this reason, it is important to grade the strip along which the furrow is to run (See Figure AE.11).

(5) Discharge of runoff water

A common practice is to divert runoff from the cultivation furrows into collecting drains made of concrete or stone which run straight or diagonally down the slope. However, such drains cannot be used in areas where cultivation is mechanized and wide and shallow vegetated waterways are not practical on slopes exceeding 15 %. Thus, the following two methods are usually applied:

a) Combining vegetated waterways with drop structures of stone or other material

The drop structures in the waterway are of the rubble riprap type, and their height is determined by discharge. Where retaining walls are set far apart, it may be necessary to construct additional drops in the waterway (See Figure AE.12).

b) Paving drains and waterway with stone

This method is rather costly, but it has a particular advantage in that the waterway can be used as a field track. The cost of the provision of tracks on steep areas is a fraction of the total cost of reclamation, so that combining the waterway with the field track is a promising solution.

(6) Cost of construction

The cost of constructing stone walls is rather high. It is impossible to give standard costs per ha, because in each location and for each crop there are different requirements. However, a few indications can be given for the estimation of the cost. Stone walls should have a width of about 0.3 m at the top and not less than 0.8 m at the bottom if they are 1 m high. At least 0.3 m should be buried in the ground as a safe foundation. This depth of foundation has to be calculated after the removal of soil for the fill in the lower terrace. Thus, a 1 m length of terrace will require 0.55 m^3 of stones, for example. The building of stone terraces is a specialized job which requires much experience.

4.7 Rockwalls

(1) Description

Rockwalls are structures which are made of large stones, rocks and boulders piled up along the contour of a hillside to provide an effective barrier to the downward movement of soil and water. The rockwalls are walls of stone running across the slope at regular intervals depending on the degree of slope of the hillside. Economic crops like corn, rootcrops, and other agricultural crops are raised in between the rows of the structures. The structures can be further stabilized by planting fast legume trees and grasses along the upslope and downslope portion of the wall.

(2) Design and construction

Rockwalls are usually built in upland areas where there is an abundant supply of rocks, stones, and boulders. An area of about 1m wide along the identified contour lines, by an A-frame, is leveled to provide a good base for the wall. Whenever possible, a shallow ditch can be dug along the identified lines to further stabilize the base materials while smaller rocks and stones, can be used to fill up the upper portions of the structure. The wall should be between 0.5 to 1 m in height, and should incline towards the top to provide more stability. The walls may be further stabilized by planting fast growing legumes and grasses. Rockwalls require a great deal of labor input at the construction stage. One farmer can construct rockwalls only at a rate of 14 linear meters per man-day (1 m high) if the rocks and other materials are readily available in the field.

Despite the high labor input, rockwalls are considered very effective soil erosion control structures. Firstly, they immediately serve their purpose after construction. For upland farms characterized by large amounts of scattered rocks, clearing is generally quite simple making field preparation activities easier. Lastly, rockwalls are usually supported by fast growing legumes and grasses, which are potential sources of animal feed, fuelwood, organic fertilizer, and mulching materials.

Table AE.1 Area and Volume for Bench Terracing for Different Percentage Slopes with Benches at 1m Vertical Interval

Ground slope	%	5	10	15	20	25	30	35
Width of benches1/	m	18.50	8.50	5.17	3.50	2.50	1.83	1.36
Width of bench terraces	m	20.00	10.00	6.67	5.00	4.00	3.33	2.86
No. of benches per 100 m of slope	-	5	10	15	20	25	30	35
Maximum depth of cut (excluding drain)	m	0.47	0.45	0.42	0.40	0.37	0.35	0.32
Area of benches1/per ha	%	0.925	0.850	0.775	0.700	0.625	0.550	0.475
Slope area of riser per ha . . .	m^2	919	1 838	2 758	3 667	4 596	5 515	6 434
Volume of cut per ha of bench terraces	m^3	1 175	1 135	1 077	1 020	963	903	847
Slope area of riser per ha of benches	m^2	994	2 162	3 559	5 253	7 354	10 027	13 545
Volume of cut per ha of benches	m^3	1 270	1 335	1 390	1 457	1 540	1 642	1 783

1/ Area on which cultivation can take place.

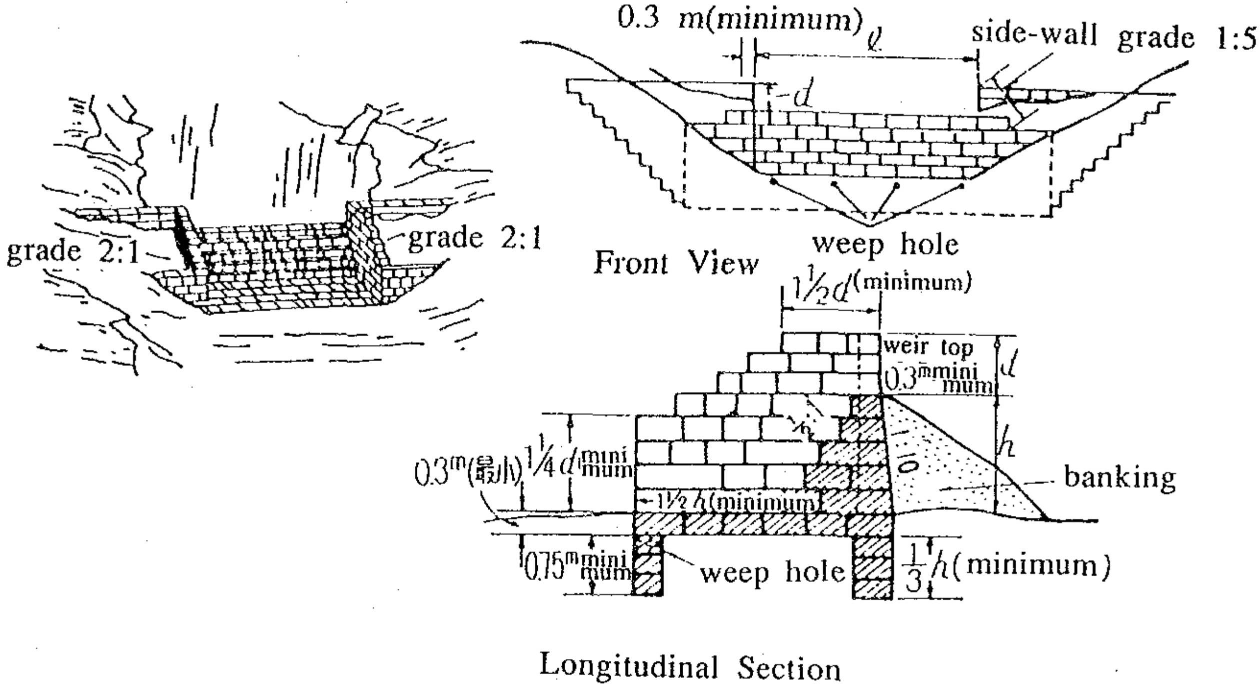
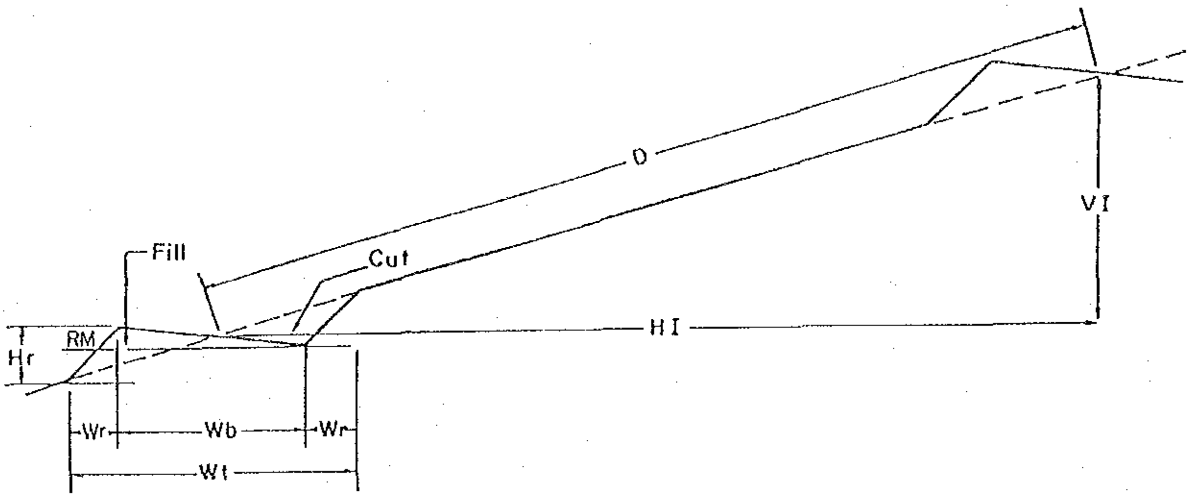


Figure AE.1 Masonry Check Dam



SYMBOLS AND COMPUTATIONS

Width of Platform	:	Wb	=	2 m
Theoretical Vertical Interval	:	TVI	=	$\frac{S \times Wb}{100 - S \times U}$
				(S : slope in %; U : 0.75 or 1)
Reverse Height	:	RH	=	Wb x 0.10
Height of Riser	:	Hr	=	(TVI + RH)/2
Width of Riser	:	Wr	=	Hr x U
Width of Terrace or Ditch	:	Wt	=	Wb + 2 Wr
Vertical Interval between two Ditches	:	VI	=	(Sx4)/10, (S+6)/10, etc.
Horizontal Interval	:	HI	=	(VI/S) x 100
				(or VI/tan of slope angle)
Inclined Distance	:	D	=	VI/sin of slope angle
Linear Length	:	L	=	10,000/HI(per ha) or 1,000/HI+Wt
Area of Platform	:	A	=	L x Wb
Percent of Platform	:	Pb	=	(A/10,000) x 100 (per ha)
Cross Section of Ditch	:	C	=	Wb x 2 Hr/8
Volume of Cut and Fill	:	V	=	L x C (per ha)

Figure AE.2 Bund Terrace

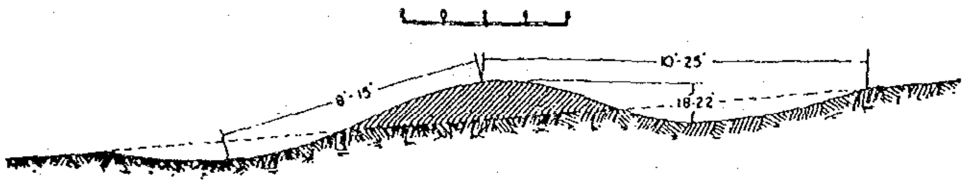


Figure AE.3 Broad Base Terrace

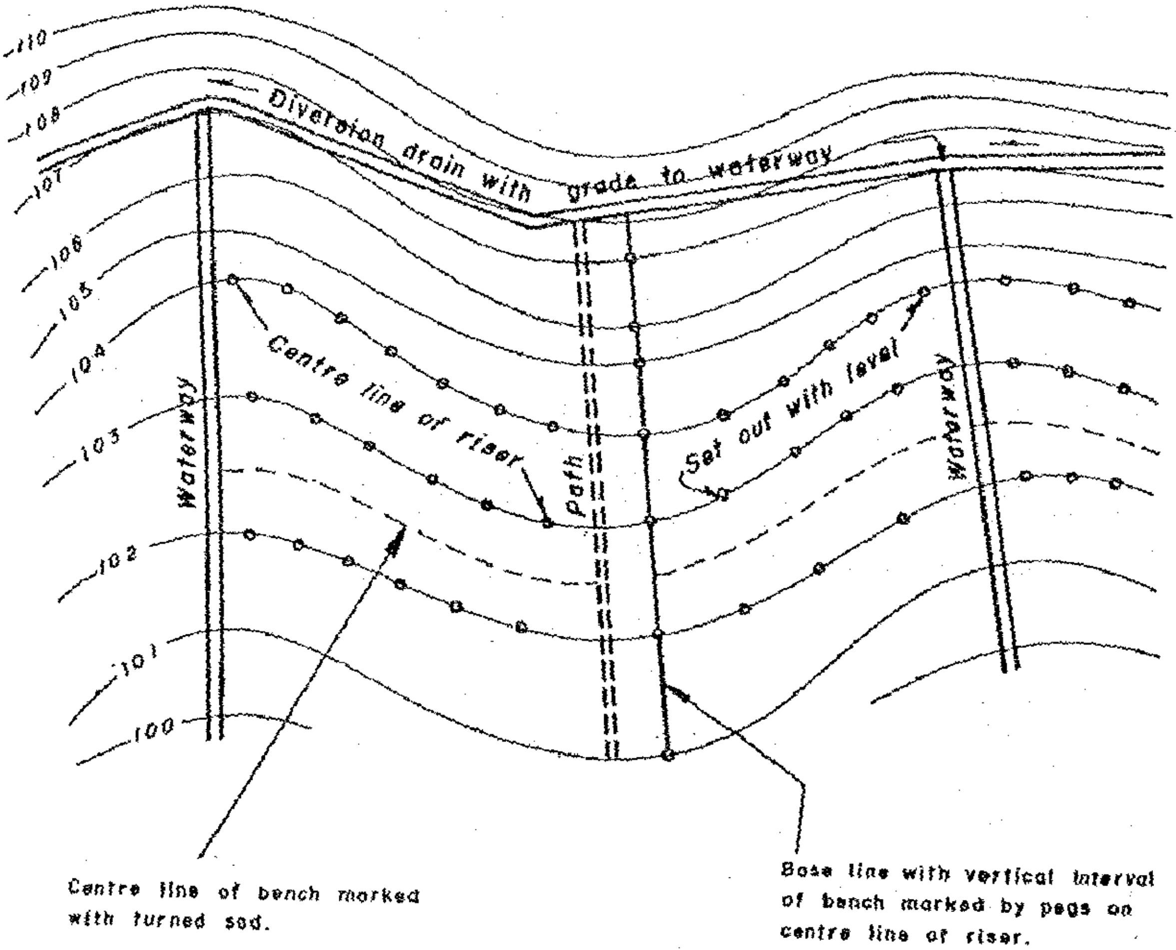


Figure AE.4 Layout for Bench Terraces

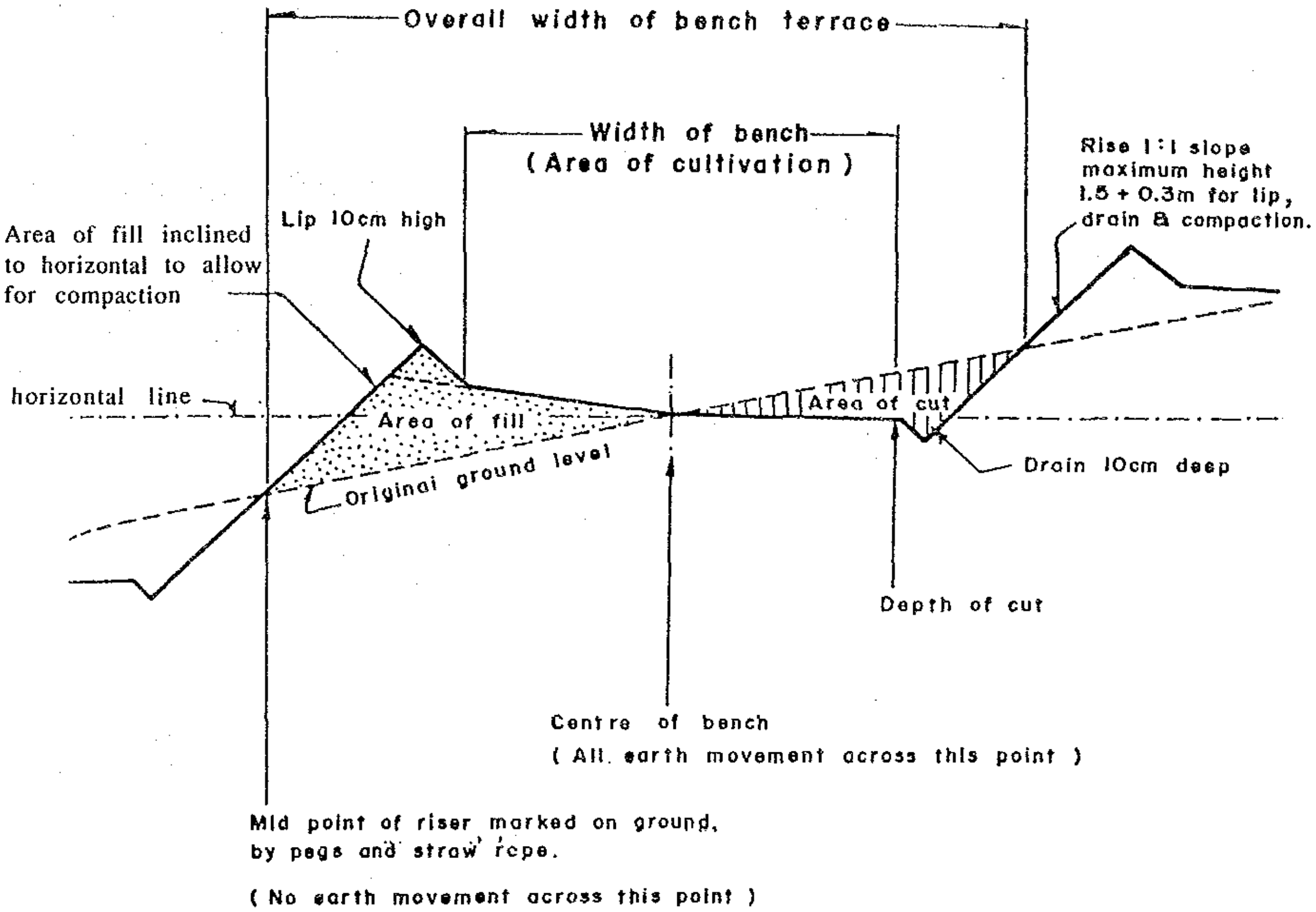


Figure AE.5 Cross Section of Bench Terraces

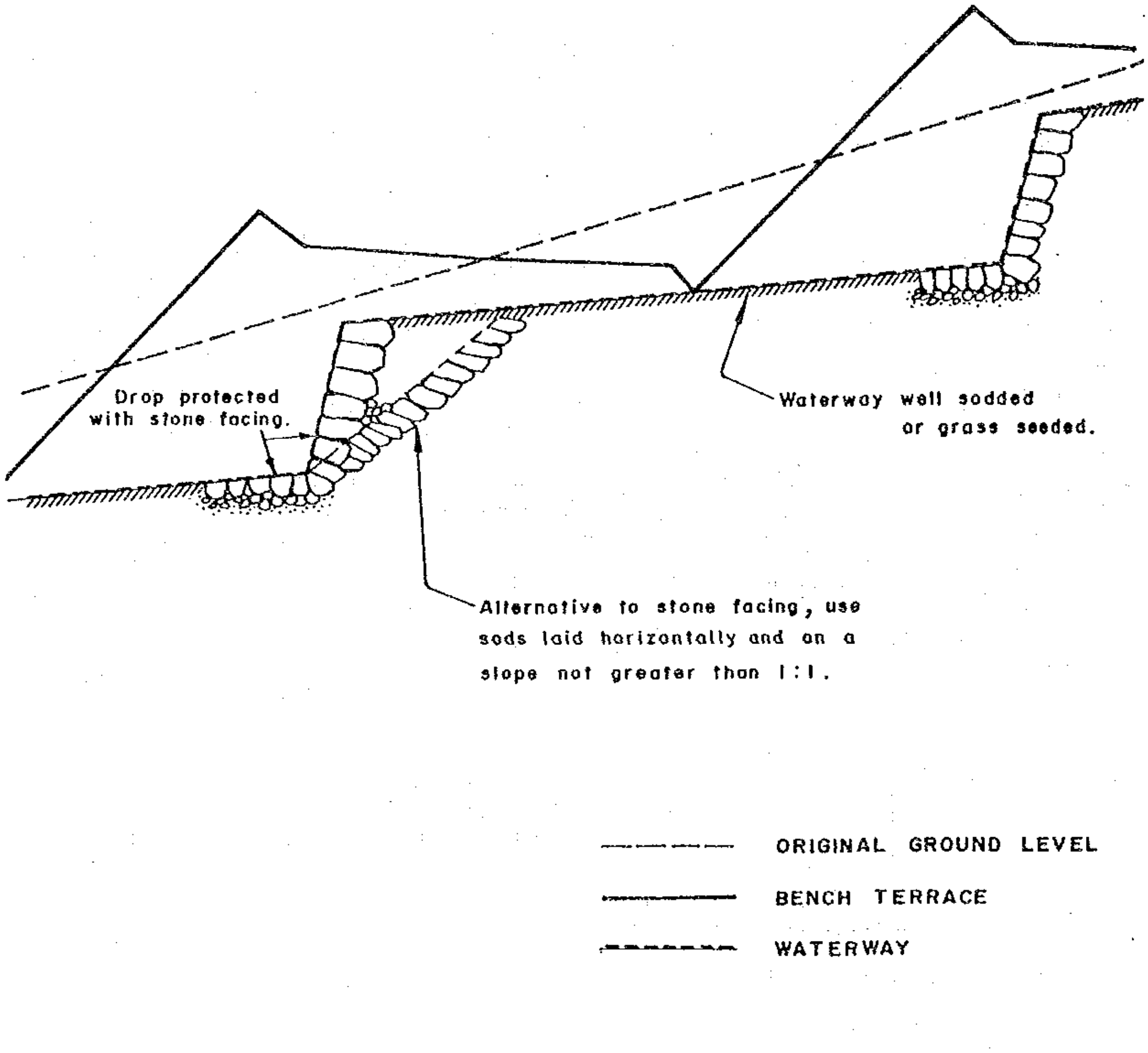


Figure AE.6 Cross Section through Bench Terrace and Waterway

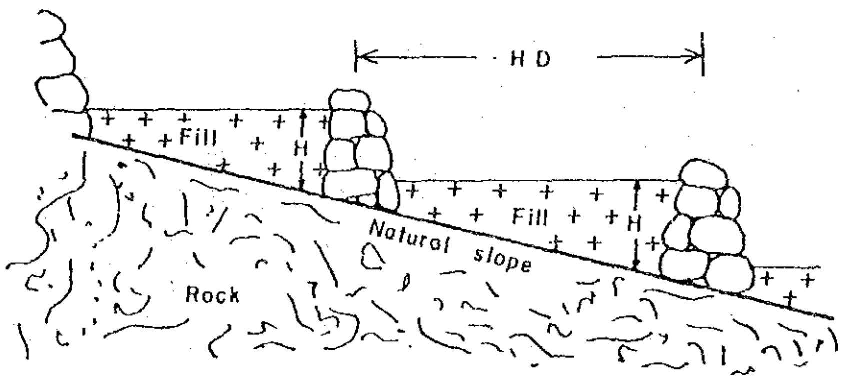


Figure AE.7 Sketch of Bench Terrace Constructed by Fill

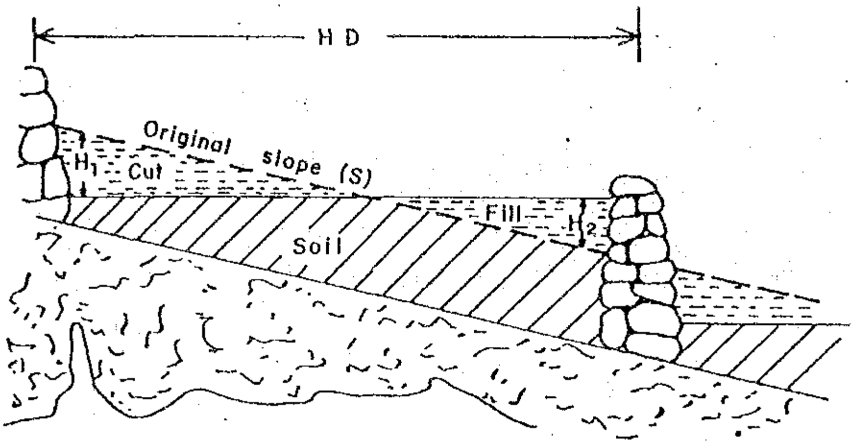


Figure AE.8 Sketch of Bench Terrace Constructed by Excavation and Fill

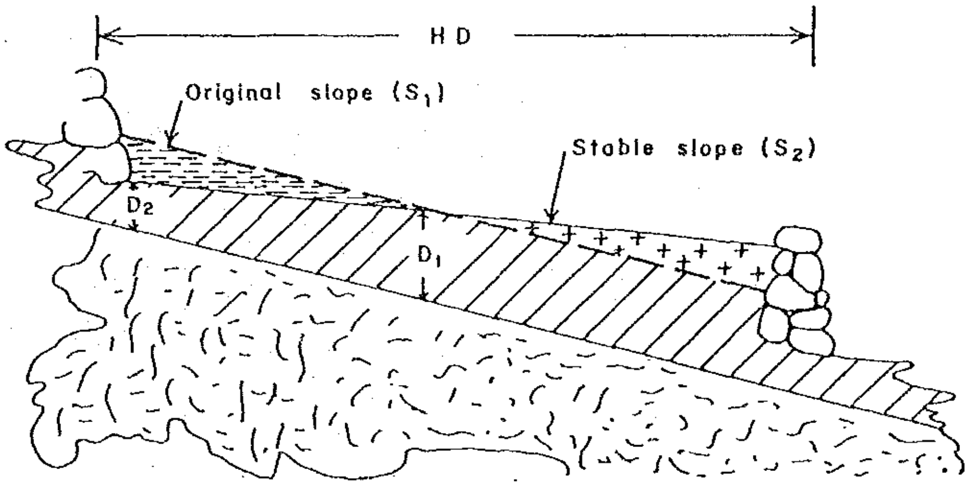


Figure AE.9 Sketch of Bench Terrace Constructed on the Principle of the Stable Slope

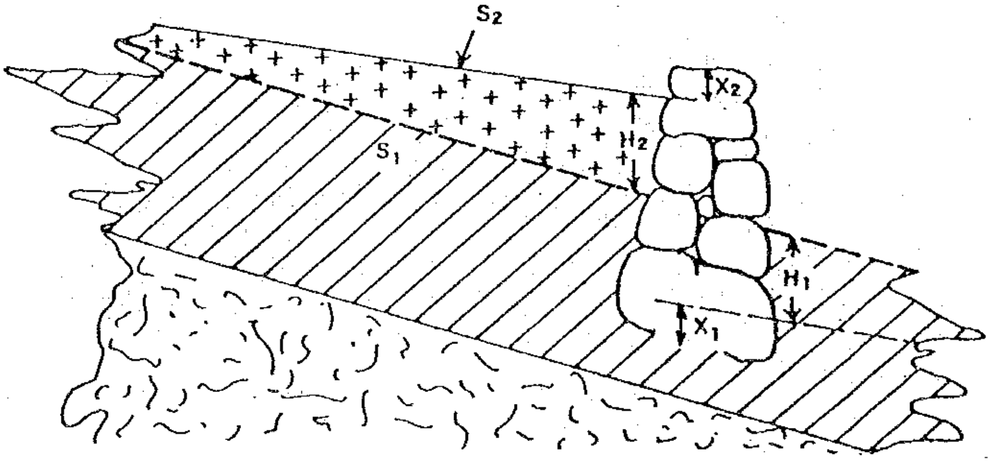


Figure AE.10 Sketch of Stone Retaining Wall

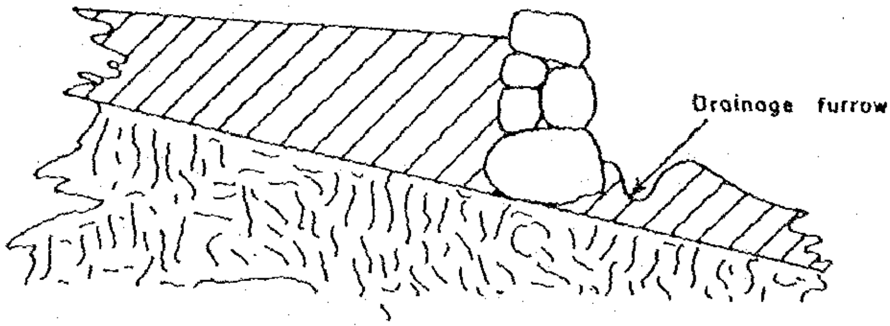


Figure AE.11 Drainage Furrow

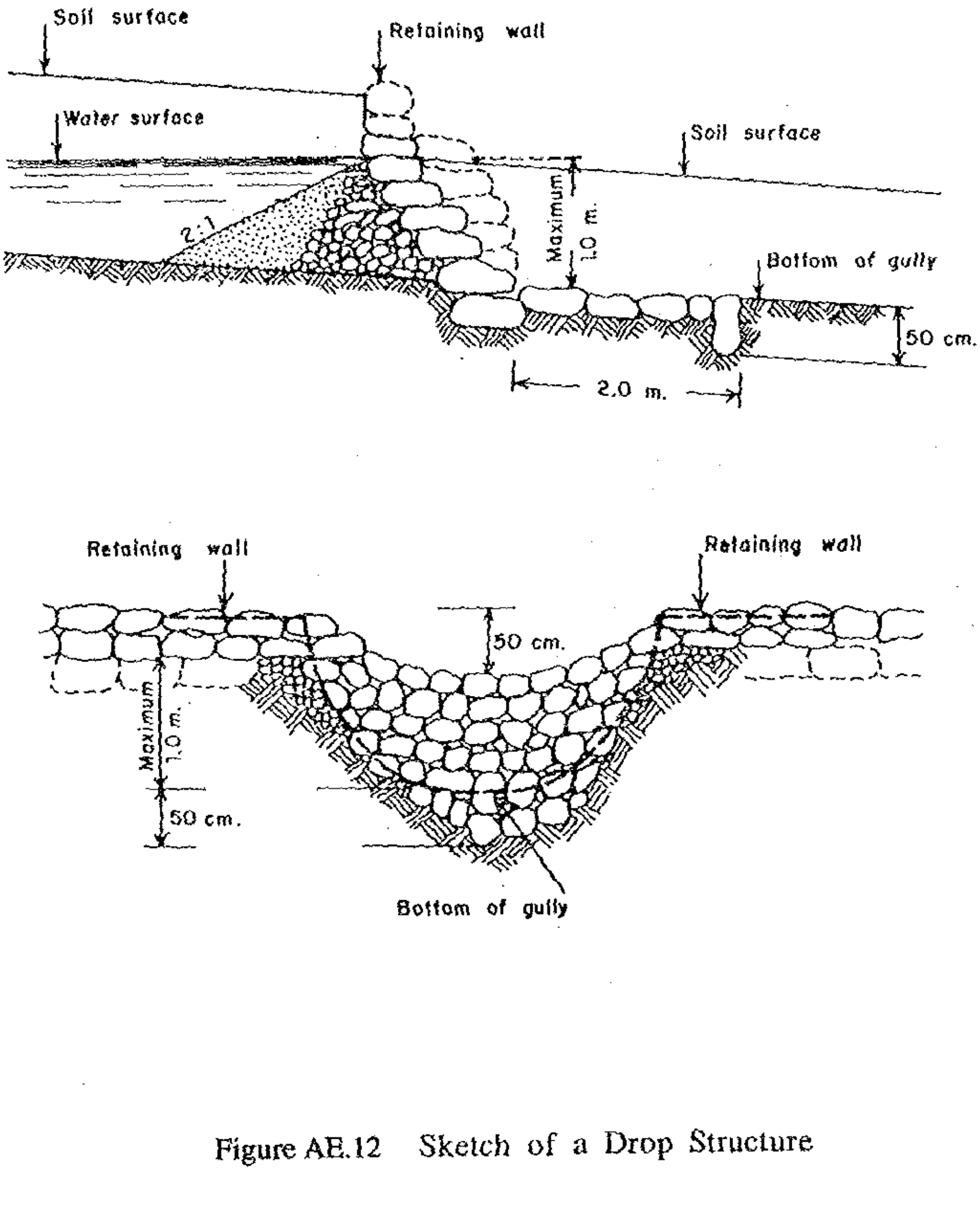


Figure AE.12 Sketch of a Drop Structure

APPENDIX E.3

APPENDIX E.3

AGRONOMIC MEASURES FOR EROSION CONTROL

1. Introduction

The agronomic measures for controlling of minimizing soil erosion in upland farming areas are based on the cultural practices involved in normal agricultural farming operations. For instance, plowing and planting are the basic farming operations in all land-based farming enterprise. No matter what crops to grow, the land is prepared by plowing or manual digging before the desired crops are planted. For soil erosion control , these operations can be slightly modified to minimize the scouring of the soil by surface runoff, thereby minimizing soil erosion losses.

2. Contour Plowing

(1) Description

This agronomic method has the potential to increase the amount of water held on hillside during heavy rains. The farmer simply plows and creates furrows following the contours of the land. Deep contour plowing increases water absorption and reduces both the quantity and velocity of surface runoff that carries soil materials downhill. Plants benefit very much from this activity because of increased moisture availability. Actual plowing is sometimes difficult. It requires some practice before a farmer learns how to divide his field into manageable sections and the draft animal to walk across the slope of the hillside.

(2) Guidelines on Contour Plowing

The area scheduled for plowing is marked off into contour strips 5 to 20 m wide by an A-frame. The top contour line serves the starting point. This procedure is easier if hedgerows or canals are already established.

The initial furrow is plowed about 1m from the upper contour line and parallel to it. The plowman then moves downhill without plowing and makes a second furrow adjacent, parallel to and above the lower contour line. This process is repeated until the entire sector and the whole field is covered. Each furrow on the contour becomes a miniature contour canal holding water on a hillside during rain showers.

3. Contour Planting

(1) Description

Planting essentially follows the contour when the crops/plants are established on the furrows built by contour plowing. However, when plowing is not required as a land preparation activity, contour planting is recommended on a hillside to simulate hedgerow structures. Crops planted along the contour act as barriers to the force of surface runoff by trapping sufficient amount of soil particles when thickly established.

(2) Establishment Procedure

For crops to be planted without contour plowing, the contour lines are marked using an A-frame (Appendix E-1) to serve as guides for the planters. Land preparation by brushing or vegetative clearing is done following these contour lines. The planting spots are prepared either by hole digging or dibbling depending on the planting material to be used. The plants in a given row are planted close enough to be effective soil erosion barriers. The distance between contour rows may vary according to the prescribed requirement of the crop/plant species.

4. Combined Vegetative, Physical and Agronomic Measures

Some non-vegetative soil erosion control structures are reinforced with vegetative rows usually formed by contour hedgerows. For example, rockwalls and contour ditches are usually constructed with napier and/or leguminous species of trees for reinforcement. Similarly, bench terraces constructed for upland farming activities are made stronger by planting grass sods along the risers to prevent them from sliding down. When grass sods are not readily available within the vicinity of the upland farms, napier grass cuttings can be planted along the risers to reinforce the terraces.

Soil erosion can be further minimized by adopting the cultural measures of upland farm establishment. Hillsides devoted to upland agriculture and integrated with combined vegetative and engineering soil conservation measures can be conserved further by employing contour plowing and planting techniques. Mulching can also give additional protection to the soil while conserving soil moisture.

5. Live Mulching

Live mulching means to cover the exposed soil around the cultivated crop by spreading leafy matters. When the soil is opened and exposed at the initial stage of plant growth, erosion is caused by rain drops striking the soil directly. Spreading the grasses and bushes is an effective method of soil conservation. Leafy matters can be obtained by cutting Savendara bushes planted on terraces and branches of Gliricidia plants (legumes) grown on the boundaries of farmlands.

Live mulching prevents surface soil erosion, controls weeds and retains the temperature and moisture contents of the soil at a favorable level for plant growth. This method should be practiced specially in the upcountry tea plantations. In addition to providing leafy matters for mulching, this method grows leguminous creepers such as Centrocima, Pureria and Desmodium in the farmlands. Leguminous cultivation helps fixation of free nitrogen absorbed from the air by Rhizobium bacteria in nodules of the root system. What bears in mind is that an extra dose of manure must be applied for growth of mulch.

6. Agroforestry for Soil Conservation

Agroforestry means activities of growing perennial trees of leguminous family such as Gliricidia with food crops in mixture. Trees are grown at a 5ft (1.5 m) distance from plant to plant in a simple row at 5ft (1.5 m) intervals between rows, but it depends on intervals of the contour lines in the slope. Short-term annual crops are grown in the area between tree planting rows along to the contour lines. What is important is to lop the branches of trees leaving one branch per tree. Leaves of branches should be spread around the main crop to add carbonic matters and nitrogen to the soil (See Figure E.13).

Normally, 500 kg of green leaves from 100 3-year old Gliricidia trees can be collected a year. This quantity is almost equivalent of 13 kg of urea containing nitrogen, 4 kg of sapos phosphate containing phosphorus, 6 kg of potash having potassium, 5 kg of dolomite having magnesium. In addition, as a result of the decayed Gliricidia leaves, the carbonic content of the soil increases. This in turn helps better formation of soil structure favorable for crops and better retention of water. Cuttings required to propagation can be obtained from Gliricidia trees having mature branches. Seedlings from seeds are also obtained with the easiest way. There are 5,000 to 10,000 seeds in 1 kg. These seeds are directly germinated in polythene bags and planted in the field after two months.

7. Savendra and Vetiver for Soil Conservation

This is proposed as a vegetative method of planting Savendra along the contour lines, and greater attention is being paid at present in the field of soil conservation. Savendra, a grass species, grows into a bush with about 1ft (0.3 m) high and its roots penetrate deep into the soil. It is more effective to combine planting Savendra along the contour lines and mechanical conservation methods like stone walls or cutting drains. After 1.5 years from planting, Savendra grows profusely forming a compact hedge. This hedge acts as a strainer which strains and retains clay and silt particles in the run-off water. Because of this action, a permanent natural contour bund is formed over a period of time. Only a small step of 1.5ft (0.5 m) high is required from the land for planting Savendra.

One shoot or plant from an uprooted Savendra bush should be separated for planting in the field. Beginning of the rainy season is the best for planting. The planting of Savendra in a single row is the same as transplant paddy in a paddy-field. If there are plenty of plants, it is better to plant them very close to one another. This way of planting makes them grow into bushes very fast. Growing into thick and compact bushes, the effects to strain the soil being washed off by rainwater are the best. A drain of 1ft x 0.5ft (0.3 m x 0.15 m) must be cut about one foot above the bund. This is important to control the velocity of surface water flow during the planting season. Otherwise the newly planted Savendra plants would get washed with the water. It is not necessary to dredge this drain again once the grass bund is well grown.

In planting Savendra in the field, it is very important to plant them very close to each other. It would take a long time for the bushes to close in and merge, if they are planted far apart. For effective soil conservation, Savendra bund should be grown without gaps as quickly as possible. By pruning the well grown Savendra bush, the cut leaves are applied as mulch to cover the surface soil and thereby increase the carbonic content in the soil. Planting of Savendra is suitable for reinforcing mechanical methods of soil conservation such as bunds and stone walls, and steep and long embankments of roads.

APPENDIX E.4

APPENDIX E.4

VEGETATIVE MEASURES FOR EROSION CONTROL

1. General

Vegetative measure is a type of soil conservation technique which primarily requires the planting and growing of plant species for controlling soil erosion. The use of vegetation serves many purposes. Besides serving as protective materials against water erosion the leaves of some species can be used as green manure and feed. The trunks and stems of trees can be utilized as firewood and small timber.

The use of trees as a vegetative material is advantageous on bigger farmlands. The trees serve as windbreak to protect agricultural crops from wind damage if these are planted around farmlots. Some agricultural crops also need partial shading which the trees can provide. In smaller farmlands, smaller plant species should also be used to avoid over-shading of main crops. Various plant species are usually available around for the farmers to use.

Considering effectiveness of erosion control, an integrated approach combining several vegetative measures such as Sloping Agricultural Land Technology (SALT) is recommendable for hilly and steep slope areas.

2. Contour Hedgerows

(1) Description

These structures are vegetative rows or strips established along the contour of a certain landscape (or across the slope). Seeds of fast growing tree species, such as Gliciridia sepium are densely sown along the contours in rows or strips and allowed to grow normally up to a certain height above the ground to serve as live barriers to surface runoff and soil erosion. Other nitrogen fixing tree species, such as Flemingia conquesta, Acacia velosa, Sesbania sesban, S. Grandiflora, and Desmonium are also used for hedgerows because of their ability to improve the soil.

Hedgerows are established 1.5-5.0 m apart from each other (slope distance) on steep hillsides, and 7-10 m apart on more gradually sloping hillsides. For alley cropping systems, the spaces between the hedgerows are used for raising short-term agricultural crops. The cutting of some tree species may also be used to establish contour hedgerows. They are similarly planted in rows along the contour following the method described above. Cane cuttings of some grass species, such as napier (Pennisetum purpureum) may also be used as hedgerows.

Vegetative hedgerows are mainly used for trapping the soil particles in surface runoff along the slopes. Because of the accumulation of soil particles along the upslope portion of the hedgerow, natural terracing is achieved, thereby lessening the degree of gradient through time. Hedgerows are also effective in reducing the velocity of the surface runoff which in turn reduces its scouring effect on the soil, consequently minimizing soil erosion. In many instances, hedgerow species are a good source of green manure which serves as organic fertilizer for agricultural crops grown in the alleys. They can also serve as a source of mulching materials to conserve soil moisture during the dry season.

(2) Establishment Procedure

The first step involves the construction of a simple A-frame following the procedure shown in Appendix E-1. An A-frame is used to locate the contour lines (or strips) of the sloping land. Next, the contour lines are prepared by plowing (or hoeing) the contour strips 1m wide. The contour strip may need three plowings during the month of establishment to eliminate the roots and totally kill the grass. At least two holes or furrows 30-50 cm apart are dug along the prepared strips. The cuttings or seeds, if the desired tree species are sown and allowed to grow 1 to 2 m in height depending on the species before pruning are planted. Weeding may be necessary during the initial growth stage to minimize competition with hedgerow species. Vacant spaces are replanted to ensure a thick and effective hedgerow structure.

(3) Advantages and Disadvantage

Generally, vegetative structures for erosion control have many advantages over solid engineering structures. Vegetative hedgerows are:

a) More economic and within the reach of most upland farmers,
b) Widely adaptable in a wide range of upland conditions where settlers are engaged in upland farming activities,
c) Easier to repair because they only involve the planting of desired hedgerow species,
d) In harmony with the natural environment, and
e) As durable as other structures if properly installed and maintained.

Because vegetative hedgerows require the full development of the plant species before they become fully effective in controlling soil erosion, they take at least one year passes before ecological benefits are attained. Moreover, they are less effective in controlling the rushing velocity of surface runoff when the slope is too steep. The ability of the hedgerows to trap a significant quantity of soil particles also depends to a large degree on the vegetative characteristics of the species. For instance, grass species are normally better trappers of soil particles than trees, because of their dense stems and low statures.

Furthermore, the natural growth of the hedgerow species causes competition with agricultural crops grown in the farm alleys. Some hedgerow species expand their coverage of the land to a point where they may be detrimental to the growth of other plant species in an upland cropping system. This can be controlled by pruning the roots of the hedgerow plants by running the plow along the strips (or hoeing) during land preparation activities for the alleys.

3. Randomized Mixed Planting

(1) Description

Mixed planting refers to the growing of economic crops with perennials (forest trees or horticultural crops) for cash and ecological benefits. This a viable alternative to the pure short-term agricultural cropping system being employed by many upland farmers which is normally risky in terms of accelerating surface runoff and soil erosion losses. In more stable soils and less steep areas, short-term crops can be grown in conjunction with perennial plant species which have the ability to intercept the erosive impact of rainfall and hold the soil particles in place. The mixture of vegetation does not follow a specified pattern of arrangement. The idea is for any vegetation to cover every available vertical and horizontal space in the area at any given time to serve as protection cover against the elements of soil erosion.

Random mixed planting as a soil conservation strategy is highly effective in intercepting rainfall that would otherwise directly hit the soil surface resulting in excessive splash erosion. Once the soil particles are disintegrated by the impact of raindrops, water carries the soil particles down the slope through surface runoff. In addition to this, most perennial vegetation species have better rooting characteristics that enable them to hold soil particles in place and increase the water infiltration capacity of most soils.

(2) Establishment Procedure

The planting area is prepared according to the needs of the vegetation species to be included in the randomly mixed plantation scheme. Only the specific spots where the seeds, seedlings or cuttings are to be planted are cleared and dug during land preparation activities. The existing trees and other vegetation cover in the area are left to serve as components of the mixed planting scheme. Steeper portions of the landscape are left untouched or stabilized using appropriate vegetative and/or solid (concrete) structures. All available spaces on the land is planted with any desired species when planting materials become available during the planting season. Planting is carried out in groups or clusters to minimize the effect of soil erosion.

(3) Advantages and Disadvantages

The major advantage of this method is that it makes use of the indigenous species in the area as soil cover. Other appropriate space can be used to raise agricultural crops for the farmer's subsistence and cash. Moreover, it requires less planning for the farmer in terms of arranging the vegetation species based on normal farming practices. Any available planting material at any given time could be planted and become an important component of the soil conservation strategy.

The effectiveness of random mixed planting is limited to more stable soils and less steep areas where most plant species can grow. It is also difficult to find vegetation species that possess all the desirable characteristics for conserving soil and yielding economic benefits. Generally, one has to decide on a mixture of trees, shrubs, grasses, and agricultural crops whose component characteristics are complementary to one another. Intimate or single tree crop mixtures cannot be done, because they are not effective soil measuresfor erosion control .

4. Wattlings

(1) Description

Wattlings are vegetative structures consisting of interwoven sproutings of brushwood laid horizontally on the top of one another around pegs driven into the ground. Wattling structures are mainly used to trap the soil particles that are eroded with surface runoff. Because of their solid structural characteristic, they are also used to reduce the velocity of surface runoff, thereby reducing the scouring effect on the topsoil. They are secured by wooden pegs driven through shallow trenches which follow the contour of the land. The rods of brushwood are interwoven in a way that the butt ends are bent down into the soil or are covered by soil while the upper portions are exposed to sprout. In many instances sprouting cuttings of desired fast growing leguminous species are inserted inside the wattling structure.

The distance between wattlings depends primarily on the stability of the soil and slope of the hillside. To effectively minimiz erosion, however, they should not be established more than 2 m apart. Wattlings can be established on contour lines or intermittently along the contour. Another technique is diagonal wattling lines crossing the slope in a rhomboid pattern.

(2) Establishment Procedure

Firstly, contour lines are located using an A-frame. Trenches, 25 cm deep are dug along each contour line using a hoe or any digging implement. Wooden pegs are then driven into the trenches 50 - 70 cm apart until they are firmly secured in the ground. Sprouting rods are woven alternately around each wooden peg one on top of the other until a fence like structure is established from the bottom up to the top end of the pegs. The butt ends of the rods are bent toward the soil to facilitate rooting. Finally, the trenches are refilled with excavated soil leaving the upper part of the wattling structure exposed. Green manure fertilizer of can be applied whenever necessary.

(3) Advantages and Disadvantages

Wattlings are very effective in keeping the eroded soil in place, because of their superb retaining ability. As with the vegetative hedgerows, wattlings can enhance the formation of natural terraces through time. Unlike the hedgerows, however,. protection is usually achieved right after establishment. When constructed diagonally, hedgerows are very stable and large-scale erosion can hardly occur.

Only long, straight, and flexible sprouting rods can be used to construct effective wattling structures. If the structures are not buried deep enough, they may be washed out and damaged by surface runoff. Moreover, the construction of wattlings in trenches is quite difficult. Since too much of the brushwood is generally exposed, sprouting may not be satisfactory.

5. Fascines

(1) Description

Fascines are soil erosion control structures consisting of sprouting brushwood bundles secured to a wooden peg driven into the ground. Just like the wattling structures, they are laid horizontally following the contour, in trenches to enhance sprouting. Unlike the wattlings, however, the sprouting brushwood does not exceed 3 m in length because of the difficulty of handling. Moreover, the brushwood can be arranged without consideration of polarity. Fascines can be constructed using hooked pegs or straight pegs with wire.

Fascines are similar to wattlings in that their primary use is to trap eroded soil particles. Because of their solid structural characteristic, they can also be very effective in reducing the velocity of surface runoff which in turn reduces soil erosion. Herbage from the sprouted brushwood can also be harvested to serve as green manure or as a source of mulching materials.

(2) Establishment Procedure

There are two methods for bundling the fascine. The first and simpler one is with the use of a "guide frame" while the other is with the use of a "fagot bundling press" which is more complicated and requires at least three individuals to carry it out. A guide frame is prepared by establishing two parallel rows of pegs 35 cm apart. Strands of wire, 1m long, are placed across the ground before the brushwood is bundled. Finally both ends of the fascine are trimmed using a saw.

After the usual preparation of the bundled fascines, contour trenches with a depth of about one half the diameter of the fascines are dug to prevent underscoring by surface runoff and drying out of the brushwood. The fascines are placed in the trench and "nailed" or anchored firmly to the ground with hooked pegs. The fascines can also be anchored by pegs driven along both sides. The opposite pegs are connected by wires. After the fascines have been laid out and nailed, the trenches are filled with soil and the fascines buried to about one half or two thirds of the their diameter. Fertilizer application and a mulch cover would enhance the sprouting of the brushwood.

(3) Advantages and Disadvantages

Just like the wattling structures, fascines can be established in a continuous line or intermittently along the contour. A diagonal layout is also possible. Fascines are very easy to establish with relatively faster progress of work at a relatively lower cost. Mechanical protection is already obtained after the establishment.

Fascines require large quantities of brushwood and are liable to dry out. If only a small quantity of the brushwood sprouts, the non-sprouters will act as dry fascines, but since they will stay low in the structure, they are hardly able to trap a significant amount of soil particles from the surface runoff.

6. Bench Brush Layers

(1) Description

Bench brush layers are erosion control structures that involve the construction of contour benches where brushwood materials are placed to induce sprouting. The distance between the branches depends on the gradient of the slope and stability of the soil. Eroded soil particles are trapped by the benches and sprouted brushwood and are kept in place. The seedlings of desired agricultural species can be planted in the spaces between the contour bench layers for economic benefits. The sprouted brushwood trap the eroded soil particles from the surface runoff.

(2) Establishment Procedure

The establishment of bench brush layers begins at the base of the slope. The first bench is dug to a depth of 50 to 120 cm with an inward inclination of about 25° slope. The brushwood materials are spread on the benches with the butt ends pointing inward. For better anchorage, the branches are placed crosswise. Branched and forked brushwood serves a better purpose than straight brushwood. For reinforcement, tall seedlings of a desired fast growing species can also be mixted with the brushwood. Although planted horizontally, the seedlings will adopt a vertical position when they grow.

subsequently, the excavated soil from the next upper bench is used to cover the brushwood and seedlings in the lower bench. This is the reason why the work has to start at the base of the slope. After refilling the soil covering the benches is carefully trampled. Fertilizer can be applied by broadcasting it before refilling to enhance the sprouting of the brushwood and growth of the seedlings.

(3) Advantages and Disadvantages

The brushwood materials are well protected against drying out. Only a small quantity of brushwood is required. Besides, irregularly formed (not straight) brushwood can be used and is, in fact, more advantageous. Based on experience, failures are relatively rare. This method is considered by the European erosion control experts as one of the best and most economic.

Since the soil surface between the benches is not well protected, sheet and rill erosion can occur in the beginning. This could be reduced by mulching the intervals between the benches after the desired forest, agroforest or agricultural crops are planted. In loose and dumped soils which are not compact, digging the benches may cause small landslides. Other measures should be adopted.

7. Bench Covers

(1) Description

Brush covers are vegetative structures consisting of large quantities of brushwood spread on the ground and held firmly by connecting wires (or bamboo splits) and secured by pegs driven into the ground. This method is sometimes called matting because the spread brushwood materials are like mats unrolled over the slope of a hillside. Other crops of economic benefit can be interspersed with the brushwood in the available space. Brush covers are mainly used to totally protect the soil surface from the direct impact of rainfall thereby minimizing splash erosion. Overall, they are very effective in holding the soil in place, especially when the brushwood sprouted and develops a well establishs root system.

(2) Establishment Procedure

Wooden pegs, 60 to 80 cm long, are prepared and driven into the ground to about 20 cm deep in a line along the contour. The distance between the pegs in the line depends on the ability of the wire to firmly secure the brushwood materials. Then, the brushwood are spread on the ground with the butt ends pointing downslope. Afterwards, the pegs are horizontally connected by wire and further driven into the ground to press the brushwood firmly to the ground. It may be necessary to cut some notches at the end of the pegs to prevent the wires form slipping off. Finally, the brush cover is partially covered with soil leaving about 40 to 50 % of the brushwood exposed. The covered parts will develop roots while the exposed portions will sprout. Without soil cover, the brushwood would dry out and the whole strategy would fail.

(3) Advantages and Disadvantages

The brush cover is probably the most stable of all the live vegetative structures, because immediately after construction, it will resist almost all the stresses of erosion. Therefore, it is recommended for steep slopes, unstable soils, and regions with a high intensity of rainfall or within a typhoon belt. Due to the cover and mulching materials, the soil does not dry easily.

A major disadvantage of this method is the large quantity of brushwood and labor required. Moreover, for upland farming systems, only a very limited amount of economic crops can be grown, because most of the space is occupied by the brushwood.

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