https://doi.org/10.29321/MAJ.10.A04116

Madras agric. J., 45 : (6) 211—222, 1958

Cost and Economics of Bench Terracing

by

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Introduction : Bench terracing is the process by which a series of platforms is constructed across the slope of a land, at suitable interval separated by "risers" or nearly vertical cut faces. These, in effect, break up the long slope into a set of steps or platforms; and as such function effectively as a measure to control erosion and conserve soil and moisture. This method is generally adopted for irrigated fields situated on sloping terrain; elsewhere in hilly country, on slopes steeper than 15% where area avilable for cultivation is scarce and soil conditions are favourable and where it is economical to have these measures for soil conservation.

While advocating adoption of bench terracing among the ryots according to its suitability to local conditions, it will be necessary not only to appraise the ryots of the advantages, constructional details and specifications of such work but also to furnish them with its estimated cost and economics. Normally ryots would like to know the cost of terracing per acre so that they can work out the economics of such a measure and decide whether such land improvement is worthwhile from the economic point of view as well. An accurate estimate is possible only after an elaborate contour and topographical survey of an area. But it is not practicable to conduct such survey for the entire area, especially when it involves large tracts, before launching extensive propaganda among ryots. It is the aim of this paper, therefore to lay down ready methods of estimating cost of bench terracing per acre.

Factors Involved : The actual cost of bench terracing depends primarily upon the following factors :

1. Conditions of soil and sub-soil ;
2. Land surface including vegetation cover on it, undulations, depressions, mounds, etc.,

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3. Slope of the area ;
4. Specifications of bench terrace on deviation of its alignment ; and
5. Terrace outlets.

The principal item that affects cost of bench terraces per acre is the total quantity of earth work involved and the rate.

The cost of earth work per unit depends upon the type of soil, its compactness, nature of land surface, vegetation cover on it and local rates of wages for the labourers. It also depends upon whether the work is executed with manual labour or by utilising earth moving implements and machinery like tractors, bull dozers, scrapers, graders, etc. The available horse power of the machinery, type and size of implements as also the efficiency of operators or workers determine the out turn of work per unit time and thereby the cost per unit work.

The quantity of earth work involved per acre depends upon the physical undulations of land, presence of depressions requiring filling in, mounds requiring additional excavation due to deviation in alignment there, type and specifications of bench terraces proposed and slope of the area. Physical conditions of land and slope of the terrain are rarely uniform and therefore it would be necessary to consider the average or predominent slope for computation of total earth work.

The cost of terrace outlets adds to the ultimate cost of bench terracing per acre. The type and specifications of the outlet and the number required per acre will determine such additional cost per acre. The total number of outlets per acre depends upon the critical length of bench terrace and the vulnerable points requiring safe drainage of excess water. From the experience gained under conditions in the Nilgiris (South India), it is found economical and effective to drain the excess water from bench terraces towards what are called "vertical drains" which are the natural downhill drainage channels or where they are too far apart, through earthen channels excavated with suitable cross sections and protected by close growing and soil binding grasses or if necessary by stone pitching. Along these channels, drop pits or silt traps of suitable size are provided at regular intervals so that the velocity of water is reduced to prevent it from attaining high erosive power. Wherever the area drained is large and the volume and rate of flow of excess water is great, stone paving along bottom and sides of channels may have to be adopted in place of grass planting.

The cost of construction of such channel can be worked out as per local rates and if the approximate total length of such channel per acre is known, the cost of outlet per acre can be easily calculated. A ready method to estimate the length of channel outlet per acre is worked out later.

Computation of Earth Work For Bench Terracing: As already explained, among other factors the type and specifications of bench terrace have great influence on the cost of work per acre; and therefore they need close consideration to determine the approximate cost of terracing. The following are the various items to be considered to arrive at cost.

(i) Critical length, number of outlets and total length per acre,

(ii) Vertical interval,

(iii) Net width of terrace; and

(iv) Cross sectional area of cutting.

(a) *Critical length and number of terrace outlets per acre:* Under similar conditions, the longer the bench terrace the greater will be the area drained and thereby the greater the rate and volume of run-off. Beyond a certain length called the critical length, the volume of excess water will attain erosive power to cause soil erosion on the terrace itself. This critical length and the number of outlets required depend upon amount, intensity and incidence of rainfall, soil characteristics, width of terrace, longitudinal gradient, crops to be grown etc.

Assuming 'N' as the number of terrace outlets theoretically needed per acre each of which receiving excess water from the terraces on both sides and 'K' as the critical length of terrace, then

$$\text{'N'} = \frac{L}{2K} \qquad \text{———————} \qquad (1)$$

were 'L' is the total length of terrace per acre.

(b) *Total length of terrace per acre:* Total length of terrace per acre is an important factor affecting total earth work involved per acre and thereby the cost. The slope of the land and vertical interval adopted to suit local conditions determine this length. For convenience in calculating the length of terrace per acre, the following equation is worked out.

Let 'L' be the total length of terrace per acre, 'D' the vertical interval and 'S' the slope of land in feet per 100 feet (See fig. 1);

$$\text{then L} = \frac{*\ 43560}{\text{Horizonal spacing of terrace in feet}}$$

* (1 acre = 43560 Sq. ft.)

Horizontal spacing of terrace for 'S' ft. percentage slope ... = 100 feet.

Horizontal spacing of terrace for 'D' feet vertical interval ... $= \frac{100\ D}{S}$ feet.

$$\text{Therefore} \quad L = \frac{435 \cdot 6\ S}{D} \qquad (2)$$

Vertical Interval: Selection of a suitable vertical interval between terraces has to be made considering the soil conditions, crops grown, tillage convenience for economic agriculture and minimum possible disturbance to the top productive soil. Therefore, no hard and fast rule can be laid down in this regard for blanket application in all conditions. Lakshmipathi and Narayanaswami 1956 have worked out an equation for the Nilgiris conditions by which it is possible to arrive at either the vertical interval or the net width of bench terrace when one of them is fixed according to local conditions. This equation which has been worked out for a batter of 1 to 1 for the riser, runs as follows:

$D = \frac{Ws}{100-S}$, where 'W' is net width of terrace and 'D' is vertical interval ———— (3)

For harder soil conditions, it should be possible to provide a batter of to 1 to 1 for the embankment with nearly vertical cutting below. As such the average batter for the riser will be ½ to 1 For this batter, the equation can be derived as follows (See Fig. 2)

$W + \frac{D}{2} = \frac{100\ D}{S}$ were 'D' is the vertical interval.

$$\text{Therefore } D = \frac{2\ Ws}{(200\text{-}S)} \qquad (4)$$

Net width of terrace: From equations (3) and (4) it is possible to derive the net width of terrace when the batter provided for riser is 1 to 1 and ½ to 1 respectively as follows:

For batter 1 to 1 of riser:

$$W = \frac{D\ (100\text{-}S)}{S} \qquad (5)$$

For batter ½ to 1 of riser:

$$W = \frac{D\ (200-S)}{2\ S} \qquad (6)$$

Cross sectional area of cutting: As shown in figure 1 or 2, bench terraces can be economically constructed by the process of balanced cutting (half cutting and half embankment), where earth work excavated on the upper half of slope is deposited on the lower half to conform to the required specification of the terrace. The cross sectional area of cutting depends upon the vertical interval of bench terrace and the corresponding net width of terrace which in turn depends on the slope of land. As could be seen in figure 1 or 2, the hatched triangular portion denotes the cross sectional area of excavation. The recommended process of construction of terrace being half cutting and half embankment, the base of this triangle is $\frac{W}{2}$, whereas the height is $\frac{D}{2}$.

Therefore Cross sectional area of cutting $= \frac{1}{2} \times \frac{W}{2} \times \frac{D}{2}$

i. e., $C.S. = \frac{WD}{8}$ ——————— (7)

The lead for earth work thus depends upon the width of terrace, it being $\frac{W}{2}$.

Earth work per acre: The major item affecting cost of construction of bench terrace is the earth work involved. To this, the cost of establishing grasses or constructing stone retaining walls along vertical face of terrace, disposal drain and other works like diversion channels, gully control, stream protection etc., will have to be added on to obtain the total cost of bench terracing and other protective works proposed in the area.

Bench terraces can be constructed with either constant vertical interval or uniform net width available for cultivation. The former method is easy for execution whereas the latter will help minimising disturbance of productive soil.

(a) *Bench terrace with constant vertical interval:* Let 'E' be the total quantity of earth work expressed in terms of units required per acre, each unit being 1000 cft. Then $E = \left\{ \frac{\text{Length of terrace per acre} \times \text{C. S. area of cutting in S. ft.}}{1000} \right.$

Substituting values of 'L' and C. S. area in equations 2 & 7,

$E = \frac{435 \cdot 6\,S}{D} \times \frac{WD}{8} \times \frac{1}{1000}$ where 'W' and 'D' are in Ft.

i. e., $= 0 \cdot 05445\ WS$ ——————— (8)

Substituting value of 'W' given in equations (5) and (6) respectively,

$$E\ (V.\ I.)\ (\text{for batter 1 to 1 of riser}) = \frac{0{\cdot}05445\ D\ (100-S)}{S} \times S$$

$$= 5{\cdot}445\ D - 0{\cdot}05445\ DS \quad \text{———————} \quad (9)$$

$$E\ (V.\ I.)\ (\text{for batter } \tfrac{1}{2} \text{ to 1 of riser}) = \frac{0{\cdot}05445\ D\ (200-S)}{2S} \times S$$

$$= 5{\cdot}445\ D - 0{\cdot}02723\ DS \quad \text{———————} \quad (10)$$

From the equations (9) and (10) above, the value of 'E' in units of 1000 cft can be worked out for any constant value of 'D' the slope of land 'E' in feet per 100 feet being known. It could be seen that for a constant vertical interval, the greater the slope the lesser will be the quantity of earth work $\left\{ \frac{dE}{dS} \right.$ is negative in equations (9) and (10) above). Hence the cost of bench terracing with any constant vertical interval per acre will decrease with increase in slope. The graphs shown in figure (3) will illustrate this point.

Bench terraces with constant width : As worked out earlier in equation (8), E (w) = 0·05445 WS which denotes that the earth work involved in construction of bench terraces with constant width, depends upon the width selected (w) and slope. From the above equation it should be possible to calculate the total earth work involved in units of 1000 cft per acre for any constant width obtained. It could be seen also from this equation that for constant width of bench terrace, the greater the slope, the greater will be the quantity of earth work (E) and thereby the cost per acre $\left\{ \frac{dE}{dS} \right.$ is positive)

Vide graph in Figure 4

Terrace outlet : As mentioned earlier the number of outlets needed per acre depends upon the critical length of terrace and vulnerable points requiring drainage. If the approximate length of vertical drains (i. e. transverse channels to dispose excess water) per acre is known, the cost of its construction can be worked out as per local rates per unit length.

Let '1' be the approximate length of vertical drain per acre -

Then, 1 = N × Horizonal spacing of terrace, where N is the No. of outlets per acre.

Substituting value of N in equation (1),

$$1 = \frac{L}{2K} \times \frac{100\ D}{S}$$

Substituting value of 'L' in equation (2),

$$1 = \frac{435 \cdot 6\,S}{2DK} \times \frac{100\,D}{S}$$

$$\text{i. e. } 1 = \frac{21780}{K} \qquad (11)$$

In this equation the critical lenth of bench terrace i. e., 'K' will have to be determined taking into consideration the local factor, if possible by actual experimentation.

Economics of bench terracing : Equations (8), (9) and (10) and graphs in Figures (3) and (4) will show that bench terracing is a fairly costly measure for conserving soil and moisture. While recommending such measure therefore, it is important to take into account its economics and effectiveness in the appropriate land use. The cost of land, its productive capacity, crops grown and area lost for cultivation due to bench terracing are the important aspects requiring careful study. If the land to be tackled is cheap, badly eroded, very steep and the soil condition is such that it does not recouperate rapidly, it would not be advisable or economical to bench terrace it for cultivation, as the disturbed soil will render the land unproductive for a long period to come and cultivation, uneconomical. Such areas could be best put under pastures or forests.

Even though the conditions of soil are favourable and the degree of erosion is not severe, it should be further examined if the crops grown and the subsequent increase in yield expected after effective conservation of soil and moisture will be sustained as to fetch economic return which will not only offset the heavy initial layout on such works but also improve the economic status of the cultivator.

Next aspect but not the least to be considered carefully is the area lost for cultivation due to bench terracing. If by terracing considerable portion of land is lost, the net yield of crops may get adversely reduced and affect the agricultural economy of the cultivator. The principal factors affecting this loss in area is the batter or back slope provided for risers of bench terraces and the slope of land. Assuming a batter of 1 to 1 for the risers it could be seen, as shown below, that the percentage area lost due to terracing is more or less the same as the percentage of slope of land.

Net area available for cultivation after bench terracing 1 acre of land } (L W) Sq. ft,

where 'L' is the total length of terrace in feet per acre and 'W' the net width of terrace available for cultivation in feet.

Substituting value of 'L' and 'W' from equations 2 and 5 respectively, this will be $\frac{435{\cdot}6\,S}{D} \times \frac{D\,(100-S)}{S}$ Sq. ft.

i. e. percentage of area available for cultivation, after terracing $= \frac{435{\cdot}6\,S}{D} \times \frac{D\,(100-S)}{S} \times \frac{100}{43560} = (100-S)$

Therefore percentage of area lost due to terracing = S which is the slope of land in % ———— (12)

Similarly for a batter of ½ to 1 of riser, it can be shown that the percentage of area lost due to terracing is $\frac{S}{2}\%$ ———— (13)

Summary: Bench terracing has been recognised as a suitable mechanical measure of conserving soil and moisture, though its adoption is restricted to irrigated lands and elsewhere on steep slopes where soil conditions are good and land suitable for cultivation is scarce and its economics permit such a measure. Since the farmers would require not only the constructional details of such bench terraces but also the cost of construction of such terraces, the following equations have been derived for ready use in calculating approximate cost of construction of bench terraces with terrace outlets. For other items of work proposed in the area, a lump sum provision on a pro-rata basis may be assumed based on local conditions after personal inspection of the area.

S. No.	Description of work	Equation applicable			
		Batter 1 to 1 of riser of Bench Terrace	Equation No.	Batter ½ to 1 of riser of Bench Terrace	Equation No.
1	2	3	4	5	6
1.	Total length of terrace per acre (L)	$L = \frac{435{\cdot}6\,S}{D}$	2	$L = \frac{435{\cdot}6\,S}{D}$	2
2.	Vertical interval (D)	$D = \frac{WS}{(100-S)}$	3	$D = \frac{2\,WS}{(200-S)}$	4
3.	Net width of terrace (W)	$W = \frac{D\,(100-S)}{S}$	5	$W = \frac{D\,(200-S)}{2\,S}$	6
4.	Cross sectional area of cutting (C. S.)	$C.\,S. = \frac{WD}{8}$	7	$C.\,S. = \frac{WD}{8}$	7
5.	Earth work in units of 1000 cft. per acre for bench terrace of constrant vertical interval (E. V. I.)	E (V. I) = 5·445 D — 0·05445 DS.	9	E (V. I) = 5·445 D — 0.02723 DS.	10
6.	Earthwork in units of 1000 cft. per acre for bench Terrace of constant width (EW)	E (w) = 0·05445 WS	8	E (w) = 0 05445 WS	8

Continued

S. No.	Description of work	Equation applicable			
		Batter 1 to 1 of riser of Bench Terrace	Equation No.	Batter ½ to 1 of riser of Bench Terrace	Equation No.
1	2	3	4	5	6
7.	No. of terrace outlet (N)	$N = \frac{L}{2K}$	1	$N = \frac{L}{2K}$	1
8.	Length of vertical drain (Outlet) per acre (1)	$1 = \frac{21780}{K}$	11	$1 = \frac{21780}{K}$	11
9.	Percentage area lost under terracing	S %	12	$\frac{S}{2}$%	13

As an illustration, the cost of constructing bench terrace and outlets on sloping lands as actually incurred in a representative area in the Nilgiris and as per calculation using the above equations are worked out in the table furnished below :

S. No.	Description.	
1.	Situation of the land	Marlimund lake area, Survey No. 4492 and 4489
2.	Area bench terraced	5·75 % acres
3.	Slope of the land (S)	32·5 % average
4.	Vertical interval followed	5 feet
5.	Batter or back slope for riser	½ to 1 average
6.	Average length of terrace followed (K)	300 feet
7.	Mode of execution	Manual labour
8.	Total Earth work - as per actuals	132·712 units
9.	do. as per equation (10) i. e., E (per acre) = 5·445 D — 0·02723 DS	130·50 units
10.	Total length of outlet (disposal drain) — as per actuals	437 ft.
11.	do. do. as per equation (11), i. e. $\left.\begin{matrix}1 = \\ \text{per acre}\end{matrix}\right\} = \frac{21780}{K}$	417 ft.
12.	Cross section of disposal drain adopted ...	$\frac{3'-6'' + 1'-0''}{2} \times 1'-3''$ = 2·81 Sq. ft.
13.	Earthwork for disposal drain as per actuals	1·228 units.
14.	do. do. as per calculation using formulae	1·172 units.

Continued

S. No.	Description	
15.	Total earth work for Bench terracing and outlets (disposal drains) - as per actuals (8+13)	133·94 units.
16.	do. do. as per equations (9 + 14)	131· 672 units.
17.	Cost per unit of 1000 cft of earth work	Rs. 17·00
18.	Total cost of bench terracing and outlet—(disposal drains) as per actuals	Rs. 2,277/-
19.	do. do. as per calculation	Re. 2,238/-
20.	Average cost per acre of Bench Terracing and outlets-as per actuals	Rs. 396/-
21.	do. do. as per equation	Rs. 389·25

Acknowledgment: The authors are very much grateful to Shri M. S. V. Rama Rao, Director of Soil Conservation, (Engineering), Dr. R. M. Gorrie, F. A. O. Expert and Shri C. P. Bhimayya, Chief Research Officer, Desert Afforestation & Soil Conservation Research Station, Jodhpur for their valuable suggestions and guidance in the preparation of this article. They acknowledge with thanks the services rendered by Shri E. V. James, Draughtsman of this Centre.

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BENCH TERRACING.

(Not to Scale)

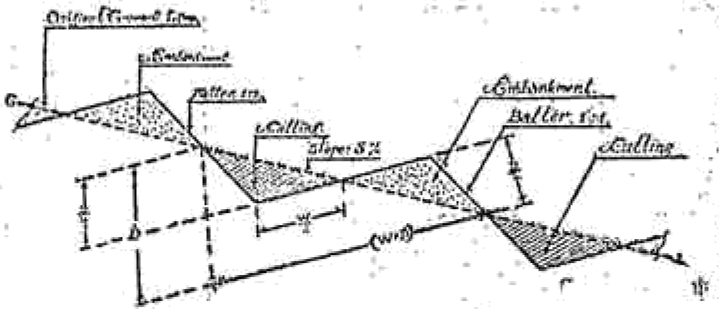

FIG. 1.

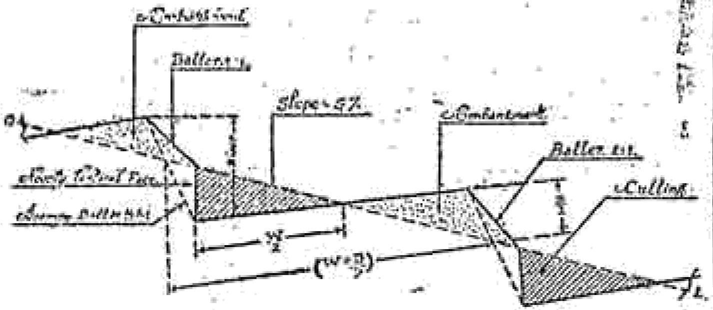

FIG. 2.

GRAPH SHOWING EARTHWORK PER ACRE FOR FORMING BENCH TERRACES OF CONSTANT VERTICAL INTERVAL ON LANDS OF DIFFERENT SLOPES.

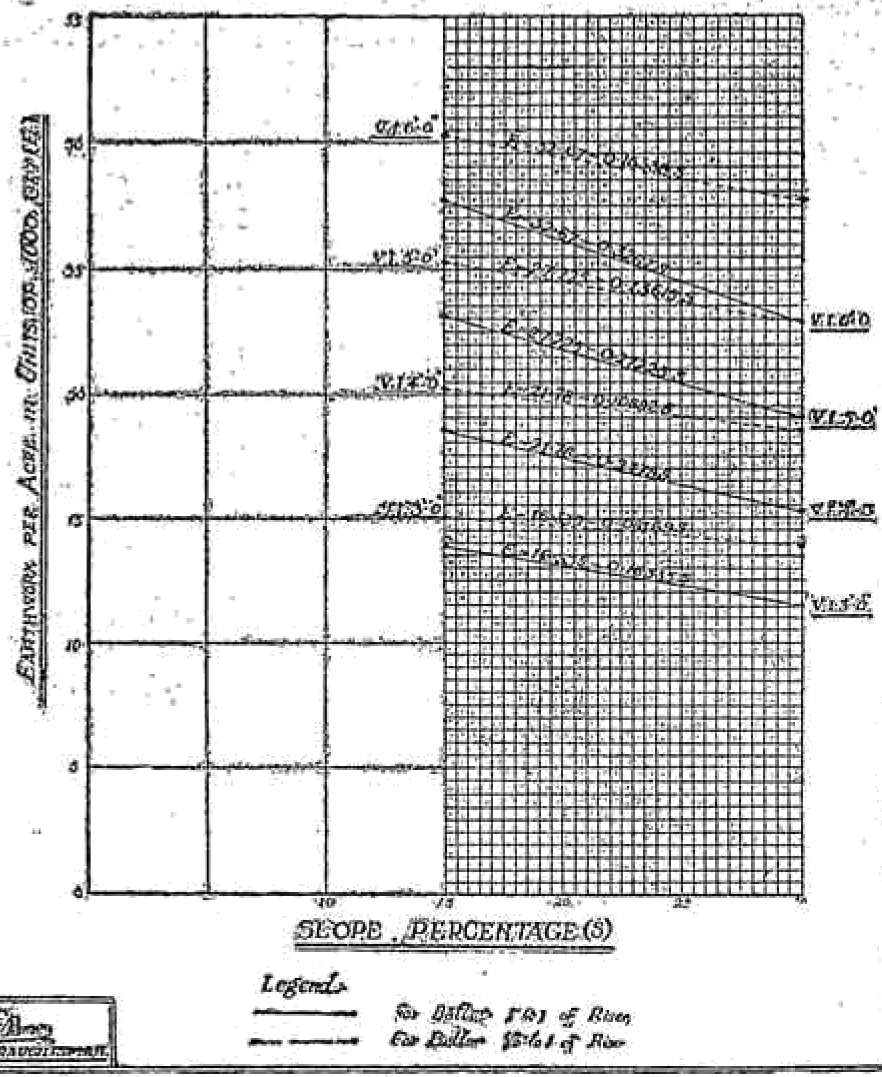

Fig. 4.

GRAPH SHOWING EARTHWORK PER ACRE FOR FORMING BENCH TERRACES OF CONSTANT WIDTH ON LANDS OF DIFFERENT SLOPES.