Ministry of Agriculture and natural resources
Natural Resource Management Directorate

# A Field Guideline on Bench Terrace Design and Construction



**By Aklilu Mesfin**

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# 1. Introduction and Background

Ethiopia had been a country with a vast natural resource, with 40% of the land covered by forest and the rural people in the country were managing their land resources pertaining to the needs of prevalent populations. However, with an increasing population and growing demands for food, more land was put under cultivation. Especially in the highlands of Ethiopia finding uncultivated fertile agricultural lands with gentle slope and deep soil are getting diminished. On the other hand the number of unemployed landless youths in the rural areas of the country and their need for owning agricultural land for agricultural production is increasing. Hence, to address the problem some regions have started to develop steep mountainous lands with bench terrace as an alternative for annual crops and fruits production. The result obtained in implementing the technology is quite impressive as it is rehabilitating and bringing mountainous areas to development.

Looking to these encouraging results obtained, the Natural Resources Management Directorate (NRMD) has planned to scale up implementing the technology in all regions with more focus on the highlands of Ethiopia. In fact, bench terraces have been traditionally practiced in many parts of the country (to mention some are: Konso in the SPNNs; Ankober in Northern Shewa; NadierAdet and Erob of Tigri; and Hararge highlands), but detailed studies and manual on how to design and construct the technology was lacking.

Hence the following manual is prepared as a reference guide to support field practitioners in implementing bench terrace and other complementary technologies that could maximize the benefit and sustainability of the technology. The manual can also assist other program and project staffs involved in the implementation of bench terrace technology for watershed development.

In the manual definition, type, use, advantage and disadvantage of bench terrace are explained. Further suitable site selection, design, construction, maintenance and management of the technology are briefly discussed.

## 2. Definition

Bench terraces are a series of level or virtually level strips running across the slope at vertical intervals, supported by steep banks or risers. Bench terraces are effective soil conservation measures used on relatively high slope lands for crop production. On the other hand it is an engineering soil conservation practice, used to control the soil erosion in highly sloped areas. Terracing involves the construction of embankment or ridge like structure, across the land slope to check the flow of surface runoff and to reduce the soil loss.

In brief the bench terrace involves the following main features.

- The structure is constructed across the slope to intercept the surface runoff and convey it to a suitable outlet, at non erosive velocity.
- It reduces the length of slope by splitting the slope length in different parts.
- The terracing practice is adopted for soil and water conservation in that area, where land slope is greater than 10% slope, soil is more erodible and prevails high rainfall intensity
- this practice is very difficult, particularly on those hilly sloped areas, where soil depth is not sufficient

## 3. Types of bench terrace

There are different types of classification used in bench terrace classification; some people mix bench terraces with terraces. Terracing is actually a more general term which includes bench terraces as one type of terrace. Terracing can be classified as:-

a) Bench Terracing b) Hillside Terracing and c) Micro-basin Terracing

- Terraces can also be continuous, discontinuous, transitional, drainage, absorption and soil retarding types.
- Continuous type terraces are bench terraces and further classified as irrigation or level bench terraces, and upland bench terraces.
- Discontinuous type terraces are hillside terraces, orchard terraces and individual basins.
- Transitional type terraces are convertible terraces, intermittent terraces and on gentle slopes (less than 7 degrees or 12%).

Figure 1. below shows the relationships between crops and the different types of terraces required on steep slopes for small and medium farms.

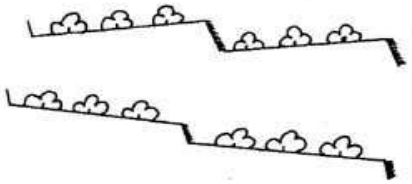
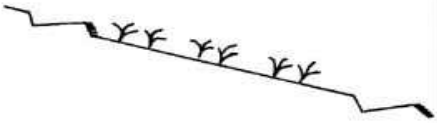
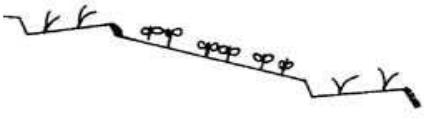
| Land Use & Crop | Cross-sectional View | Type |
|---|---|---|
| A. Continuous type (on deep soils and slopes of 7° to 25°) | | |
| 1. For rice or for flood irrigation |  | Irrigation or level bench terraces |
| 2. For mainly rain-fed crops or irrigated crops in dry season |  | Upland bench terraces:<br>a. Reverse sloped<br>b. Outward sloped |
| B. Discontinuous type (on shallow to deep soils and slopes of 7° to 30°) | | |
| 3. For upland crops, especially semi-permanent crops |  | Hillside ditches |
| 4. For tree crops or fruit trees on steep slopes |  | Orchard terraces |
| 5. For planting individual trees or plants |  | Individual basins |
| C. Transitional type (on deep soils and slopes of 7° to 25°) | | |
| 6. For mixed farming or for flexible future land use |  | Convertible terraces |
| 7. For completing full bench terraces over a period of time |  | Intermittent terraces |

Figure 1 Major types of terraces for steep slopes

When we come to bench terrace classification, the following are different types of bench terrace classification based on their sites, design and major uses of them.

I. Based on time taken for their make-up or on the way of their development (i.e. speed of their formations) bench terrace can be classified as
   a) **Excavated bench terraces** carried out at one through the cut and fill process and some time are known as **"Radical terraces"**
   b) **Developed bench terraces** are the gradually developed terraces through the action of erosion, cultivation operation, and deposition sometimes known as **"Progressive terraces"**. Progressive is adhered to the conventional farmland conservation structures (Soil, fanyajuu and stone bunds) where the benching is achieved gradually.

II. Sometimes classified based on irrigation water availability as:-
   a) Irrigation or level bench terraces, and
   b) Upland bench terraces.

III. On the other hand bench terraces can be classified as
   a. Graded bench terrace or
   b. Level bench terraces

These are depending on either retention of rainfall/runoff or flood water or its safe evacuation when it is excess. Level terraces apart from being used for moisture retention from rainfall/runoff can be used for irrigation i.e. diverting irrigation water or flood water in to the benched field (the case of paddy fields).

IV. When it comes to the classification of bench terraces a more comfortable classification is given by Rama Rao (1974). He has classified the bench terraces on the basis of the slope of the bench, as
   1. Level bench terrace
   2. Bench terrace sloping outward, and
   3. Bench terrace sloping inward

## 3.1. Level bench terrace

This type of bench terrace consists of level top surface. Level bench terraces are generally used in the areas which receive medium rainfall and have highly permeable soils. Since the soils are highly permeable, it is expected that most of the flowing surface runoff passing through these terraces are absorbed by the soil and the remaining portion is drained in to a drain. The level bench terraces are also called irrigated bench terraces provided that they must be under irrigation. Sometimes level bench terraces are also called as table top or paddy terraces, because such terraces have level top surface that can be easily impounded with water and plantation of paddy crop can be performed. The level bench terraces used for paddy cultivation, the bench slope is kept as mild as < 1%, so that uniform water impounding over them can be easily made.

## 3.2. Bench Terrace Sloping Outward

Such bench terraces are adopted in low rainfall areas with permeable soil. For these terraces a shoulder bund is essential even though this bund is to provide the stability to the outer edge of the terrace. In addition, this bund also helps in retaining the surface runoff on the benches that is either absorbed by the soil or drained. Bench terraces sloping outward are also known as orchard type bench terraces. For outwardly slopping bench terraces constructed on soils having poor permeability, the provision of graded channel at lower end is most essential for disposing surplus surface water to the grass waterway. Whereas, in very less permeable soil case, a strong bund along with spillway arrangement should be essentially equipped, for making the terrace safe against heavy storm and allowing the water very safely, downward to the next terrace.

## 3.3. Bench Terraces Slopping Inward

Bench terraces slopping inward are preferred to construct in the areas of heavy rainfall and less permeable soils, from where large portion of rain water is drained as surface runoff. Such types of bench terraces have a provision to drain the runoff from their inner side by constructing a drainage channel, as shown in Fig. 2. The drain ultimately leads to a suitable outlet (grassed water ways). This type of bench terrace is also known as hill type bench terrace. The inwardly sloping bench terraces are usually preferred for growing those crops, which are extremely susceptible to water logging, such as potato.

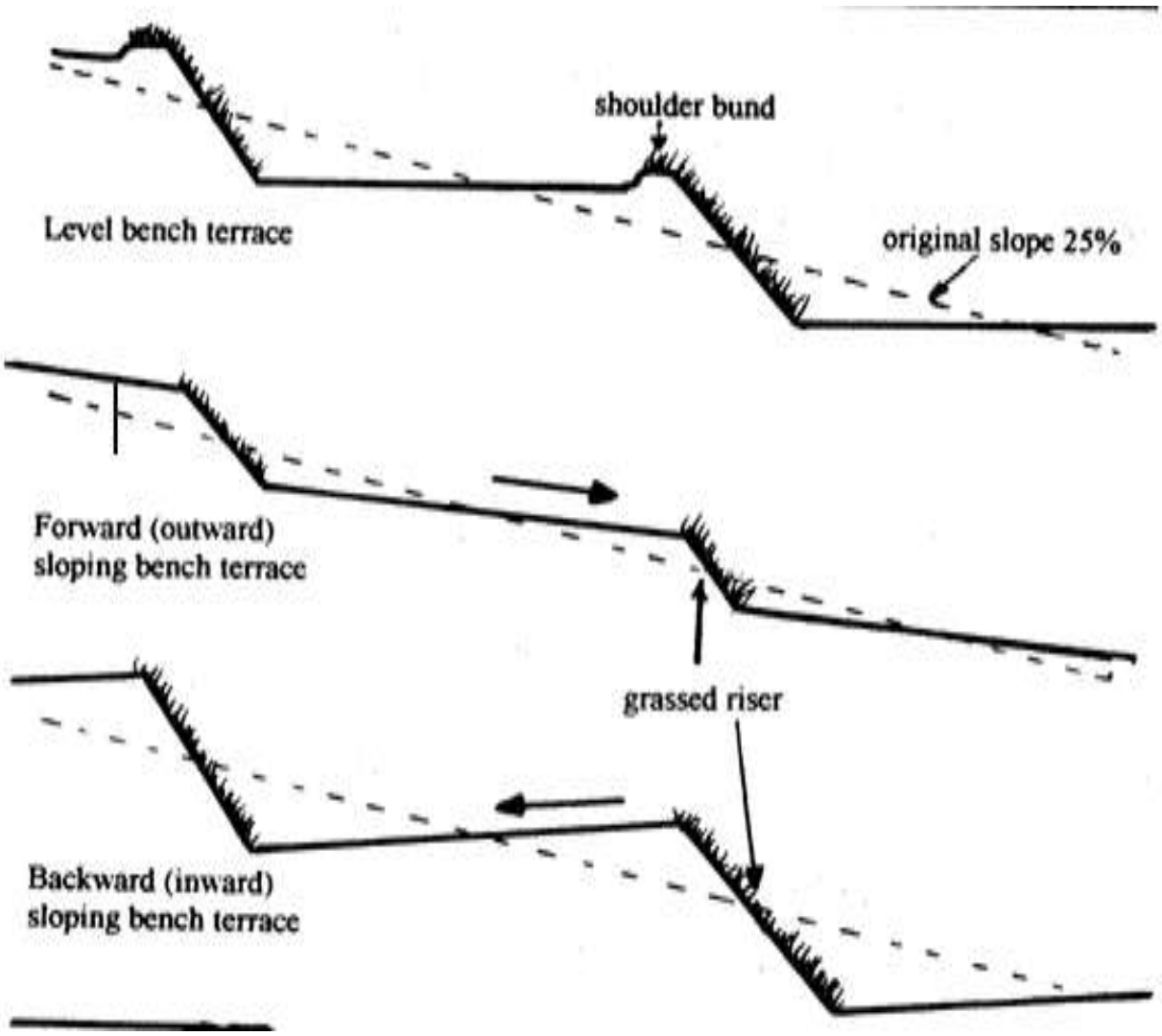



Figure 2. Bench terrace classification on the basis of the slope of the bench

## 4. Objectives

The major objectives of bench terracing include:

- To reduce run-off or its velocity and to minimize soil erosion.
- To conserve soil moisture and fertility

- To contribute for maximum moisture retention in the soil especially they are more relevant for moisture stress areas and soils of poor water holding capacity
- To promote intensive land use and permanent agriculture on slopes and reduce shifting cultivation
- To ease the cultivation operation and to facilitate modem cropping operations i.e. mechanization, irrigation and transportation on sloping land.
- To achieve uniform plant growth over the width of the bench

## 5. Suitability

Bench terraces are particularly suitable in the following areas:

- Suitable in all agro ecology zones, on steep and fairly steep slope land having deep and moderately deep soil,
- For high and moderate rainfall, areas inward sloping and for dry areas level bench terrace is suitable.
- On slopes above 12% and not exceeding 30 degrees or 60% provided that the soils are deep and stable enough.
- Severe erosion hazards but on sites which are not dissected by gullies
- Bench terracing is always a major reclamation job, whether carried out on steep cultivated and eroding slopes or uncultivated land.
- Areas not too stony/ soils not with shallow bed rock
- In areas of unstable soils, the increases in infiltration can cause high water pressure in the soil pores and collapse terrace embankments. In such areas it would not be advisable to make bench terraces on slopes over $15^0$ (30%).
- Areas with small holdings and a dense population
- Areas where there are food/land shortages or high unemployment rates
- Areas where crops require impounding water or flood irrigation
- Bench terraces are much more cost-effective if there is potential for growing high-value crops, irrigation and mechanized farming

## 6. Limitation

Terraces or bench terraces should not be constructed on the following conditions:

- With sandy or rocky soils, non-cohesive or highly erodible soils, or decomposing rock including other depositional materials
- On recently soil-cuts and soil filled up segment – this is because the cut part could be infertile and the fill may have not settled properly
- With soft-rock laminations in thin layers oriented so that the strike is approximately parallel to the slope face and the dip approximates the staked slope line
- Benches terraces may cause sloughing if too much water infiltrates in the soil and are effective only where suitable runoff outlets are available
- Avoid benching, if possible, in areas where there is potential for rock-fall slide problems

## 7. Design basics for bench terrace

we all agree that before going directly to the design of bench terraces designers should understand design basics i.e

- Design terraces according to the needs of farmers, crops, climate, and tools to be used for farming.
- Use simple arithmetic and a step-by-step approach to design, this to mean that start on simple parameters that you easily determine. For example using land slope and the width of the bench (flat part) as two starting points, the design proceeds step by step with basic arithmetic that can be easily understood by field workers, land users, or farmers.
- Design bench terraces such that the volumes of cut and fill are to be equal for minimizing construction cost.

## 8. Design of bench terrace

When planning, designing, constructing and managing bench terraces some common terms/terminologies that one needs to be familiarize with are given below: Soil depth; Width of terrace; Terrace riser; Lip; Toe; Drain; Forward sloping; Outward sloping; Backward sloping; Reverse sloping; Inward sloping; Double sloping; Level vs graded terraces; Vertical interval; Height of riser; Riser slope; Cut-depth; Fill height; Dike height; Dike cross-section; Horizontal

interval; Width of riser; Width of bench; Cut section; Fill section; Linear length of terraces; Net area of bench terrace; Bulk density of the soil; Angle of repose; Percentage of bench; Cross-sectional area of the bench terrace; Reverse height; Outward height; Wider terrace versus narrow terrace etc. Determination of design components of bench terrace mainly depends on the average annual rainfall, soil types, soil depth, and average slope of the land. these information are essential for the design of the same. In addition, the purpose of bench terrace should be considered for the design. The design of bench terrace involves the following major parameters for determination.

1. Type of bench terrace
2. Length of bench terrace
3. Gradient of bench terrace
4. Width of bench terrace
5. Spacing of bench terrace
6. Terrace cross section (Risers and riser slopes, Depth of Cut, net area, cross-section area, volume of cut and fill,

## 9. Design procedures of bench terrace

**step 1 Decide the type of bench terrace to be constructed**

Type of bench terrace to be constructed among all above types, is based on the rainfall and soil condition of the area. For example if an area receives medium average rainfall and the soil is highly permeable the bench terrace with level top is recommended for construction

**step 2 Decide on the length of the bench**

The length of a terrace is limited by the size and shape of the field, the degree of dissections and the permeability and erodibility of the soil. The longer the terraces, the more efficient they will be, but it should be borne in mind that long terraces cause accelerated runoff and greater erosion hazards. A maximum of 100 m in one draining direction is recommended for typical conditions in a humid tropical climate. The length can be slightly increased in arid and semi-arid areas or regions.

**Step 3 Decide on the gradient of the bench**

The gradient of bench terrace has to be decided for both the lateral gradient (gradient of bench terrace along the contour) and the gradient of the bench (gradient of bench along the slope or the slope of the flat part) i.e to select on level Vs graded terraces to construct which is based on the rainfall amount and soil type And a as well as decide on whether to construct level, inward and outward bench terrace respectively.

**Step 4 Decide the Width of Bench**

In designing bench terraces, the width of the bench (flat part) needs to first be determined by the farmers according to crop needs, tillage tools, as well as their individual preferences. Field technicians or extension officers need to check soil depths and inform farmers that wide benches require deep soils and higher construction costs.

Experience has shown that for hand cultivation 2.5 m to 5 m wide are appropriate widths whereas for mechanization 3. 5 m to 8 m are proper where depth of soil does not constitute a limit. The workable bench width can be estimated based on soil depth and slope of the area; therefore to find the bench width you can use this table 1 below.

Table 1. Bench width based on soil depth and slope of the area

| Slope | Soil depth in cm | | | |
|---|---|---|---|---|
| | 50 cm | 75 cm | 100 cm | 125 cm |
| 20% | 5.63m | 8.44m | 11.25m | 14.05 m |
| 30% | 3.54m | 5.31m | 7m | 8.83m |
| 40% | 2.5m | 3.25m | 5m | 6.25m |
| 50% | 1.9m | 2.8m | 3.75m | 4.65m |

**Step 5 Measure the Slope of the land**

Slopes can be measured by using a hand level or a clinometers. In design of terraces, a representative slope or a mode slope should be obtained from the field. The maximum and minimum suitable slopes for construction of bench terrace depends on wheather it is handmade or machine made. If we build terraces by hand, the appropriate slope range vary from country to

country in Ethiopia. (Daniel, 2001) recommends bench terrace to be constructed 12% to 30 degrees (or 60%). while for machine based construction, while (Sheng T. C. 2002) recommends the range to be from 7 degrees to 20 degrees (or 12.3% to 36.4% ) based on his past experience. Using machines on a slope over 20 degrees is unsafe. Slopes gentler than 7 degrees may best use simple conservation measures or agronomic measures.

**Step 6 Calculate the terrace spacing (Vertical Interval)**

Terrace spacing is the vertical distance between two successive bench terraces. It is equal to the double of depth of cut, it depends on the soil depth, bench width and land slope. the depth of cut should not be too deep to expose bed rocks, as well as wider bench widths may result in higher value of vertical interval which might be unstable, especially at higher slopes.

After the slope and the width are determined, the Vertical Interval (*VI*) can be calculated by a simple equation. *VI* is the elevation difference between two succeeding terraces. It is essential to calculate the *VI*; it not only shows roughly the height of future terraces but also provides the basis for further designing.

The simple equation using slope and the width of the bench as the main inputs is as follows:

$$\mathbf{VI} = \frac{\boldsymbol{S} * \boldsymbol{Wb}}{\mathbf{100} - (\boldsymbol{S} * \boldsymbol{U})}$$

Where VI: Vertical interval in m

S: Slope in percent (%)

Wb: Width of bench (flat strip) in m

U: Slope of riser (using value 1 for machine-built terraces, 0.75 for hand-made earth risers and 0.5 for rock risers).

**Example:** The *VI* of 4m-wide bench, machine-built, on 15 degree (26.8%) slope is as follows:

*VI* = (26.8 4) / (100 – 26.8 1) = 107.2 / 73.2 = 1.46 m

**Example**: Calculate the vertical interval (VI) of 4 metres wide hand-made benches on a 30% slope with hand-made earth risers of 0.75.

$$\mathrm{VI} = \frac{\mathrm{S}*\mathrm{Wb}}{100 - (\mathrm{S}*\mathrm{U})} = \frac{30*4}{1\,00 - (30*0.75)} = 1.55 \text{ m}$$

Table 2 Empirical formulae for calculating VI in different countries

Empirical Formulae for calculating the vertical interval

For computation of bench terrace interval various empirical equations have also been developed

USSCS formula: $VI = aS + b$

In which, VI is expressed in feet, a & b are constants, the values of a varies from 0.3 for South to 0.6 for North USA. and b is 1 or 2 according to the limit of soil erodibility.

Zimbabwe formula: $VI = \frac{Sf}{2}$

$f$ is the constant varies from 3 to 6 depending upon soil erodibility value. VI and S the same like above

South Africa formula: $VI = \frac{S}{a} + b$

VI, S, a and b are the same like above but a values differ from 1.5 for low and 4 to high rainfall areas and b varies from 1 up to 3 depending on soil erodibility

Algerian formula: $VI(m) = \frac{S}{10} + 2$

Israeli formula: $VI(m) = X.S + Y$

X and Y are constants X varies from 0.25-0.3 up on rainfall, Y varies from 1.5 to 2.0 upon soil erodibility.

Kenyan formula: $VI = \frac{0.3(S+2)}{4}$

New South Wales formula:

$VI = KS^{-0.5}$ k=1.0-1.4 based on soil erodibility

Taiwan/Jamaica formula: $VI = \frac{Wb * S}{100 - SU}$

**Step 7 Calculate risers and riser slopes**

Riser material can be either compacted earth, protected with grass, or rocks. In order to ensure easy maintenance, terrace riser height should not exceed 2 m, after allowing for settling, especially for earth risers. Riser slopes are calculated by the ratio of the horizontal distance to the vertical rise as follows:

- Hand-made benches with earth material: 0.75:1
- Hand-made benches with rocks: 0.5:1
- Machine-built benches with earth material: 1:1

For level terraces, the following formula is used for determining the riser height (for reverse-sloped terraces see Fig. 2):

Hr = VI + DH

Hr: height of riser in m.

VI: vertical interval in m.

DH: dyke height i.e. 15 or 20 cm.

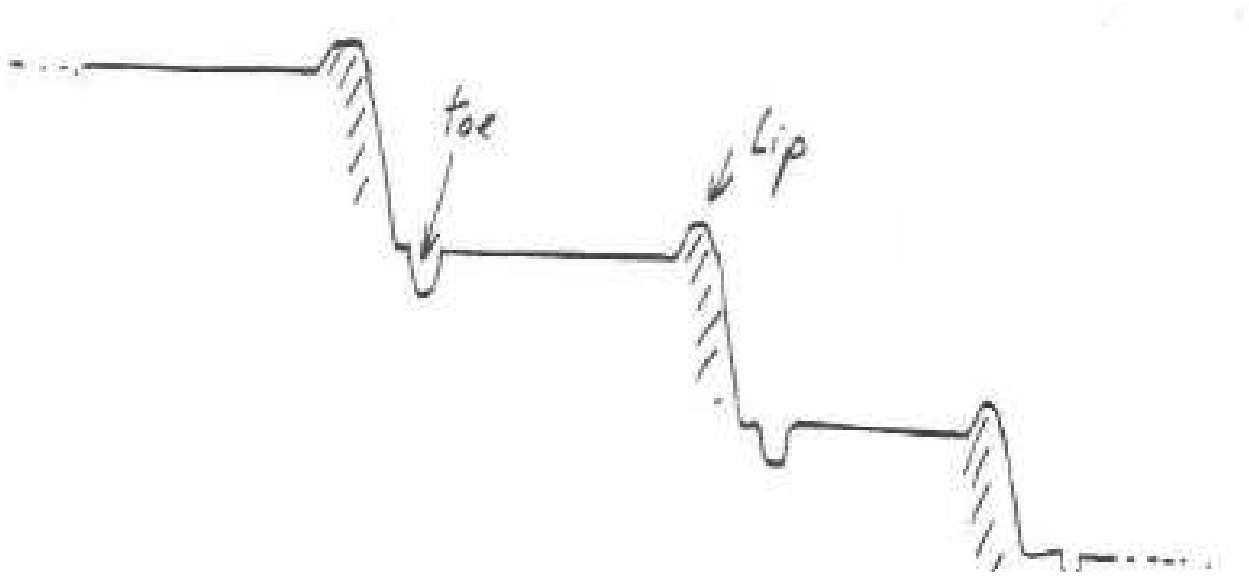



Figure 3 Toe (dike) and lip (riser height) of bench terrace

**Step 8 Calculate depth of cut**

The depth of cut can be calculated according to the following formula:

$$D = \frac{Wb}{2} \tan \emptyset \text{ (for level terraces)}$$

$$D = \frac{Wb}{2} \tan \emptyset + \frac{RH}{2} \text{ (for reverse} - \text{sloped terraces)}$$

$$D = \frac{Wb}{2}\tan \emptyset \ - \frac{OH}{2} \ (foroutward - slopedterraces)$$

D: depth of cut in m.

Wb: width of bench in m

tan ∅: tangent of the slope angle.

RH : reverse height

OH: Outward height

Example: Calculate the depth of cut for a 4 m wide reverse-sloped bench terrace on a 15 degree slope:

$$D = \frac{Wb}{2}\tan \emptyset + \frac{RH}{2} = \frac{4}{2} * 0.26795 \ + \frac{0.2}{2} = 0.64\ m$$

Where RH = 4 x 0.05 = 0.2

**Step 9 Calculate Net Area**

This is the area in benches or flat strips which is used for cultivation. The net area can be calculated by using the following formula:

$$\text{A} = \frac{10{,}000 * Wb}{Wt}$$

Where A is net area of benches per ha in $m^2$

Wt: width of terraces (the sum of the width of the bench and the width of the riser), in m

Wb: width of the bench, in m

When calculating the net area of level terraces, the dyke width should be subtracted.

**Step 10 calculate cross section area**

The cross-section can be computed by the following formula:

$$C_A = \frac{Wb * Hr}{8}$$

$C_A$: Cross-sectional area of the cut triangle, in $m^2$

Wb: Width of bench, in m

Hr: Height of riser, in m

The linear length of terraces per hectare can be calculated by the following equation:

$$L = \frac{10{,}000}{Wt}$$

The linear length of terraces per acre can be calculated by the following equation:

$$L = \frac{43{,}560}{Wt}$$

L: Linear length of terraces in one hectare, in m.

Wt: Width of terrace, in m (where Wt = Wb + Wr).

**Step 11 Calculate the volume of cut and fill**

The volume (V) can be calculated by multiplying the linear length (L) by the cross-sectional area ($C_A$).

V = L * $C_A$). (for calculating linear length, see Fig. 2)

When calculating the volume to be cut and filled it should be noted that only one cross-section is used. This is because the same cross-section is moving downslope to form a terrace.

For level terraces, the following formulas should be used for computing cross-sectional area:

$$C_A = \frac{Wb * VI}{8} + DC$$

C : cross-section, in square m, Wb : width of bench, in m, VI : vertical interval, in m,

DC: Dyke cross-section, in square m (or $m^2$)

For outward-sloped terrace a modification of the riser height (Hr) is required for calculating cross-section and volume as follows:

Hr = VI - OH

Hr: Height of riser, VI: Vertical interval, OH: Outward height (equals width of bench multiplied by 0.03)

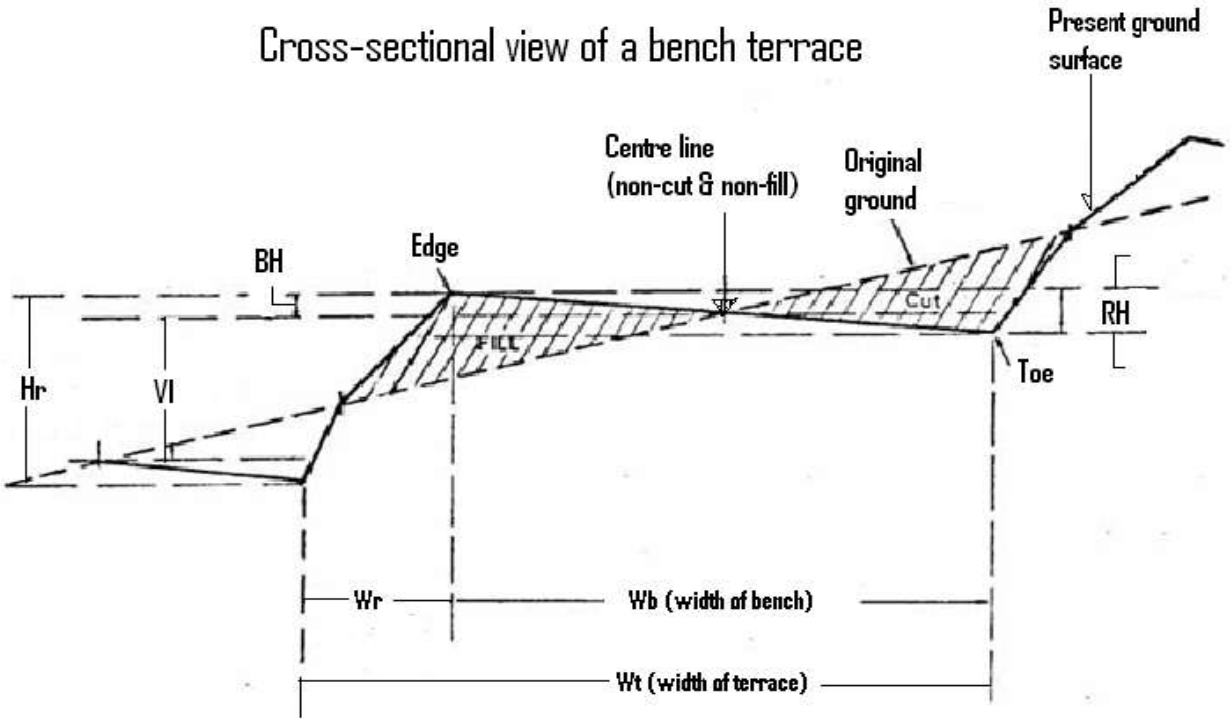



Figure 4. Cross-sectional view and computation for reverse-sloped bench terrace

Table 3 Summary of formulae for computing the specifications of the terraces

| | | |
|---|---|---|
| 1 | Vertical Interval (VI) | $VI = \frac{S * Wb}{100 - (S * U)}$ |
| 2 | Depth of cut (D) | $D = \frac{Wb}{2} \tan \square$ (for level terraces) |
| 3 | Depth of cut (D) | $D = \frac{Wb}{2} \tan \square + \frac{RH}{2}$ (reverseslope) |
| 4 | Depth of cut (D) | $D = \frac{Wb}{2} \tan \square - \frac{OH}{2}$ (outwardslope) |
| 5 | Revers Height (RH) | RH = Wb * 0.05 |
| 6 | Height of Riser (HR) | HR = VI + RH |
| 7 | Width of riser (Wr) | Wr = Hr * U |
| 8 | Width of terrace (Wt) | Wt = Wb + Wr |
| 9 | Linear length (L) | $L = \frac{43,560}{Wt}$ (per acre) |
| 10 | Linear length (L) | $L = \frac{10,000}{Wt}$ (per ha) |
| 11 | Net Area of bench (A) | $A = L * Wb$ |
| 12 | Percent of bench (Pb %) | $Pb = \frac{43,560}{Wt} * 100$ (per acre) |
| 13 | Percent of bench (Pb %) | $Pb = \frac{10,000}{Wt} * 100$ (per ha) |
| 14 | Cross-sectional Area ($C_A$) | $C_A = \frac{Wb * Hr}{8}$ |
| 15 | Volume of cut and fill (V) | $V = L * C_A = L * \frac{Wb * Hr}{8}$ |

# 10.Layout and Surveying

## 10.1. Layout:

The layout of terraces should include an examination of the site's physical conditions such as slope, soil depth, texture, erosion, presence of rocks, wetness, vegetation cover and present land use. The layout design should include specifications of the terraces (or treatments), sites and types of waterways, sites of roads and other farm installation needs. Human factors such as the farmers' plans and resources, labour conditions, and the tools to be used, must also be considered.

## 10.2. Surveying of Bench Terraces

**Preparatory work**

This entails preparing survey equipment, stakes, colour ribbons or markers, and deciding on survey methods and sequences, and clearing the area in the direction of surveying,

**Equipment**

The equipment usually consists of:

- line level, dumpy level, abney level or A-frame;
- measuring tape and rod;
- soil auger.

**Basic techniques**

For level terraces: use contouring or levelling techniques.

For graded terraces: use graded-contouring techniques.

**Special techniques**

(i) **Setting of base-line**: An up-and-down base-line should be set at the site along a representative slope.

(ii) **Use of centre-line method**: When specification tables are not available, a quick calculation of the VI can be made in the field. Use a level to determine and stake the

VI of the terraces along the base line. This should be followed by graded contouring or levelling surveys according to the type of terrace to be built.

After staking out all the contours or graded contours, add one line of marked stakes in between them. This line serves as the bottom line of the upper terrace and the top line of the lower one. Continue adding stakes so as to cover the whole area. A top line should be added to the first terrace on the upward slope, and a bottom line to the last terrace on the downward slope. This method is recommended for hand-made terraces where centre-lines should be kept and observed as non-cut and non-fill lines.

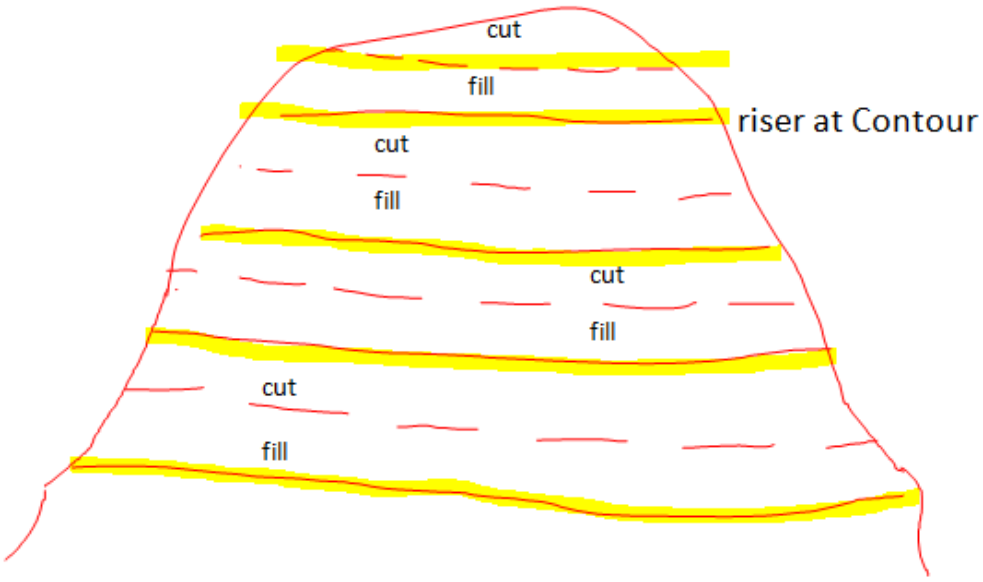



Figure 5 Centre line method of surveying

**(iii)Use of two-line method**: Design details can be readily obtained when a set of specification tables are available. The base line should be staked out with the width of the terrace (Wt), using a tape. A contour or graded contour line should be run from each stake until the whole area is covered. These lines serve as the bottom lines of the upper terraces as well as the top lines of the succeeding terraces. This method is recommended for terrace construction using mechanical power, as any centre-lines will obstruct the construction operation and should be omitted.

The stakes should be streamlined if there are sharp turns and narrow bottlenecks as these will interfere with future operations. Streamlining the stakes entails extra cuts or fills but is worthwhile in the long run.

**Marking stakes**

Each contour line of stakes should be marked with a different colour ribbon or paint in order to avoid confusion during construction, (e.g. centre lines in red, and side lines in yellow or green, etc.).

# 11.Construction methods

Construction of bench terrace can be carried out by manual labour or can be constructed by a machine. For the time being this manual deals with manual labour. During the manual construction it is advisable that the terrace must be built when the soil is **neither too dry nor too wet**. The cut and fill of the terraces should be done gradually and at an equal pace so that there is neither an excess nor a lack of soil. This principle applies regardless of what kinds of tools are used for the operation. Bench terrace is constructed either from top to bottom or from bottom to top both methods have their own advantage and disadvantage the decision is left for development agents in agreement with community or land owners.

## 11.1. Top-Down method

In the Top-Down method start building the terrace from the top of a hill and proceed down slope as shown in Figure 6 and 7 below. In this method if there is unexpected rain during construction or if we didn't finish/perform as per our plan the bench terrace will not be danger to be washed away in the case of heavy rain. It is also possible to allocate piece of work without waiting for somebody to finish. More over if there is a need to construct stone support, only half of the riser needs the support. It is not labour consuming compared to the bottom-up approach. However, this type of construction needs a berm for foundation stability of the riser which competes land for cultivation.

## 11.2. Bottom-Up method

The Bottom-Up is the most preferred method of construction as shown in Figure 8 below, it allows the construction of support the whole height of the riser starting from the bottom with good foundation which gives more stability to the bench. Hence berm is not needed, allowing the whole bench width to be used for cultivation. It is more stable when supported by stones. However, it is impossible to start working on the next bench above before the first or the lower bench is completed this is to mean that the people participating in the construction are limited to work on single row bench, labour management could be difficult as some people may be idle. In addition, if upper area treatment or preservation is not carried out or ensured, the constructed terrace is under treat from excess floods/runoff coming from the land above. Hence, temporary protection measures should be constructed for such cases. Construction of cut-off drain is recommended to protect the terraces from damage by the runoff that may come from the upper and untreated areas. If the bench riser is constructed from stone it needs more stones and labour compared to the top-down method.

## 11.3. Basic Construction steps for both methods

- Remove the topsoil and pile it convenient place.
- Dig the foundation and start to construct the riser along the contour
- Dig the sub soil on the cut section and fill on the fill section ,with raising the riser, until it make level,
- Finally spread the top soil all across the terrace. Figure 5 below illustrates clearly the construction steps
- The riser/ terrace wall need to be compacted during construction of earthen raisers/ terrace wall should be inclined at a slope of 1:1
- In areas where stones are plenty raiser can be constructed with stone wall.
- Earthen terrace wall or riser would be stabilized with grass

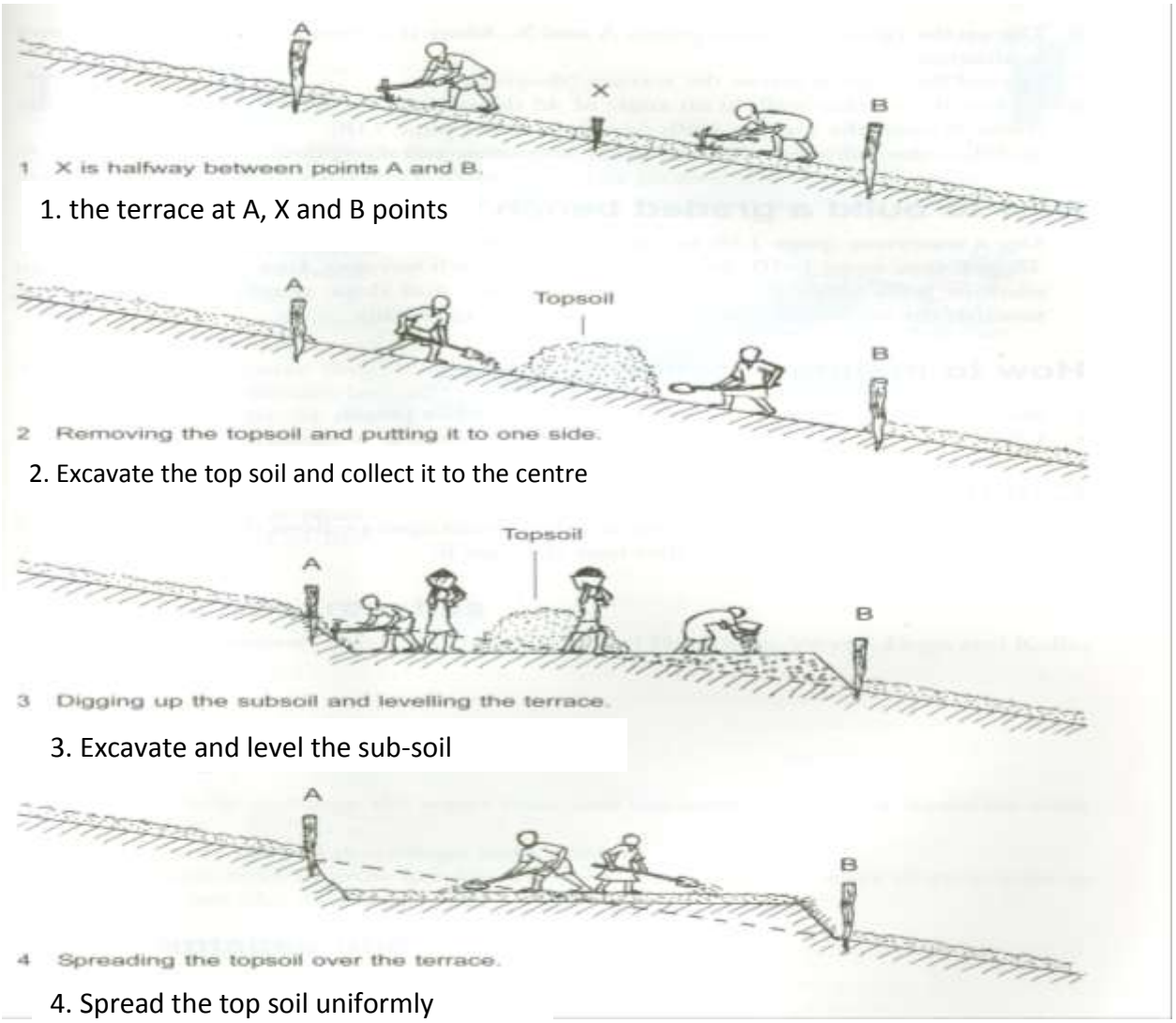



Figure 6 Steps in constructing bench terraces

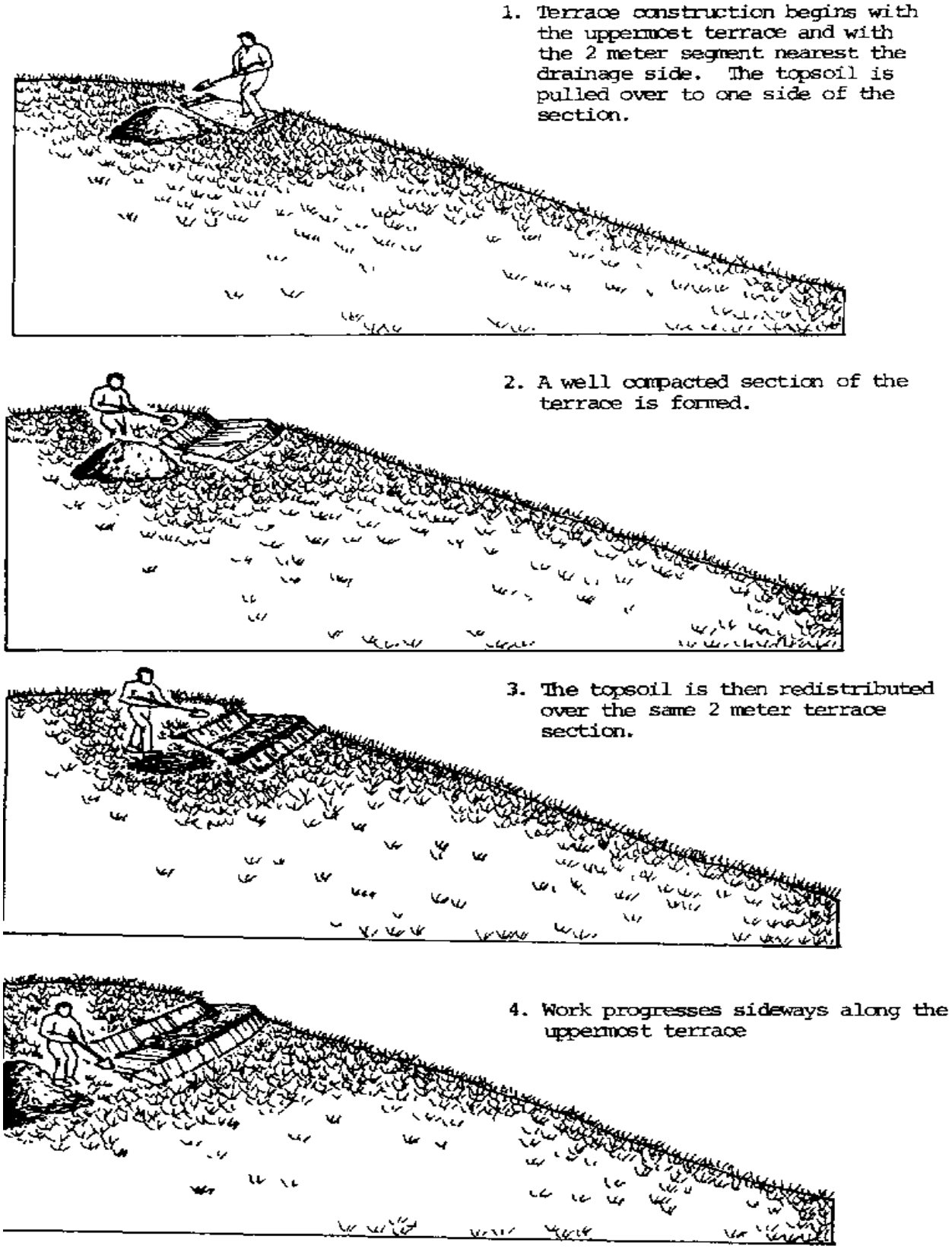



Figure 7 Top-Down construction method

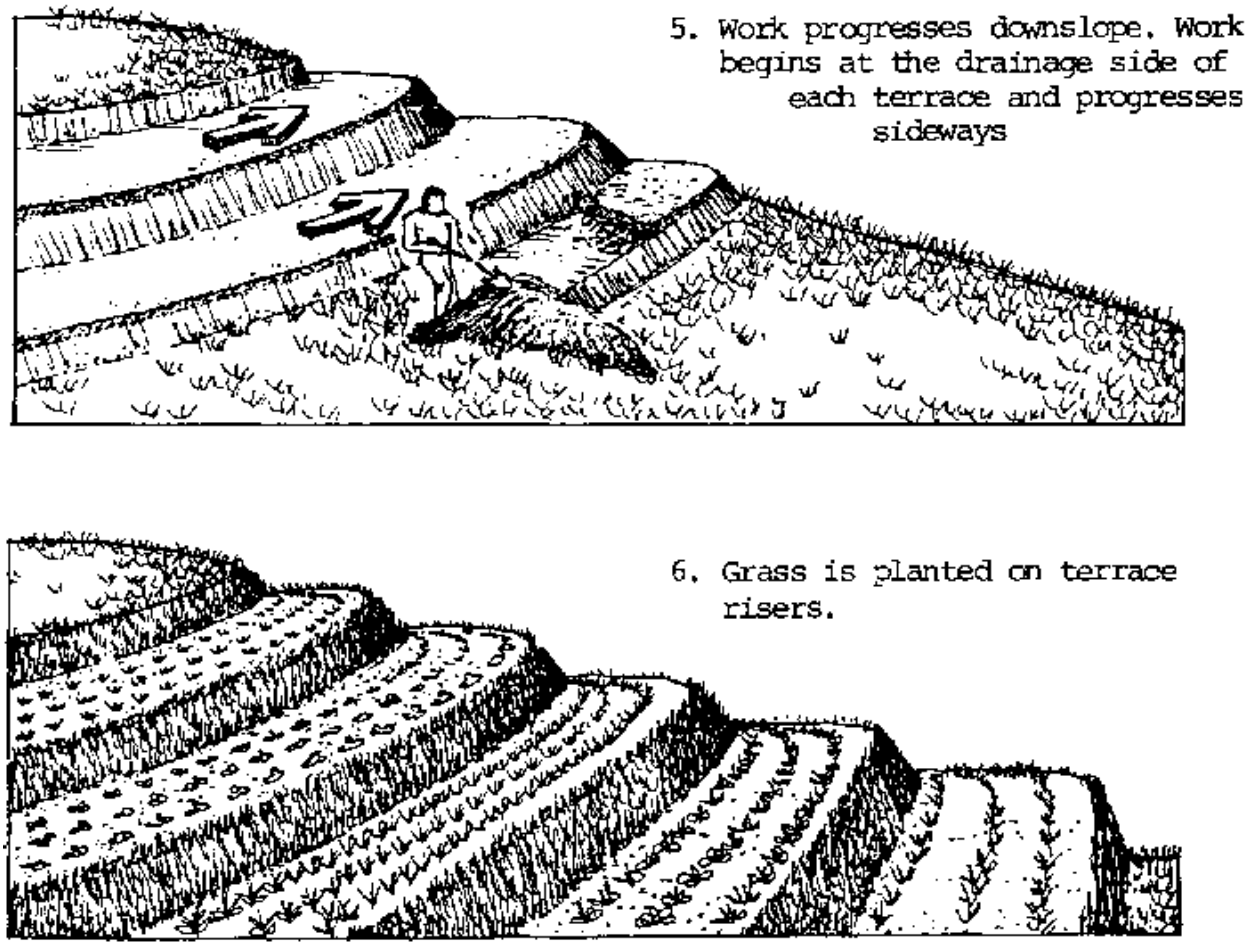



Figure 8 Top-Down construction method continued

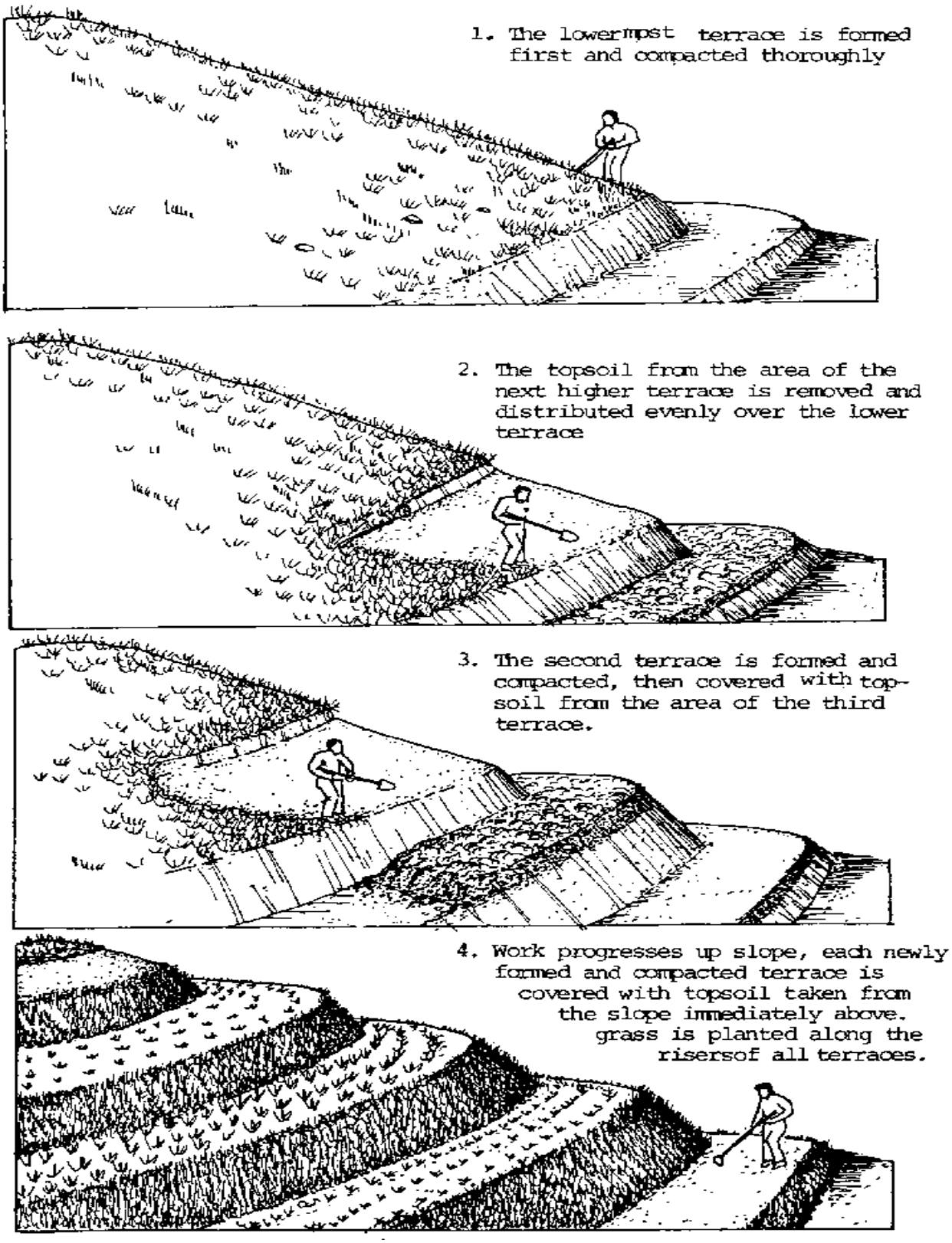



Figure 9 Bottom-Up construction method

Sometimes, rocks or clods of earth can be placed along the bottom line of the stakes to serve as a foundation before filling. During the filling operation, the soil should be compacted firmly by a beater every 15 cm layer. If the layer of soil fill is thick, the compacting process becomes difficult. Terraces which go across existing depression areas should be built particularly strong. The edge of a terrace should be built a little higher than planned because of settling. The rate of settling may be as high as 10% of the depth of the fill.

Figure 10 Compaction of fill soil

Both the reverse and horizontal grades should be checked by a level during construction work and corrections must be made promptly wherever necessary. The slope of the riser should be shaped to 0.75:1. Waterway shaping should be commenced only after the terraces are cut. Make sure all the terrace outlets are higher than the waterway bottom.

## 12.Topsoil treatment or preservation

Bench terraces usually expose the infertile subsoil and this can result in lower production unless some prevention or improvement measures are undertaken. One such a measure is topsoil treatment or preservation. When fertile topsoil exists, topsoil treatment is always worthwhile. Two alternative methods follow:

1. The terraces should be built from the bottom of the slope upwards. After the bottom terrace is roughly cut, the topsoil from the slope above is then pulled down to the lower bench and spread on its surface. Repeat this procedure for the next terrace up the slope

and proceed uphill in this way until the top terrace is built. Of course, the top terrace will not have topsoil unless it is obtained from another place.

2. The second method is to push the topsoil off horizontally to-the next section before cutting the terrace. The topsoil should be pushed back when the bench is completed. For hand-made terraces, the topsoil can be piled along the centre line provided that the bench is wide enough.

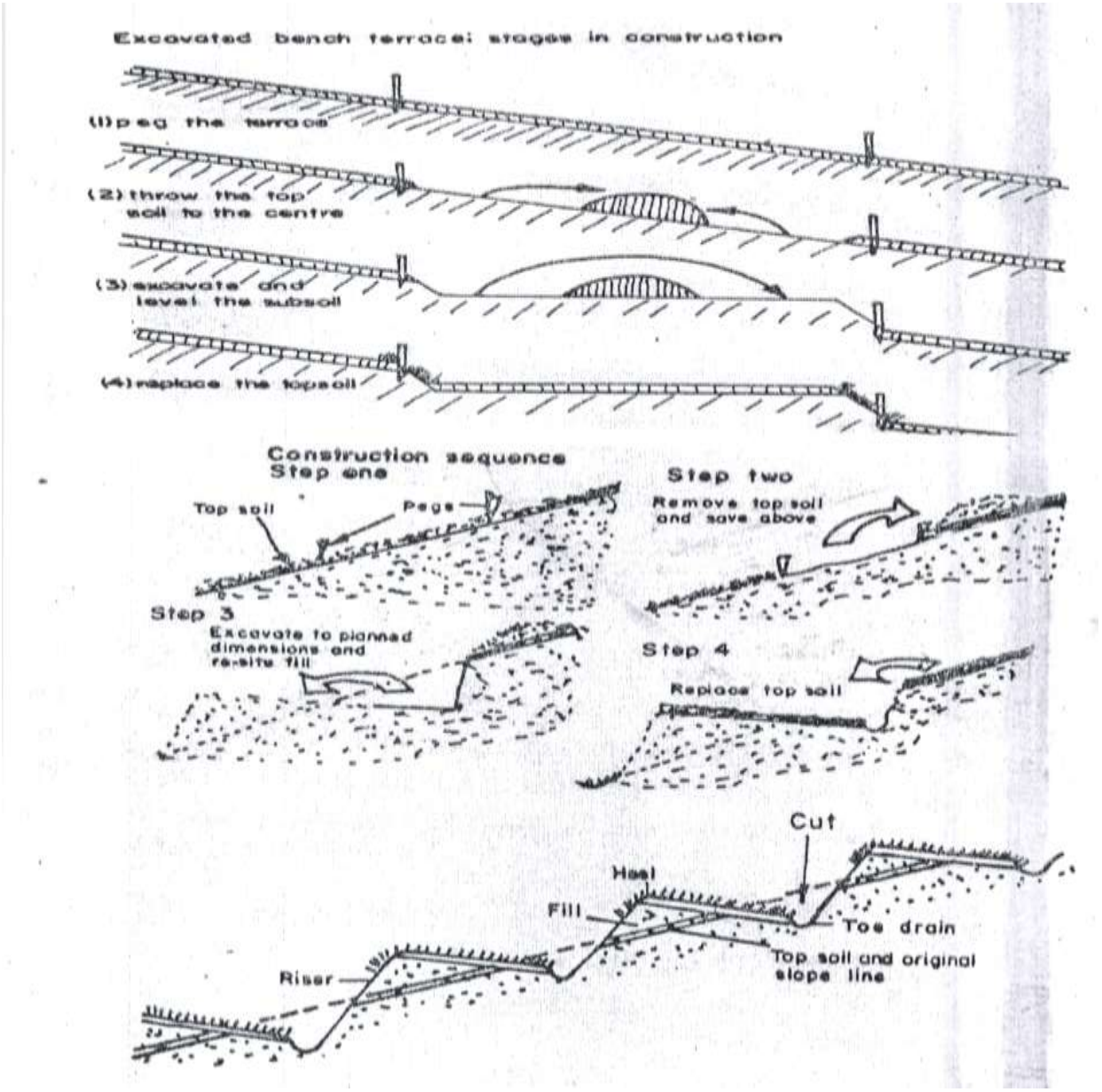



Figure 11 Different types of top soil management methods during construction

## 13.Work norm

We all are aware that, the current work norm specified in the CBPWD guideline is 500pd/km This is to mean that a person can construct 2m long bench terrace per day, without considering the volume of cut and fill that could vary based on the width and slope of the land as well as the addition labour required for collecting, and construction of risers built from stones. Hence the work norm which has been developed before some three decades ago is currently under challenge. Generally-speaking, a person can cut and fill 3 to 4 cubic m of earth dusting eight hours of supervised work, although output may vary depending on the type of soil and if rocks are present. If a terrace is wider than 4 m, output will be reduced because the transporting of the earth requires extra time. In some countries a team of 3 persons/m for narrow terraces and 4 persons/m for wider terraces is recommended for efficient terracing work. In the case of wider terraces, two persons should be employed for cutting, the third for compacting and consolidating the risers, and the fourth for transporting the soil. In our country some regions have raised the issue as one factor for lack of quality of construction which needs revision of the work norm.

## 14.Cost and cost relations

Once the terracing volume per unit area is calculated with the formula illustrated in the previous section or from the specification tables, the construction cost can be computed as follows:

$$C = \frac{V}{T} * R$$

C : Cost of constructing terraces

V : Volume of cut and fill

T : Output per person-day

R : Wage per person-day, etc.

For topsoil preservation, add 40 person-days per hectare for manual labour.

[1]**Worknorms:** for example 2PD/$M^3$ as cut and fill is involved and higher if stone risers are to be included.

**Example**: To calculate the construction cost for 0.5 ha of 3.5 m wide bench terraces on a 30% slope using the topsoil preservation method:

**Step 1**: The volume for 0.5 ha is 719 $m^3$. This figure is calculated by the formula mentioned earlier or taken from specification tables (Table l).

**Step 2:**Expected output for the proposed site is 3.5 $m^3$ per person-day for the proposed site (under average conditions)[1].

**Step 3:** Calculate the local wage per person-day, e.g. Ethiopian. Birr**.**

**Step 4**: C $= \frac{V}{T} * R = \frac{719\ m^3}{3.5\ m} * 20 = EBirr\ 4{,}108.57$

**Step 5:** **C** =Ethiopian Birr 4,108.57 + (20 x 20) = E. Birr 4,508.57 (including top soil preservation or clearing).

The cost of terracing per unit area depends on the following factors: slope, soil, width of bench, presence of rocks or tree stumps, and tools to be used for construction. The wider the bench (flat strip) the more costly it will be, even though the percentage of the bench remains the same. With a fixed width, the steeper the slope, the more expensive the terracing work will be.

# 15. Inspection, protection, maintenance, management and integration requirements

## 15.1. Inspection

- Conduct close inspections during and after construction as per standard specifications.
- Periodic inspection and maintenance will be required based on post-construction site conditions.
- Make any repairs necessary to ensure the measure is operating properly.
- During the construction phase, if there is major maintenance beyond the capacity of the individual farmers, mobilizing labour support from the community will be the

responsibility of the field technicians and kebele administrators to ensure that these measures are properly functioning.

- Damaged benching and terracing areas shall be repaired immediately and reseeded as soon as possible. If excessive seepage or surface runoff is a problem, the seepage/runoff should be controlled with appropriate drainage facilities. Desho grass is well adopted by farmers in some areas.
- Prompt action shall be taken as needed to ensure proper drainage and slope stability. Rills shall be prepared and damaged areas shall be reseeded as they develop.
- Substantial maintenance of the newly planted or seeded vegetation may be required.

## 15.2. Protection

New terraces should be protected at their risers and outlets and should be carefully maintained, especially during the first two years. After cutting a terrace, its riser should be shaped and planted with grass as soon as possible. Sod-forming, or rhizome-type grasses are better than those of the tall or bunch-type. Although tall grasses may produce considerable forage for cattle, they require frequent cutting and attention. The rhizome-type of local grass has proved very successful in protecting risers. Stones, when available, can also be used to protect and support the risers. An additional protection method is hydro-seeding.

The outlet for drainage-type terraces is the point where the run-off leaves the terrace and goes into the waterway or safe outlets. Its gradient is usually steep and should be protected by sods of earth. A piece of rock, a brick, or a cement block, is sometimes needed to check the water flow on steeper channels. Similar checks on water flow are required for level bench terraces where the water falls from the higher terraces onto those below. A piece of rock should be placed on the lower terrace to dissipate the energy of the flowing water. Grasses should also be established on the area of the bench crossed by the waterway.

## 15.3. Maintenance

Bench terraces require regular care and maintenance. If a small break is neglected, large-scale damage will result. Following is a list of maintenance work that should be carried out after heavy storms and cropping, especially in the first two to three years period.

**Benches:** the toe drains should be always open and properly graded; water must not be allowed to accumulate in any part of the terrace. All runoff should be allowed to collect at the toe drains for safe disposal to the protected waterway. Obstacles such as continuous mounds or beds must be removed at regular intervals to allow water to pass to the toe drain. Grasses and weeds should be removed from the benches. Correct gradients should be maintained and reshaped immediately after crops are harvested. Ploughing must be carried out with care so as not to destroy the toe drains and the grade.

**Risers:** keep grasses growing well on the risers. Weeds which threaten the survival of the grasses should be cut back or uprooted. Grasses should not be allowed to grow too high. Any small break or fall from the riser must be repaired immediately. Cattle should not be allowed to trample on the risers or eat the grass. Runoff should not be allowed to flow over the risers on reverse-sloped terraces.

## 15.4. Management and integration requirements

The lower part of the benched field is planted with perennials such as coffee, Gesho (Rhamnuspranoides), and Chat (Cataedulis). On the benched field annuals such as sorghum, maize and others are cropped. Cassava is grown on the top edge of the terrace to make use of the accumulated soft soil, in view of root crop. Making use of the residual moisture ratooning with sorghum is practiced. Farmyard manure and compost is intensively applied. A rotation can be considered to alternate cropping in the catchment in wetter seasons and fallow in the drier ones.

## 15.5. Outlets for drainage types of terrace

The outlets should be checked to see whether they are adequately protected. Make sure that the water flows through the outlets instead of going around them. Any breaks must be repaired or maintained immediately.

## 15.6. Soil productivity

Deep ploughing, or sub-soiling is needed to improve the structure of the soils on the cut part of the bench terraces. Green manuring, or compost application is needed in the initial period in order to increase soil fertility. Soil productivity should be maintained by means of proper crop rotation and the use of fertilizers.

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## Specification Tables for Bench Terraces

Table 4 Specification of bench terrace for hand-made for Riser Slope = 0 .75:1 Reverse Slope = 0.05

| Bench Width (Wb, m) | Slope | | SPECIFICATION | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | Grade | VI m | RH m | Hr m | Dc m | Wr m | Wt m | L m | A m² | Pb % | C m² | V m³ |
| **2.50** | 12 | 6.8 | 0.33 | 0.13 | 0.46 | 0.21 | 0.35 | 2.85 | 3509 | 8773 | 88 | 0.14 | 491 |
| | 14 | 8.0 | 0.39 | 0.13 | 0.52 | 0.24 | 0.39 | 2.89 | 3460 | 8650 | 87 | 0.16 | 554 |
| | 16 | 9.1 | 0.46 | 0.13 | 0.59 | 0.27 | 0.44 | 2.94 | 3401 | 8503 | 85 | 0.18 | 612 |
| | 18 | 10.2 | 0.52 | 0.13 | 0.65 | 0.29 | 0.49 | 2.99 | 3345 | 8363 | 84 | 0.20 | 669 |
| | 20 | 11.3 | 0.59 | 0.13 | 0.72 | 0.31 | 0.54 | 3.04 | 3290 | 8225 | 82 | 0.23 | 757 |
| | 22 | 12.4 | 0.66 | 0.13 | 0.79 | 0.34 | 0.59 | 3.09 | 236 | 8090 | 81 | 0.25 | 809 |
| | 24 | 13.5 | 0.73 | 0.13 | 0.86 | 0.37 | 0.65 | 3.15 | 3175 | 7938 | 80 | 0.27 | 857 |
| | 26 | 14.6 | 0.81 | 0.13 | 0.94 | 0.39 | 0.71 | 3.21 | 3115 | 7788 | 78 | 0.29 | 903 |
| | 28 | 15.6 | 0.89 | 0.13 | 1.02 | 0.41 | 0.77 | 3.27 | 3058 | 7645 | 77 | 0.32 | 979 |
| | 30 | 16.7 | 0.97 | 0.13 | 1.10 | 0.44 | 0.83 | 3.33 | 3003 | 7508 | 75 | 0.34 | 1021 |
| | 32 | 17.7 | 1.05 | 0.13 | 1.18 | 0.47 | 0.89 | 3.39 | 2950 | 7375 | 74 | 0.37 | 1092 |
| | 34 | 18.8 | 1.14 | 0.13 | 1.27 | 0.49 | 0.95 | 3.45 | 2899 | 7248 | 73 | 0.40 | 1160 |
| | 36 | 19.8 | 1.23 | 0.13 | 1.36 | 0.51 | 1.02 | 3.52 | 2841 | 7103 | 71 | 0.43 | 1222 |
| | 38 | 20.8 | 1.33 | 0.13 | 1.46 | 0.54 | 1.10 | 3.60 | 2778 | 6945 | 70 | 0.46 | 1278 |
| | 40 | 21.8 | 1.43 | 0.13 | 1.56 | 0.57 | 1.17 | 3.67 | 2725 | 6813 | 68 | 0.49 | 1335 |
| | 42 | 22.8 | 1.53 | 0.13 | 1.66 | 0.59 | 1.25 | 3.75 | 2667 | 6668 | 67 | 0.52 | 1387 |
| | 44 | 23.7 | 1.64 | 0.13 | 1.77 | 0.61 | 1.33 | 3.83 | 2610 | 6525 | 65 | 0.55 | 1436 |
| | 46 | 24.7 | 1.76 | 0.13 | 1.89 | 0.64 | 1.42 | 3.92 | 2551 | 6378 | 64 | 0.59 | 1505 |
| | 48 | 25.6 | 1.88 | 0.13 | 2.01 | 0.67 | 1.51 | 4.01 | 2494 | 6235 | 62 | 0.63 | 1571 |
| | 50 | 26.6 | 2.00 | 0.13 | 2.13 | 0.69 | 1.60 | 4.10 | 2439 | 6098 | 61 | 0.67 | 1634 |
| **2.75** | 12 | 6.8 | 0.36 | 0.14 | 0.50 | 0.23 | 0.38 | 3.13 | 3195 | 8786 | 88 | 0.17 | 543 |
| | 14 | 8.0 | 0.43 | 0.14 | 0.57 | 0.26 | 0.43 | 3.18 | 3145 | 8649 | 87 | 0.20 | 629 |
| | 16 | 9.1 | 0.50 | 0.14 | 0.64 | 0.29 | 0.48 | 3.23 | 3096 | 8514 | 85 | 0.22 | 681 |
| | 18 | 10.2 | 0.57 | 0.14 | 0.71 | 0.32 | 0.53 | 3.28 | 3049 | 8385 | 84 | 0.24 | 732 |
| | 20 | 11.3 | 0.65 | 0.14 | 0.79 | 0.34 | 0.59 | 3.34 | 2994 | 8324 | 82 | 0.27 | 808 |
| | 22 | 12.4 | 0.73 | 0.14 | 0.87 | 0.37 | 0.65 | 3.40 | 2941 | 8088 | 81 | 0.30 | 882 |
| | 24 | 13.5 | 0.81 | 0.14 | 0.95 | 0.40 | 0.71 | 3.46 | 2890 | 7948 | 80 | 0.33 | 954 |

| | | |
|---|---|---|
| VI = Vertical Interval | Wr = Width of the riser | Pb = Percentage of benches |
| RH - Reverse height | Wt = Width of the terrace | C = Cross section of the terrace |
| Hr = Height of the riser | L = Length of the terrace per ha | V = Volume of cut per ha |
| Dc = Depth of cut | A = Arc of the benches (flat arc) per ha | |

## BENCH TERRACES 2: HAND-MADE

**Riser Slope = 0 .75:1**
**Reverse Slope = 0.05**

| Bench width (Wb, m) | Slope | | SPECIFICATION | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | Grade | VI m | RH m | Hr m | Dc m | Wr m | Wt m | L m | A m² | Pb % | C m² | V m³ |
| 2.75 | 26 | 14.6 | 0.89 | 0.14 | 1.03 | 0.43 | 0.77 | 3.52 | 2841 | 7813 | 78 | 0.35 | 994 |
| | 28 | 15.7 | 0.98 | 0.14 | 1.12 | 0.46 | 0.84 | 3.59 | 2786 | 7662 | 77 | 0.39 | 1087 |
| | 30 | 16.7 | 1.07 | 0.14 | 1.21 | 0.48 | 0.91 | 3.66 | 2732 | 7513 | 75 | 0.42 | 1147 |
| | 32 | 17.7 | 1.16 | 0.14 | 1.30 | 0.51 | 0.98 | 3.73 | 2681 | 7373 | 74 | 0.45 | 1207 |
| | 34 | 18.8 | 1.26 | 0.14 | 1.40 | 0.54 | 1.05 | 3.80 | 2632 | 7238 | 72 | 0.48 | 1263 |
| | 36 | 19.8 | 1.36 | 0.14 | 1.50 | 0.57 | 1.13 | 3.88 | 2577 | 7086 | 71 | 0.52 | 1340 |
| | 38 | 20.8 | 1.46 | 0.14 | 1.60 | 0.59 | 1.20 | 3.95 | 2532 | 6963 | 70 | 0.55 | 1393 |
| | 40 | 21.8 | 1.57 | 0.14 | 1.71 | 0.62 | 1.28 | 4.03 | 2481 | 6823 | 68 | 0.59 | 1464 |
| | 42 | 22.8 | 1.69 | 0.14 | 1.83 | 0.64 | 1.37 | 4.12 | 2427 | 6674 | 67 | 0.63 | 1529 |
| | 44 | 23.7 | 1.81 | 0.14 | 1.95 | 0.67 | 1.46 | 4.21 | 2375 | 6531 | 65 | 0.67 | 1591 |
| | 46 | 24.7 | 1.93 | 0.14 | 2.07 | 0.70 | 1.55 | 4.30 | 2326 | 6397 | 64 | 0.71 | 1652 |
| | 48 | 25.6 | 2.06 | 0.14 | 2.20 | 0.73 | 1.65 | 4.40 | 2273 | 6251 | 63 | 0.76 | 1728 |
| 3.00 | 12 | 6.8 | 0.40 | 0.15 | 0.55 | 0.25 | 0.41 | 3.41 | 2933 | 8799 | 88 | 0.21 | 616 |
| | 14 | 8.0 | 0.47 | 0.15 | 0.62 | 0.29 | 0.47 | 3.47 | 2882 | 8648 | 87 | 0.23 | 663 |
| | 16 | 9.1 | 0.55 | 0.15 | 0.70 | 0.32 | 0.53 | 3.53 | 2883 | 8499 | 85 | 0.26 | 737 |
| | 18 | 10.2 | 0.62 | 0.15 | 0.77 | 0.35 | 0.58 | 3.58 | 2793 | 8397 | 84 | 0.29 | 810 |
| | 20 | 11.3 | 0.71 | 0.15 | 0.86 | 0.37 | 0.65 | 3.65 | 2740 | 8220 | 82 | 0.32 | 877 |
| | 22 | 12.4 | 0.79 | 0.15 | 0.94 | 0.40 | 0.71 | 3.71 | 2695 | 8085 | 81 | 0.35 | 943 |
| | 24 | 13.5 | 0.88 | 0.15 | 1.03 | 0.43 | 0.77 | 3.77 | 2653 | 7959 | 80 | 0.39 | 1035 |
| | 26 | 14.6 | 0.97 | 0.15 | 1.12 | 0.47 | 0.84 | 3.84 | 2604 | 7812 | 78 | 0.42 | 1094 |
| | 28 | 15.6 | 1.06 | 0.15 | 1.21 | 0.49 | 0.91 | 3.91 | 2558 | 7674 | 77 | 0.45 | 1151 |
| | 30 | 16.7 | 1.16 | 0.15 | 1.31 | 0.53 | 0.98 | 3.98 | 2513 | 7539 | 75 | 0.49 | 1231 |
| | 32 | 17.7 | 1.26 | 0.15 | 1.41 | 0.55 | 1.06 | 4.06 | 2463 | 7389 | 74 | 0.53 | 1305 |
| | 34 | 18.8 | 1.37 | 0.15 | 1.52 | 0.57 | 1.14 | 4.14 | 2416 | 7248 | 73 | 0.57 | 1377 |
| | 36 | 19.6 | 1.48 | 0.15 | 1.63 | 0.60 | 1.22 | 4.22 | 2370 | 7110 | 71 | 0.61 | 1446 |
| | 38 | 20.8 | 1.59 | 0.15 | 1.74 | 0.63 | 1.31 | 4.31 | 2320 | 6960 | 70 | 0.65 | 1508 |
| | 40 | 2.18 | 1.71 | 0.15 | 1.86 | 0.67 | 1.40 | 4.40 | 2273 | 6819 | 68 | 0.70 | 1591 |

| | | |
|---|---|---|
| VI = Vertical Interval<br>RH - Reverse height | Wr = Width of the riser<br>Wt = Width of the terrace | Pb = Percentage of benches<br>C = Cross section of the terrace |
| Hr = Height of the riser | L = Length of the terrace per ha | V = Volume of cut per ha |
| Dc = Depth of cut | A = Arc of the benches (flat arc) per ha | |

## BENCH TERRACES 3: HAND-MADE

**Riser Slope = 0 .75:1**
**Reverse Slope = 0.05**

| Bench width (Wb (m) | Slope | | SPECIFICATION | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | Grade | VI m | RH m | Hr m | Dc m | Wr m | Wt m | L m | A m² | Pb % | C m² | V m³ |
| **3.00** | 42 | 22.8 | 1.84 | 0.15 | 1.99 | 0.71 | 1.49 | 4.49 | 2227 | 6681 | 67 | 0.75 | 1670 |
| | 44 | 23.7 | 1.97 | 0.15 | 2.12 | 0.73 | 1.59 | 4.59 | 2179 | 6537 | 65 | 0.80 | 1743 |
| **3.25** | 12 | 6.8 | 0.43 | 0.16 | 0.59 | 0.27 | 0.44 | 3.69 | 2710 | 8809 | 88 | 0.24 | 650 |
| | 14 | 8.0 | 0.51 | 0.16 | 0.67 | 0.31 | 0.50 | 3.75 | 2666 | 8665 | 87 | 0.27 | 720 |
| | 16 | 9.1 | 0.59 | 0.16 | 0.75 | 0.34 | 0.57 | 3.82 | 2617 | 8505 | 85 | 0.31 | 811 |
| | 18 | 10.2 | 0.68 | 0.16 | 0.84 | 0.37 | 0.63 | 3.88 | 2577 | 8375 | 84 | 0.34 | 876 |
| | 20 | 11.3 | 0.77 | 0.16 | 0.93 | 0.41 | 0.70 | 3.95 | 2532 | 8229 | 82 | 0.38 | 962 |
| | 22 | 12.4 | 0.86 | 0.16 | 1.02 | 0.44 | 0.77 | 4.02 | 2488 | 8086 | 81 | 0.41 | 1020 |
| | 24 | 13.5 | 0.95 | 0.16 | 1.11 | 0.47 | 0.83 | 4.08 | 2451 | 7966 | 80 | 0.45 | 1103 |
| | 26 | 14.6 | 1.05 | 0.16 | 1.21 | 0.50 | 0.91 | 4.16 | 2404 | 7813 | 78 | 0.49 | 1178 |
| | 28 | 15.6 | 1.15 | 0.16 | 1.31 | 0.53 | 0.98 | 4.23 | 2364 | 7683 | 77 | 0.53 | 1253 |
| | 30 | 16.7 | 1.26 | 0.16 | 1.42 | 0.57 | 1.07 | 4.32 | 2315 | 7524 | 75 | 0.58 | 1343 |
| | 32 | 17.7 | 1.37 | 0.16 | 1.53 | 0.61 | 1.15 | 4.40 | 2273 | 7387 | 74 | 0.62 | 1409 |
| | 34 | 18.8 | 1.48 | 0.16 | 1.64 | 0.63 | 1.23 | 4.48 | 2232 | 7254 | 73 | 0.67 | 1495 |
| | 36 | 19.8 | 1.60 | 0.16 | 1.76 | 0.67 | 1.32 | 4.57 | 2188 | 7111 | 71 | 0.72 | 1575 |
| | 38 | 20.8 | 1.73 | 0.16 | 1.89 | 0.70 | 1.42 | 4.67 | 2141 | 6958 | 70 | 0.77 | 1649 |
| | 40 | 21.8 | 1.86 | 0.16 | 2.02 | 0.73 | 1.52 | 4.77 | 2096 | 6812 | 68 | 0.82 | 1719 |
| | 42 | 22.8 | 2.00 | 0.16 | 2.16 | 0.76 | 1.62 | 4.87 | 2053 | 6672 | 67 | 0.88 | 1801 |
| **3.50** | 12 | 6.8 | 0.46 | 0.18 | 0.64 | 0.30 | 0.48 | 3.98 | 2513 | 8796 | 88 | 0.28 | 704 |
| | 14 | 8.0 | 0.55 | 0.18 | 0.73 | 0.34 | 0.55 | 4.05 | 2469 | 8642 | 86 | 0.32 | 790 |
| | 16 | 9.1 | 0.64 | 0.18 | 0.82 | 0.37 | 0.62 | 4.12 | 2427 | 8495 | 85 | 0.36 | 874 |
| | 18 | 10.2 | 0.73 | 0.18 | 0.91 | 0.41 | 0.68 | 4.18 | 2392 | 8372 | 84 | 0.40 | 957 |
| | 20 | 11.3 | 0.82 | 0.18 | 1.00 | 0.44 | 0.75 | 4.25 | 2353 | 8236 | 82 | 0.44 | 1035 |
| | 22 | 12.4 | 0.92 | 0.18 | 1.10 | 0.47 | 0.83 | 4.33 | 2310 | 8085 | 81 | 0.48 | 1109 |
| | 24 | 13.5 | 1.02 | 0.18 | 1.20 | 0.51 | 0.90 | 4.40 | 2273 | 7956 | 80 | 0.53 | 1205 |
| | 26 | 14.6 | 1.13 | 0.18 | 1.31 | 0.54 | 0.98 | 4.48 | 2232 | 7812 | 78 | 0.57 | 1272 |
| | 28 | 15.6 | 1.24 | 0.18 | 1.42 | 0.58 | 1.07 | 4.57 | 2188 | 7658 | 77 | 0.62 | 1357 |

| | | |
|---|---|---|
| VI = Vertical Interval<br>RH - Reverse height<br>Hr = Height of the riser<br>Dc = Depth of cut | Wr = Width of the riser<br>Wt = Width of the terrace<br>L = Length of the terrace per ha<br>A = Arc of the benches (flat arc) per ha | Pb = Percentage of benches<br>C = Cross section of the terrace<br>V = Volume of cut per ha |

## BENCH TERRACES 4: HAND-MADE

**Riser Slope = 0 .75:1**
**Reverse Slope = 0.05**

| Bench width (Wb (m) | Slope | | S P E C I F I C A T I O N | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | Grade | VI m | RH m | Hr m | Dc m | Wr m | Wt m | L m | A m² | Pb % | C m² | V m³ |
| **3.50** | 30 | 16.7 | 1.36 | 0.18 | 1.54 | 0.62 | 1.16 | 4.66 | 2146 | 7511 | 75 | 0.67 | 1438 |
| | 32 | 17.7 | 1.47 | 0.18 | 1.65 | 0.65 | 1.24 | 4.74 | 2110 | 7385 | 74 | 0.72 | 1519 |
| | 24 | 18.8 | 1.60 | 0.18 | 1.78 | 0.69 | 1.34 | 4.84 | 2066 | 7231 | 72 | 0.78 | 1612 |
| | 26 | 19.8 | 1.73 | 0.18 | 1.91 | 0.72 | 1.43 | 4.93 | 2028 | 7098 | 71 | 0.84 | 1704 |
| | 28 | 20.8 | 1.86 | 0.18 | 2.04 | 0.75 | 1.53 | 5.03 | 1988 | 6958 | 70 | 0.89 | 1769 |
| | 40 | 21.8 | 2.00 | 0.18 | 2.18 | 0.79 | 1.64 | 5.14 | 1946 | 6811 | 68 | 0.95 | 1849 |
| **3.75** | 12 | 6.8 | 0.50 | 0.19 | 0.69 | 0.32 | 0.52 | 4.27 | 2342 | 8783 | 88 | 0.32 | 749 |
| | 14 | 8.0 | 0.59 | 0.19 | 0.78 | 0.35 | 0.59 | 4.34 | 2304 | 8640 | 87 | 0.37 | 853 |
| | 15 | 9.1 | 0.69 | 0.19 | 0.88 | 0.39 | 0.66 | 4.41 | 2268 | 8505 | 85 | 0.41 | 930 |
| | 18 | 10.2 | 0.78 | 0.19 | 0.97 | 0.43 | 0.73 | 4.48 | 2232 | 8370 | 84 | 0.46 | 1027 |
| | 20 | 11.3 | 0.88 | 0.19 | 1.07 | 0.47 | 0.80 | 4.55 | 2198 | 8243 | 82 | 0.50 | 1099 |
| | 22 | 12.4 | 0.99 | 0.19 | 1.18 | 0.51 | 0.89 | 4.64 | 2155 | 8081 | 81 | 0.55 | 1185 |
| | 24 | 13.5 | 1.10 | 0.19 | 1.29 | 0.55 | 0.97 | 4.72 | 2119 | 7946 | 80 | 0.61 | 1293 |
| | 26 | 14.6 | 1.21 | 0.19 | 1.40 | 0.58 | 1.05 | 4.80 | 2083 | 7811 | 78 | 0.66 | 1375 |
| | 28 | 15.6 | 1.33 | 0.19 | 1.52 | 0.62 | 1.14 | 4.89 | 2045 | 7669 | 77 | 0.71 | 1452 |
| | 30 | 16.7 | 1.45 | 0.19 | 1.64 | 0.65 | 1.23 | 4.98 | 2008 | 7530 | 75 | 0.77 | 1546 |
| | 32 | 17.7 | 1.58 | 0.19 | 1.77 | 0.69 | 1.33 | 5.08 | 1969 | 7384 | 74 | 0.83 | 1634 |
| | 34 | 18.8 | 1.71 | 0.19 | 1.90 | 0.73 | 1.43 | 5.18 | 1931 | 7241 | 72 | 0.89 | 1719 |
| | 36 | 19.8 | 1.85 | 0.19 | 2.04 | 0.77 | 1.53 | 5.28 | 1894 | 7103 | 71 | 0.96 | 1818 |
| | 38 | 20.8 | 1.99 | 0.19 | 2.18 | 0.81 | 1.64 | 5.39 | 1855 | 6956 | 70 | 1.02 | 1892 |
| **4.00** | 12 | 6.8 | 0.53 | 0.20 | 0.73 | 0.34 | 0.55 | 4.55 | 2198 | 8792 | 88 | 0.37 | 813 |
| | 14 | 8.0 | 0.63 | 0.20 | 0.83 | 0.38 | 0.62 | 4.62 | 2165 | 8660 | 87 | 0.42 | 909 |
| | 16 | 9.1 | 0.73 | 0.20 | 0.93 | 0.42 | 0.70 | 4.70 | 2128 | 8512 | 85 | 0.47 | 1000 |
| | 18 | 10.2 | 0.83 | 0.20 | 1.03 | 0.46 | 0.77 | 4.77 | 2096 | 8384 | 84 | 0.52 | 1090 |
| | 20 | 11.3 | 0.94 | 0.20 | 1.14 | 0.50 | 0.86 | 4.86 | 2058 | 8232 | 82 | 0.57 | 1173 |
| | 22 | 12.4 | 1.05 | 0.20 | 1.25 | 0.54 | 0.94 | 4.94 | 2024 | 8096 | 81 | 0.63 | 1275 |
| | 24 | 13.5 | 1.17 | 0.20 | 1.37 | 0.58 | 1.03 | 5.03 | 1988 | 7952 | 80 | 0.69 | 1372 |

| | | |
|---|---|---|
| VI = Vertical Interval | Wr = Width of the riser | Pb = Percentage of benches |
| RH - Reverse height | Wt = Width of the terrace | C = Cross section of the terrace |
| Hr = Height of the riser | L = Length of the terrace per ha | V = Volume of cut per ha |
| Dc = Depth of cut | A = Arc of the benches (flat arc) per ha | |

## BENCH TERRACES 5: HAND-MADE

**Riser Slope = 0 .75:1**
**Reverse Slope = 0.05**

| Bench width (Wb (m) | Slope | | SPECIFICATION | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | Grade | VI m | RH m | Hr m | Dc m | Wr m | Wt m | L m | A m² | Pb % | C m² | V m³ |
| **4.00** | 26 | 14.6 | 1.29 | 0.20 | 1.49 | 0.62 | 1..12 | 5.12 | 1953 | 7812 | 78 | 0.75 | 1465 |
| | 28 | 15.6 | 1.42 | 0.20 | 1.62 | 0.66 | 1.22 | 5.22 | 1916 | 7664 | 77 | 0.81 | 1552 |
| | 30 | 16.7 | 1.55 | 0.20 | 1.75 | 0.70 | 1.31 | 5.31 | 1883 | 7532 | 75 | 0.00 | 1657 |
| | 32 | 17.7 | 1.68 | 0.20 | 1.83 | 0.74 | 1.41 | 5.41 | 1843 | 7392 | 74 | 0.94 | 1737 |
| | 34 | 18.8 | 1.83 | 0.20 | 2.03 | 0.78 | 1.52 | 5.52 | 1812 | 7248 | 73 | 1.02 | 1848 |
| | 36 | 19.8 | 1.97 | 0.20 | 2.17 | 0.82 | 1.63 | 5.61 | 1776 | 7104 | 71 | 1.09 | 1936 |
| **4.25** | 12 | 6.8 | 0.56 | 0.21 | 0.77 | 0.36 | 0.58 | 4.83 | 2070 | 8798 | 88 | 0.41 | 849 |
| | 14 | 8.0 | 0.67 | 0.21 | 0.88 | 0.40 | 0.66 | 4.91 | 2037 | 8657 | 87 | 0.47 | 957 |
| | 16 | 9.1 | 0.77 | 0.21 | 0.98 | 0.45 | 0.74 | 4.99 | 2004 | 8517 | 85 | 0.52 | 1042 |
| | 18 | 10.2 | 0.88 | 0.21 | 1.09 | 0.49 | 0.82 | 5.07 | 1972 | 8381 | 84 | 0.53 | 1144 |
| | 20 | 11.3 | 1.00 | 0.21 | 1.21 | 0.53 | 0.91 | 5.16 | 1938 | 8237 | 82 | 0.64 | 1240 |
| | 22 | 12.4 | 1.12 | 0.21 | 1.33 | 0.57 | 1.00 | 5.25 | 1905 | 8096 | 81 | 0.71 | 1353 |
| | 24 | 13.5 | 1.24 | 0.21 | 1.45 | 0.62 | 1.09 | 5.34 | 1873 | 7960 | 80 | 0.72 | 1442 |
| | 26 | 14.6 | 1.37 | 0.21 | 1.58 | 0.66 | 1.19 | 5.44 | 1838 | 7812 | 78 | 0.84 | 1544 |
| | 28 | 15.6 | 1.51 | 0.21 | 1.72 | 0.70 | 1.29 | 5.54 | 1805 | 7671 | 77 | 0.91 | 1643 |
| | 30 | 16.7 | 1.65 | 0.21 | 1.86 | 0.74 | 1.40 | 5.65 | 1770 | 7523 | 75 | 0.99 | 1752 |
| | 32 | 17.7 | 1.79 | 0.21 | 2.00 | 0.78 | 1.50 | 5.75 | 1739 | 7391 | 74 | 1.06 | 1843 |
| | 34 | 18.8 | 1.94 | 0.21 | 2.15 | 0.83 | 1.61 | 5.86 | 1707 | 7255 | 73 | 1.14 | 1946 |
| | 36 | 19.8 | 2.10 | 0.21 | 2.31 | 0.87 | 1.73 | 5.98 | 1672 | 7106 | 71 | 1.23 | 2052 |
| **4.50** | 12 | 6.8 | 0.59 | 0.23 | 0.82 | 0.38 | 0.62 | 5.12 | 1953 | 8789 | 88 | 0.46 | 893 |
| | 14 | 8.0 | 0.70 | 0.23 | 0.93 | 0.43 | 0.70 | 5.20 | 1923 | 8654 | 87 | 0.52 | 1000 |
| | 16 | 9.1 | 0.82 | 0.23 | 1.05 | 0.48 | 0.79 | 5.29 | 1890 | 8505 | 85 | 0.52 | 1115 |
| | 18 | 10.2 | 0.94 | 0.23 | 1.17 | 0.52 | 0.88 | 5.38 | 1859 | 8366 | 84 | 0.66 | 1227 |
| | 20 | 11.3 | 1.00 | 0.23 | 1.29 | 0.57 | 0.97 | 5.47 | 1828 | 8226 | 82 | 0.73 | 1334 |
| | 22 | 12.4 | 1.19 | 0.23 | 1.42 | 0.61 | 1.07 | 5.57 | 1795 | 8078 | 81 | 0.80 | 1436 |
| | 24 | 13.5 | 1.32 | 0.23 | 1.55 | 0.66 | 1.16 | 5.66 | 1767 | 7952 | 80 | 0.87 | 1537 |

| | | |
|---|---|---|
| VI = Vertical Interval | Wr = Width of the riser | Pb = Percentage of benches |
| RH - Reverse height | Wt = Width of the terrace | C = Cross section of the terrace |
| Hr = Height of the riser | L = Length of the terrace per ha | V = Volume of cut per ha |
| Dc = Depth of cut | A = Arc of the benches (flat arc) per ha | |

## BENCH TERRACES 6: HAND-MADE

**Riser Slope = 0 .75:1**
**Reverse Slope = 0.05**

| Bench width (Wb (m) | Slope | | SPECIFICATION | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % | Grade | VI m | RH m | Hr m | Dc m | Wr m | Wt m | L m | A m² | Pb % | C m² | V m³ |
| **4.50** | 26 | 14.6 | 1.45 | 0.23 | 1.68 | 0.70 | 1.26 | 5.76 | 1736 | 7812 | 78 | 0.95 | 1649 |
| | 28 | 15.6 | 1.60 | 0.23 | 1.83 | 0.75 | 1.37 | 5.87 | 1704 | 7668 | 77 | 1.03 | 1755 |
| | 30 | 16.7 | 1.74 | 0.23 | 1.97 | 0.79 | 1.48 | 5.98 | 1672 | 7524 | 75 | 1.11 | 1856 |
| | 32 | 17.7 | 1.90 | 0.23 | 2.13 | 0.83 | 1.60 | 6.10 | 1639 | 7376 | 74 | 1.20 | 1967 |
| | 34 | 18.8 | 2.05 | 0.23 | 2.28 | 0.88 | 1.71 | 6.21 | 1610 | 7245 | 73 | 1.28 | 2061 |
| **4.75** | 12 | 6.8 | 0.63 | 0.24 | 0.87 | 0.40 | 0.65 | 5.40 | 1852 | 8797 | 83 | 0.52 | 963 |
| | 14 | 8.0 | 0.74 | 0.24 | 0.98 | 0.45 | 0.74 | 5.49 | 1822 | 8635 | 87 | 0.58 | 1057 |
| | 16 | 9.1 | 0.86 | 0.24 | 1.10 | 0.50 | 0.83 | 5.58 | 1792 | 8512 | 85 | 0.65 | 1165 |
| | 18 | 10.2 | 0.99 | 0.24 | 1.23 | 0.55 | 0.92 | 5.67 | 1764 | 8379 | 84 | 0.73 | 1288 |
| | 20 | 11.3 | 1.12 | 0.24 | 1.36 | 0.60 | 1.02 | 5.77 | 1733 | 8232 | 82 | 0.81 | 1404 |
| | 22 | 12.4 | 1.25 | 0.24 | 1.49 | 0.64 | 1.12 | 5.87 | 1704 | 8094 | 81 | 0.88 | 1500 |
| | 24 | 13.5 | 1.39 | 0.24 | 1.63 | 0.69 | 1.22 | 5.97 | 1675 | 7956 | 80 | 0.97 | 1625 |
| | 26 | 14.6 | 1.53 | 0.24 | 1.77 | 0.73 | 1.33 | 6.08 | 1645 | 7814 | 78 | 1.05 | 1727 |
| | 28 | 15.6 | 1.68 | 0.24 | 1.92 | 0.78 | 1.44 | 6.19 | 1616 | 7676 | 77 | 1.14 | 1842 |
| | 30 | 16.7 | 1.84 | 0.24 | 2.08 | 0.83 | 1.56 | 6.31 | 1585 | 7529 | 75 | 1.24 | 1965 |
| | 32 | 17.7 | 2.00 | 0.24 | 2.24 | 0.88 | 1.68 | 6.43 | 1555 | 7386 | 74 | 1.33 | 2068 |
| **5.00** | 12 | 6.8 | 0.66 | 0.25 | 0.91 | 0.42 | 0.68 | 5.68 | 1761 | 8805 | 88 | 0.57 | 1004 |
| | 14 | 8.0 | 0.78 | 0.25 | 1.03 | 0.48 | 0.77 | 5.77 | 1733 | 8665 | 87 | 0.64 | 1109 |
| | 16 | 9.1 | 0.91 | 0.25 | 1.16 | 0.53 | 0.87 | 5.87 | 1704 | 8520 | 85 | 0.73 | 1244 |
| | 18 | 10.2 | 1.04 | 0.25 | 1.29 | 0.58 | 0.97 | 5.97 | 1675 | 8375 | 84 | 0.81 | 1357 |
| | 20 | 11.3 | 1.18 | 0.25 | 1.43 | 0.62 | 1.07 | 6.07 | 1648 | 8240 | 82 | 0.89 | 1467 |
| | 22 | 12.4 | 1.32 | 0.25 | 1.57 | 0.68 | 1.18 | 6.18 | 1618 | 8090 | 81 | 0.98 | 1585 |
| | 24 | 13.5 | 1.46 | 0.25 | 1.71 | 0.73 | 1.28 | 6.28 | 1592 | 7960 | 80 | 1.07 | 1703 |
| | 26 | 14.6 | 1.62 | 0.25 | 1.87 | 0.78 | 1.40 | 6.40 | 1563 | 7815 | 78 | 1.17 | 1829 |
| | 28 | 15.6 | 1.77 | 0.25 | 2.02 | 0.82 | 1.52 | 6.52 | 1534 | 7670 | 77 | 1.26 | 1933 |
| | 30 | 16.7 | 1.94 | 0.25 | 2.19 | 0.88 | 1.64 | 6.64 | 1506 | 7530 | 75 | 1.37 | 2063 |

| | | |
|---|---|---|
| VI = Vertical I28nterval | Wr = Width of the riser | Pb = Percentage of benches |
| RH - Reverse height | Wt = Width of the terrace | C = Cross section of the terrace |
| Hr = Height of the riser | L = Length of the terrace per ha | V = Volume of cut per ha |
| Dc = Depth of cut | A = Arc of the benches (flat arc) per ha | |