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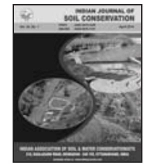

Decision support system for contour trenching

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ABSTRACT

Trenching is the most efficient practice for restoration of degraded non-arable lands. Government and various agencies put tremendous efforts and spend lot of money in the rehabilitation of degraded lands by carrying out trenching. Design and layout of trenches under different rainfall conditions involve lot of computation based on watershed information to derive maximum benefit of the technology. However, in the absence of clear guidelines for computation of trench specifications (spacing, cross section and density), desirable results are not achieved from this intervention. Under field conditions wide fluctuations in trench specifications are observed in different regions of the country, due to highly diverse land forms and climatic conditions. A Decision Support System is designed to bridge the knowledge gap between experts and actual field level implementers by helping the user to make decisions for the design and layout of Continuous Contour Trenches (CCT) and Staggered Contour Trenches (SCT) under varied land forms and climatic conditions. The DSS will be of immense importance and of practical use for persons working in State government agencies, NGOs and Forest Departments implementing watershed development programmes.

1. INTRODUCTION

Depleting natural resources, land degradation and environmental pollution due to excessive human interference in natural processes has become the biggest problem of mankind. Land degradation together with pressure of ever growing demands for food, fuel and fiber from such lands is intensifying the problem and putting extra burden on limited resources. Adoption of intensive cultivation technologies and use of inorganic, non-degradable inputs for production, particularly from degraded lands is further aggravating the problem. It has been estimated by various agencies that out of 329 m ha total geographical area of the country; the area under degraded lands is between 63.9 to 187.0 m ha. However, a general consensus agrees at about 120.72 m ha (Maji *et al*., 2010). Degraded lands are characterized by low productivity potential due to various constraints related to rainfall management, soil, topography and biotic interference. Trenching is one of the most efficient technologies for restoration of degraded lands which brings desirable changes through *in-situ* conservation of moisture, soil, nutrients and energy fluxes. A contour trench is a micro depression or tiny reservoir constructed across the slope without a spillway with the objective to trap runoff, sediment, nutrient, organic matter etc. and provides more opportunity time to the collected runoff to get infiltrated before the occurrence of the next rainfall. Contour trenching is an efficient technology for rehabilitation of degraded lands, particularly in semi-arid and arid regions where rainfall intensities are high and soils are sandy with relatively high permeability. It is very effective in re-vegetation of denuded land slopes and for development of orchards on sloping lands by reducing runoff and sediment loss and conservation of moisture for longer period in the soil profile. It also helps in obtaining higher biomass productivity from watersheds due to improvement in physical and chemical properties of the soil (Samra *et al.,* 2004). Contour trenching in non-arable lands constitutes the single most popular measure and has been given the highest priority for the treatment of sloping lands in the entire national and international watershed rehabilitation programs. SCT in combination with vegetative barrier are more effective in controlling soil loss (Madhu *et al.,* 2011).

A number of agencies, such as government organizations (forest, agriculture, soil and water conservation departments), agriculture universities and NGOs are engaged in implementing watershed programmes on large scale. Its importance can be realized from the allocation of ₹19251.22 crores in 11th Plan (Anon., 2007) by Govt. of India. A major share has been allocated for trenching and other measures for *in-situ* moisture conservation and to improve the establishment and growth of vegetation to meet rural requirements. However, in the absence of clear cut guidelines as well as tools for optimum designing of trenches (spacing, cross section and density), many such programmes could not come up to expectations. Significant variations in trench specifications have been observed under different agro climatic regions of the country, which are bound to occur due to varied land forms and climatic conditions.

Accurate estimates of runoff generated from watersheds, trench specifications, cost estimates and layout of trenches in the field is a very tedious and time taking process. Often, accuracy suffers due to insufficient technical knowhow at end users. Even today under field conditions the estimates are based upon thumb rules and hence they are either over designed or under designed. This either results in incurring of high costs and wastage of resources or in other cases failed to bring desired changes due to under.

DSS is an interactive user friendly system which incorporates knowledge and expertise within the framework of the decision support mechanism. The DSS is an integrated assembly of models, data, interpretive routines and other relevant information which efficiently processes input data, runs the model and displays the result in an easy to interpret format (George *et al.,* 2002, Rao and Rajput, 2009). DSS helps in analyzing the facts and situations, decision making process, to understand the problem and explore various alternative courses of actions and identification of the most appropriate decision (Rao and Rajput, 2009). Keeping these considerations in view the present decision support system is developed as a readymade tool using standard methods and techniques for runoff estimation from fields and trench design. It provides opportunity to the user to get rid of tedious and time consuming calculations, avoid chances of mistakes and helps in making accurate decisions for various options that can be applicable for implementing the technology.

2. MATERIALS AND METHODS

Design Procedure

To begin with the decision support system and making estimations of runoff, one needs some basic data as input for the area for which trenches have to be made, these include: One day maximum rainfall for 2 years return period (mm), Average slope of land (%), Curve Number (CN), Soil depth (cm), Width of plot (m), Length of plot (m), Plantation spacing (m x m), rate of earth work (Rs./m^3).

Design Storm

It is the maximum rainfall (mm) recorded during the desired return period in the given area for which estimations for trench design are to be prepared. Considering the life span, objective of making a trench and availability of data for daily maximum rainfall, a return period of two years is appropriate for designing a trench (Maps for this value are available from India Meteorological Department). The software has been uploaded with inbuilt rainfall data for more than 500 places across the country.

Slope

It is an input related to the average slope (%) of the area for which trenches are to be designed.

Estimation of Direct Runoff from Watershed Area

Direct runoff (Q) estimation from watersheds based on input data is done by the software based on the runoff equation developed by Soil Conservation Service (1972).

$$Q = (P - Ia)^2 / (P - Ia + S) \qquad (1)$$

Where, Q = direct runoff (mm); P = rainfall (mm); S = potential maximum retention (mm); and Ia = initial abstraction during the period between beginning of rainfall and runoff (mm).

Under Indian condition, initial abstractions have been estimated to be 0.3S for various soils except in black soil for which it is estimated as 0.1S (Samra *et al.,* 2004). The above equation has been used for estimation of direct runoff in the software as under:

$$Q = (P - 0.3S)^2 / (P + 0.7S) \text{ for all other soils} \qquad (2)$$

$$Q = (P - 0.1S)^2 / (P + 0.9S) \text{ for black soil} \qquad (3)$$

The runoff curve number (CN) is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. It is widely used and is an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area. The runoff curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition.

The potential maximum retention S in mm and curve number (CN) is related by:

$$CN = 25400 / (254 + S) \qquad (4)$$

Runoff is greatly influenced by antecedent moisture condition. Moisture conditions are expressed in terms of AMC-I, AMC-II and AMC-III based on total rainfall of preceding five days. In the software the values of CN for

AMC II are computed based on physical features and hydrologic conditions of the watersheds as provided by the user based on procedure described by Chow (1964).

Since trenches are designed to store runoff expected under wet conditions (AMC III) the values of CN given for AMC II are converted to AMC III by using the following formula (Samra *et al.,* 2004):

$CN_3 = CN_2 \times e^{0.00673\,(100\text{-}CN2)}$ ……………………………..(5)

Effect of slope (Sl) is considered using following equations.

$CN_{2Sl} = (1/3)\,(CN_3 - CN_2)\,[1 - 2e^{(-13.86Sl)}] + CN_2$……….(6)

$CN_{3Sl} = CN_{2Sl} \times \exp\,[0.00673(100\text{-}CN_{2Sl})]$………….(7)

Where, Sl is the average land slope in percent.

Trench Cross Section

The trench cross section is used either as default input or as an input variable in the software and user has to submit the desired values for trench dimensions viz. trench width and depth (for rectangular section) and trench top and bottom wodth (for trapezoidal section) depending upon soil type, infiltration rate, rainfall amount and intensity. In general it is recommended to have the trench depth ranging between 40-50 cm in soils with reasonable depth, and for shallow soils, trench depth may be reduced up to 25-30 cm. The cross section of the trench usually varies from 1000 cm^2 to 2500 cm^2 (Samra *et al.,* 2004). In areas of low rainfall 30 cm x 30 cm cross section is adequate while in areas of high rainfall, cross section of 50 cm x 50 cm is appropriate. After fixing the depth (D) and width (W) of trench, the horizontal spacing is determined.

Trench Spacing

Spacing is calculated in terms of horizontal and vertical interval. The definition sketch of a contour trench is presented in Fig.1.

Horizontal Spacing

Trench cross-sections of the trapezoidal, rectangular and triangular shapes are usually constructed for runoff impoundment. Relationship between horizontal spacing of contour trenches, runoff depth and dimensions of trenches is expressed as:

Spacing = Cross sectional area of the trench / Expected runoff = A / Q…………… (8)

Where, A = Cross sectional area (cm^2)

For rectangular section, A = W x D ……………….. (9)

For trapezoidal section, A = (T + B)*D/2 ……….. (10)

Where, T and B are top and bottom widths, respectively; and Q = depth of expected runoff from the watershed area (cm).

Horizontal interval (HI) in m is estimated using equation, HI = A / (100 x Q)……………………….…. (11)

The above equation is used to find spacing for continuous contour trench. In case of staggered trenches, HI is expressed as:

HI = A / [100 Q x (1 + X/L)] (Samra *et al.,* 2004)… (12)

Where, X = gap in between the trenches (m); and L = length of the trench (m).

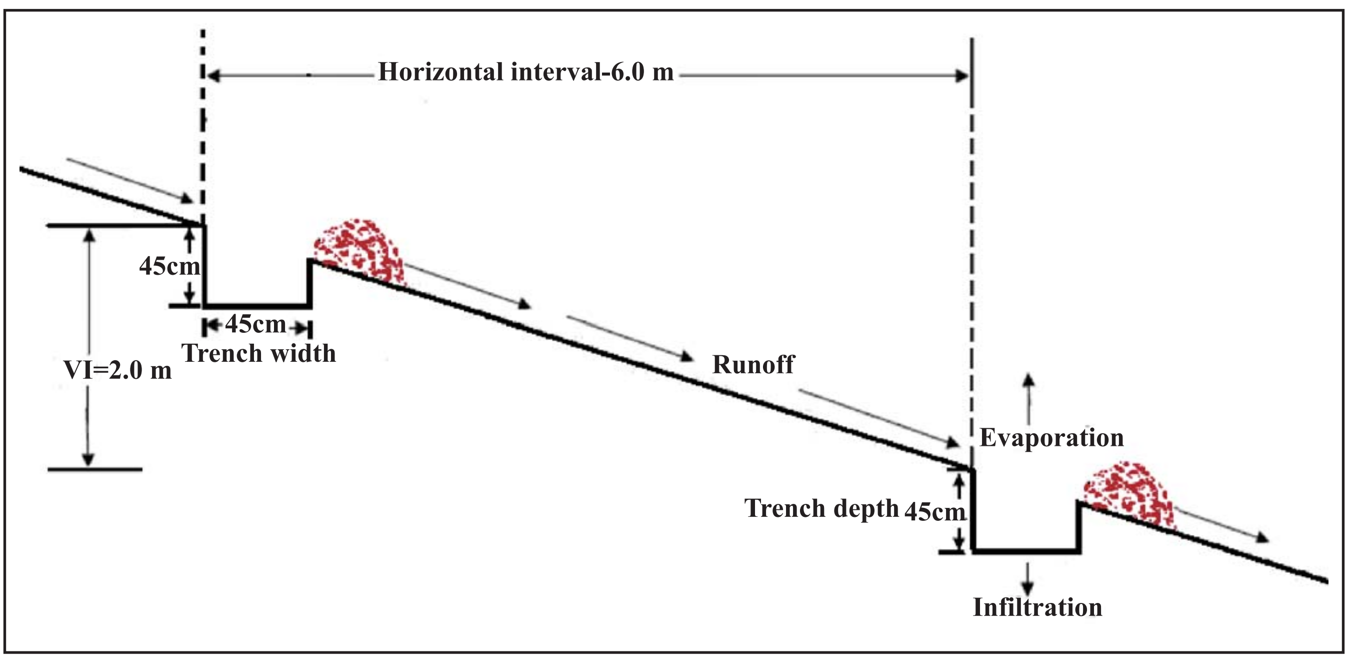


Fig. 1. Schematic diagram of contour trench

Vertical Spacing

After determining the horizontal spacing the vertical spacing is determined by using the equation:

$VI = Sl \times HI/100$ ………………………………..(13)

Where, VI = Vertical interval (m); Sl = Average land slope (%); and HI = horizontal interval (m).

Volume of Earth Work

If 100% runoff of the design storm is to be collected then

Volume of earth work (m^3) = $L_{plot} \times W_{plot} \times Q/100$…(14)

In case a fraction of direct runoff is to be trapped, then

Volume of earth work (m^3) = $V \times L_{plot} \times W_{plot} \times Q/100$……………………………………………(15)

Where, L_{plot} = plot length (m); W_{plot} = plot width (m); and V = % of direct runoff to be trapped.

Cost of Earth Work

The cost of earth work involved in execution of trenching depends upon two factors viz. cost of earth work per cu m and the quantity of earth work required to be done to store desired quantity of runoff.

Cost of trenching = Volume of earth work x cost of earth work.

Design Options for Various Constraints

Based on the results obtained by running the software the user gets detailed information about horizontal interval, vertical interval, number of trenches, length of trench, volume of earth work, cost of earth work and the surface area that will be covered by trenches. The user may wish to redesign the trench specifications for a specific condition for following situations.

100 Percent Runoff

The software initially computes all the specifications with a view to trap 100% runoff that is expected to be generated from the area. Based on the results obtained, the user may have to decide on what percent of runoff he may target to harvest so that acceptable specifications are obtained.

Soil Depth

A major concern while designing trenches is trench depth which may become a limiting factor under certain circumstances such as when soil depth is less than the suggested trench depth which may not be acceptable or practically impossible to implement. Similarly the calculated trench depth may exceed easily workable depth (60 cm.) which is difficult to execute under field conditions and hence the user may desire to opt for a different trench width.

Area under Trenches

The software will calculate the per cent of surface area that is occupied by the trenches and will display it for user's consideration. If the user thinks that the proposed surface area occupied by trenches is exceeding the area that is acceptable to him, he may opt for change in surface area. It is required to submit the desired area that user intends to devote as against the area calculated by the software and choosing the dimension that needs to be modified i.e. either depth alone or depth as well as width of the trenches. On submission of the input the software will recalculate the trench dimensions to harvest the desired runoff as well as for obtaining the desired surface area.

Plantation Spacing

The user may like to raise a plantation so that the conserved soil moisture in the trenches will be effectively utilized for the establishment of vegetation. The user can provide the spacing of plantation and the DSS will rework the dimensions and the changes in the layout and size of trenches will be adjusted such that each plant will be planted near the trench as the prevailing practice in case of SCT.

Trench Type

The user may opt for the type of trench he is willing to construct to fulfill the specific purpose of trenching viz. continuous contour trenches with rectangular or trapezoidal shape or staggered trenches with rectangular or trapezoidal shape. The user may select the type of trenches based on his choice and purpose of constructing trenches. If more runoff is to be stored CCT may be preferred to SCT.

Cost

Another important aspect in trench designing is the amount of funds available for trenching. It may be possible that the cost of trenching as per the inputs provided by the user may exceed the amount of fund available with the implementing agency and therefore it is required to redesign the trenches to adjust the cost constraint. The user can fill the amount available with him and submit for recalculation. The software will recompute the amount of runoff that can be trapped by spending the available amount and present the revised results as per the user's choice. However, 100% runoff will not be trapped if sufficient funds are not available.

3. RESULTS AND DISCUSSION

Development of decision support system is an incremental process and the life cycle of such systems can be classified into four key stages viz. knowledge acquisition, problem structuring and system design, problem encoding and system testing (Buchanan and Shorfliffe, 1984). A number of sources of information and knowledge has been referred and employed in the development of the decision support system. These sources include textbooks, manuals, research articles and personal experience. Using the above information a user friendly decision support system has been developed at CSWCRTI, Research Centre Vasad. The DSS is developed in the form of a computer programme using the input interactive controls and algorithms of Visual Basic 6.0 programming. The nested 'If…Then…Else' statements were extensively used to construct interactive algorithm for the generation of alternative decisions using the input information. Basics and steps used in formulation of decision support system for design, layout and alignment of contour trenches are described in Fig. 2.

DSS Operation

The software provides opportunity to the user to compute direct runoff (cm) under two different kinds of soil *i.e.* coarse textured soils (other soils) and fine textured soil (black soils) where trenching has to be carried out. The DSS provides trench specifications and layout for various options. The operation and results obtained by running the software have been discussed below:

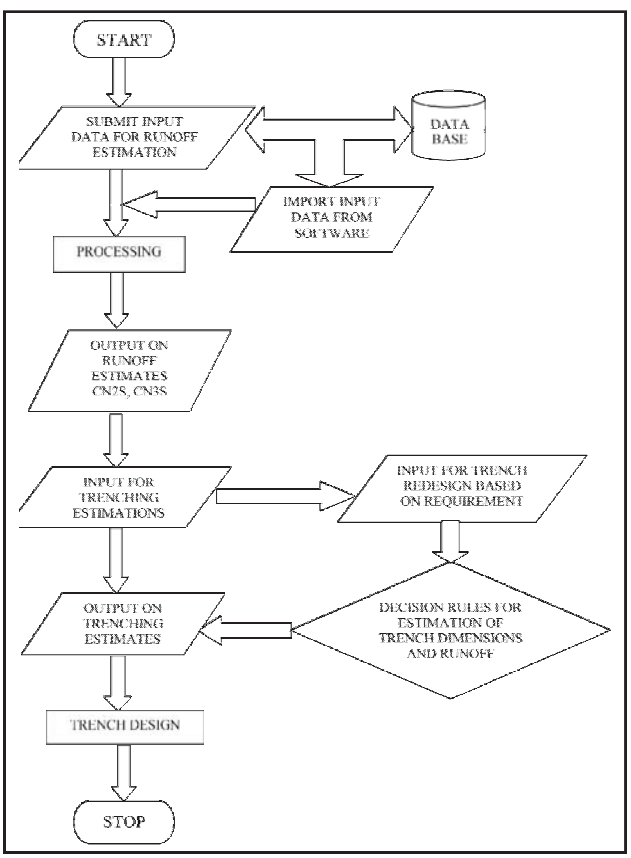


Fig. 2. Flow chart of decision support system for trench design and estimate

Direct Runoff Estimation

The operation of the DSS is explained below through an example. In the present example the input data on rainfall is 125 mm for the desired return period, slope percent, 5 and curve number, 58 and average soil depth of the site is 100 cm. This information is entered into the input screen as shown in Fig. 3. If these parameters are not available user has the option to use the inbuilt data base or he can use maximum one day point rainfall (about 500 locations for various states) as suggested by (Dhar *et al*., 1980). If the user does not have the value of CN_2 he can determine it by providing information of land use/cover treatment/ practice, hydrologic condition and hydrologic soil group. First three input items for curve number determination are self explanatory but there are chances that soil hydrologic group may not be known to the user, This can also be determined by the user by selecting relevant information on runoff potential, soil type and infiltration rate at specified places and clicking on determine hydrologic soil group button provided in the menu for the determination of hydrologic soil group. After determining hydrologic soil group curve number can be obtained by clicking on the

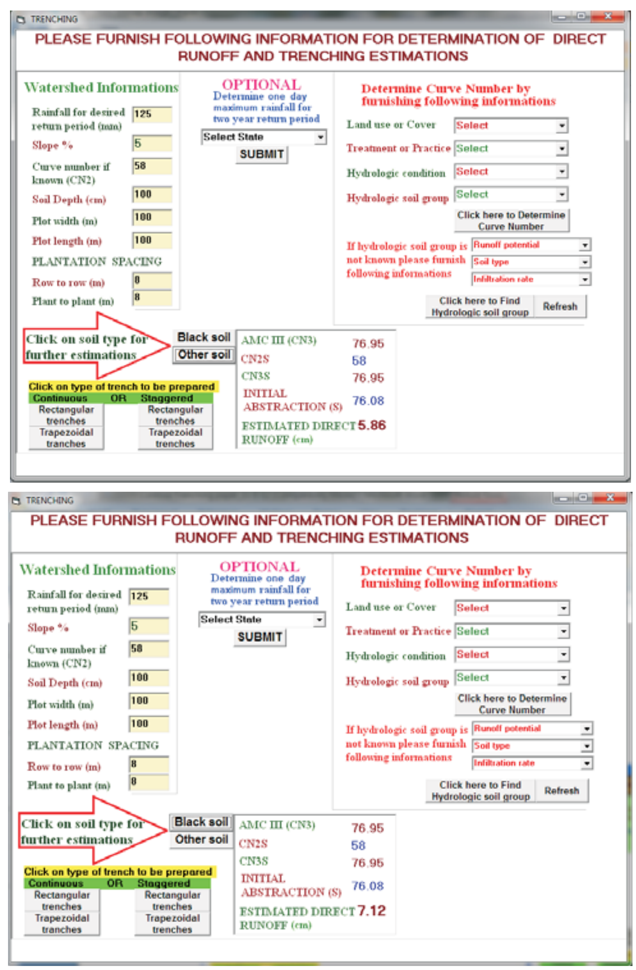


Fig. 3. Input values and runoff expected under different soils

determine curve number button provided in the menu and will be filled in the appropriate place automatically.

In the above example, plot size of one ha (width = 100 m and length = 100 m) is adopted. The user may fill the actual dimensions of his plot. The DSS can make the design considering the spacing of plantation under continuous contour trenches and staggered contour trenches. After furnishing these information user has to click on the soil type, here in this case (other soil) and direct runoff value of 5.86 cm has been generated by the software along with choice of trenches (CCT/SCT) with rectangular or trapezoidal cross section. Similarly this information for fine textured soil (black soil) can be determined by adopting the same procedure and pressing the black soil button provided in the form. For the same set of data, direct runoff of 7.12 cm is estimated for black soil (Fig. 3).

Trench Design

Clicking on the desired type of trench *viz.* continuous contour trenches or staggered contour trenches with rectangular or trapezoidal sections; design dimensions of the trenches, and cost of earth work can be made based on plot size and the amount of runoff to be trapped. On clicking the calculate button the information related to horizontal interval, vertical interval, number of trenches, trench length, volume of earth work and cost estimates can be generated for the specific input information along with the amount of surface area captured by the trenches and quantity of water harvested in trenches.

Case Study

In the above example, if the user wants to build continuous contour trenches (CCT) the screen will show default values of per cent runoff to be stored, trench width and trench depth as 100%, 45 cm and 45 cm, respectively. The user may change these default values for trench dimensions at his will for his site conditions. The user then provides the prevalent cost of earth work for instance ₹ 60 m^{-3} and he needs to click on submit and calculate button. On clicking calculate button the results for various parameters for CCT of horizontal interval; 3.46 m, vertical interval; 0.17 m, number of trenches 29 (rounded off value to the next higher digit), trench length 2890.17 m, volume of earth work 585.26 m^3, cost ₹ 35116 and percent of surface area covered by trenches; 13.01% and the amount of runoff stored in terms of cm and liters (Fig. 4) are displayed.

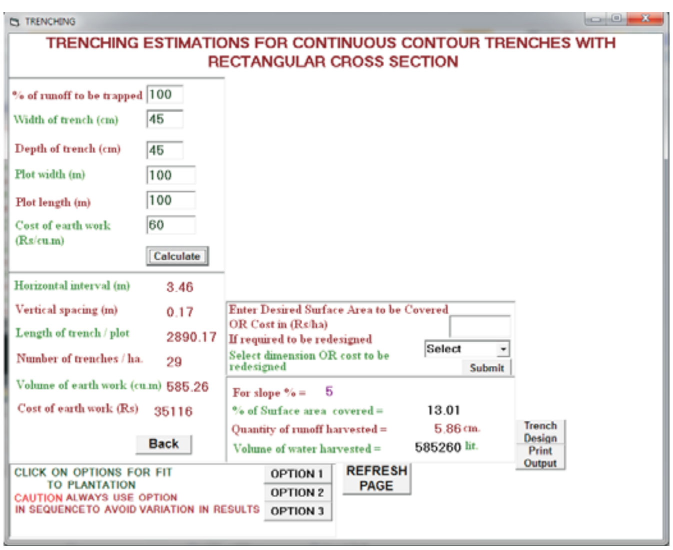
Similarly, information for staggered trenches can also be generated. The results for various parameters for staggered trenches, having values of per cent runoff (100), width of trench (38.64 cm), depth of trench (60 cm), gap between trenches (2 m) and length of trench (2 m), are horizontal interval; 1.98 m, vertical interval; 0.1 m, number of trenches 1262, trench length 2525 m, volume of earth work 585.4 m^3, cost ₹ 35124 and percent of surface area covered by trenches 9.76% for the given amount of runoff stored in terms of cm and liters (Fig. 5).

Trench Sketch and Layout

After making all the estimations, the user can generate a representative sketch showing all the dimensions of trenches to be constructed and the field layout by pressing the trench design button provided in the form (Fig. 6 and 7).

Decision Options for Various Requirements/ Constraints

The procedure described above gives the generalized specifications for trench design. The DSS also provides options to the user to modify design specifications for



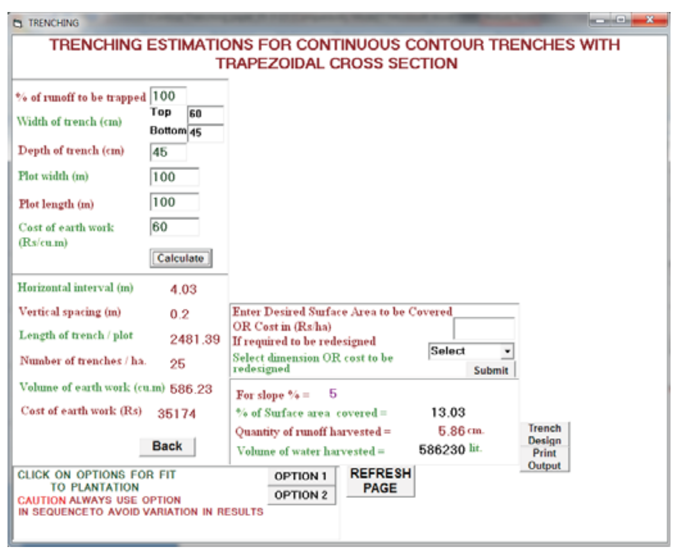


Fig. 4. Results obtained for CCT with rectangular and trapezoidal cross section

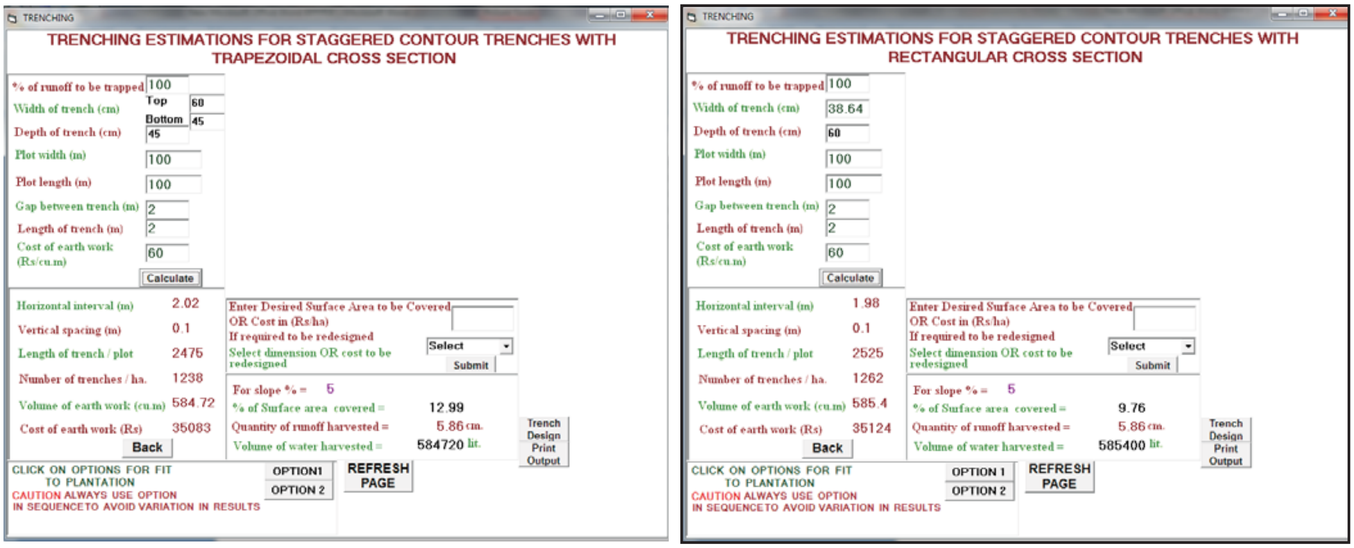


Fig. 5. Results obtained for staggered trenches with rectangular and trapezoidal cross section

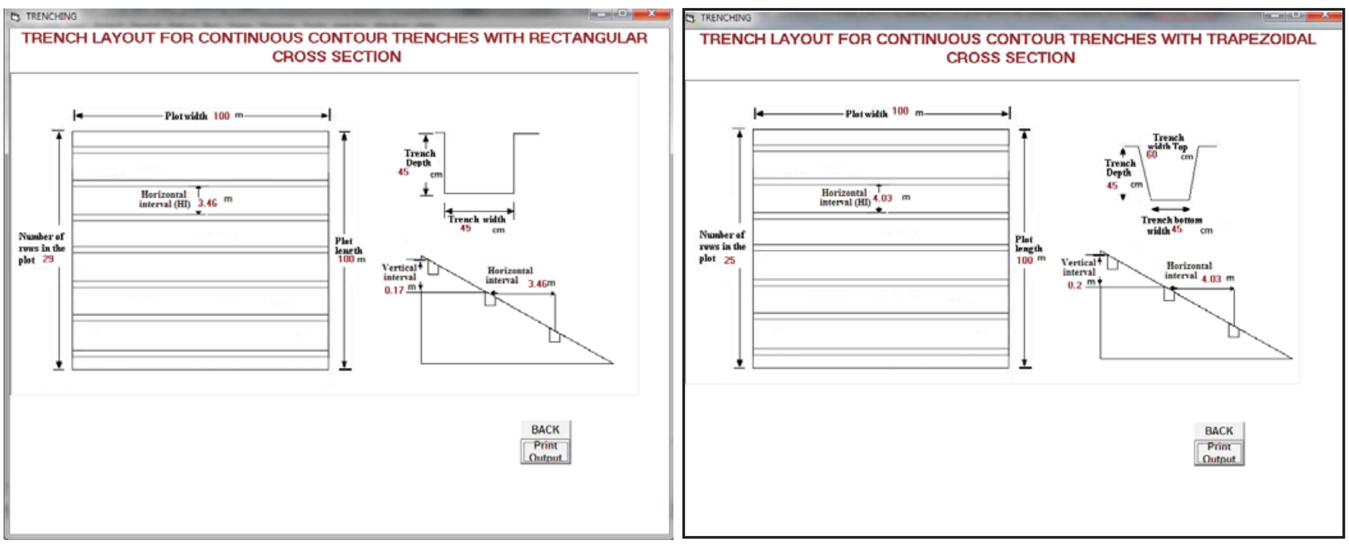


Fig. 6. Layouts for CCT with rectangular and trapezoidal cross section

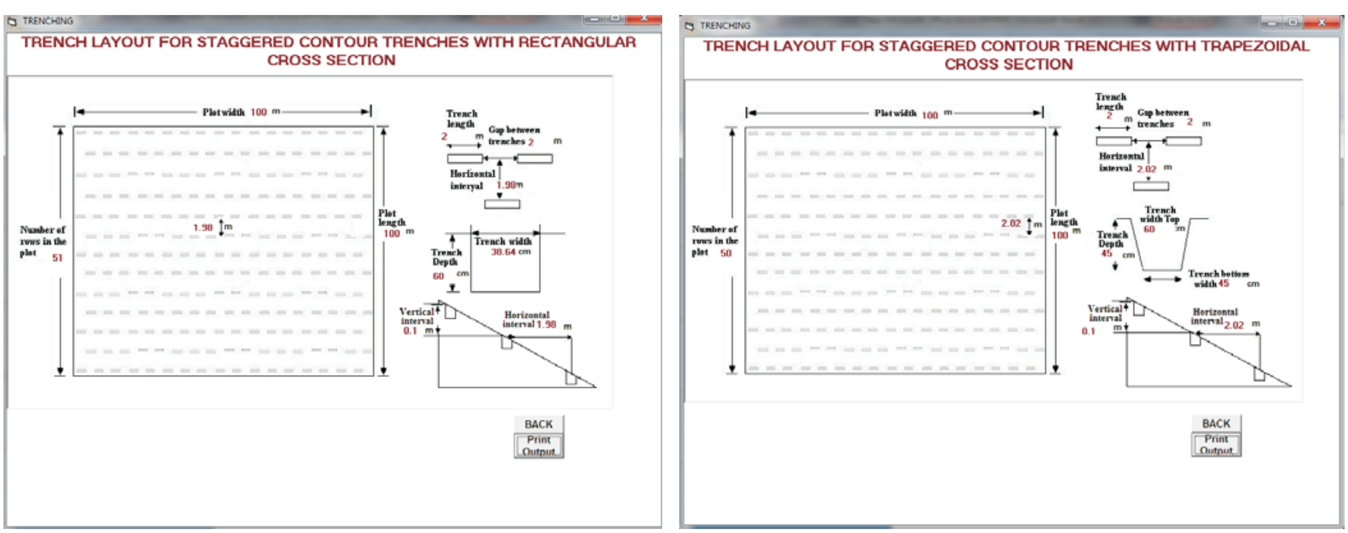


Fig. 7. Layouts for staggered trenches with rectangular and trapezoidal cross Section

specific requirements/constraints like surface area covered by the trenches, plantation spacing for a species and availability of funds (cost constraint).

Changing Surface Area

By modifying depth only

If the user wants to decrease or increase the surface area covered by the trenches, the software is provided with a window where the user can furnish parameters which he wants to modify and can redesign the trenches to trap the desired quantity of runoff. In the above example the surface area coverage with trenches is 13.01% of the total surface area. If the user wishes to reduce the surface area coverage to 10% then he can submit this information in the window along with the dimension to be modified (depth). The revised depth will be generated in the respective window (*i.e.* 58.54 cm instead of 45 cm) and on pressing the calculate button revised estimates for all the parameters will be generated as shown in Fig. 8.

By modifying both depth and width

To decrease or increase the surface area covered by the trenches, in the above example submit this information in the window along with the dimensions to be modified i.e. both depth and width. The revised depth and width will be generated in the respective window (*i.e.* 51.33 cm for width and 58.54 cm for depth instead of 45 cm for both) and on pressing the calculate button revised estimates for other parameters will be generated as shown in Fig. 9.

Plantation spacing

Often there are chances that the horizontal interval between trenches as computed by the software may not be appropriate to accommodate the desired plant species at

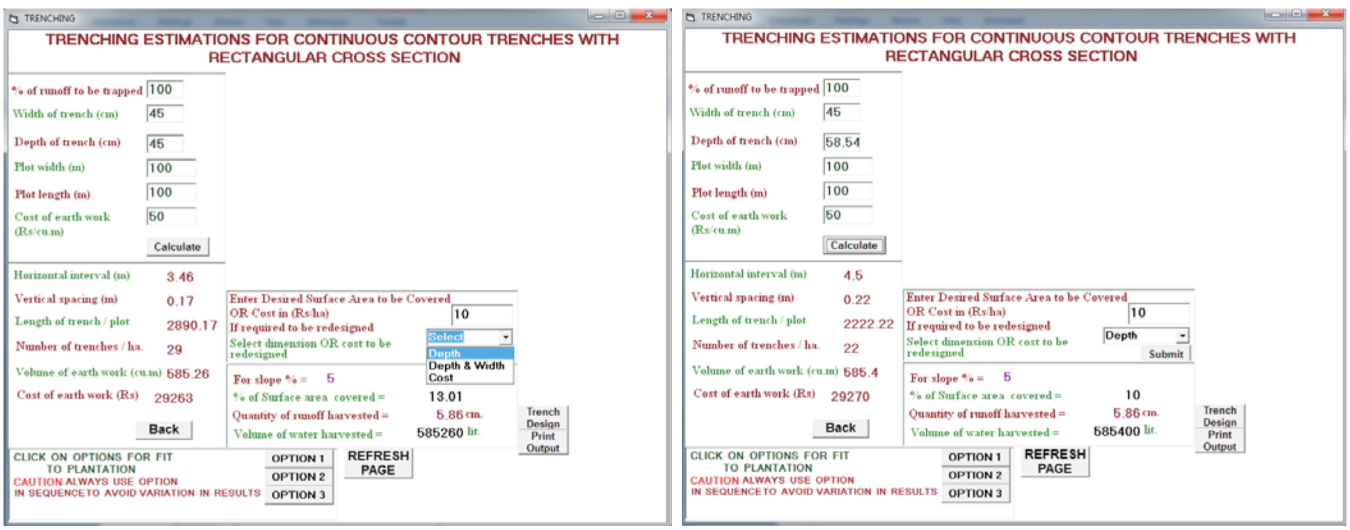


Fig. 8. Procedures for changing surface area by modifying depth

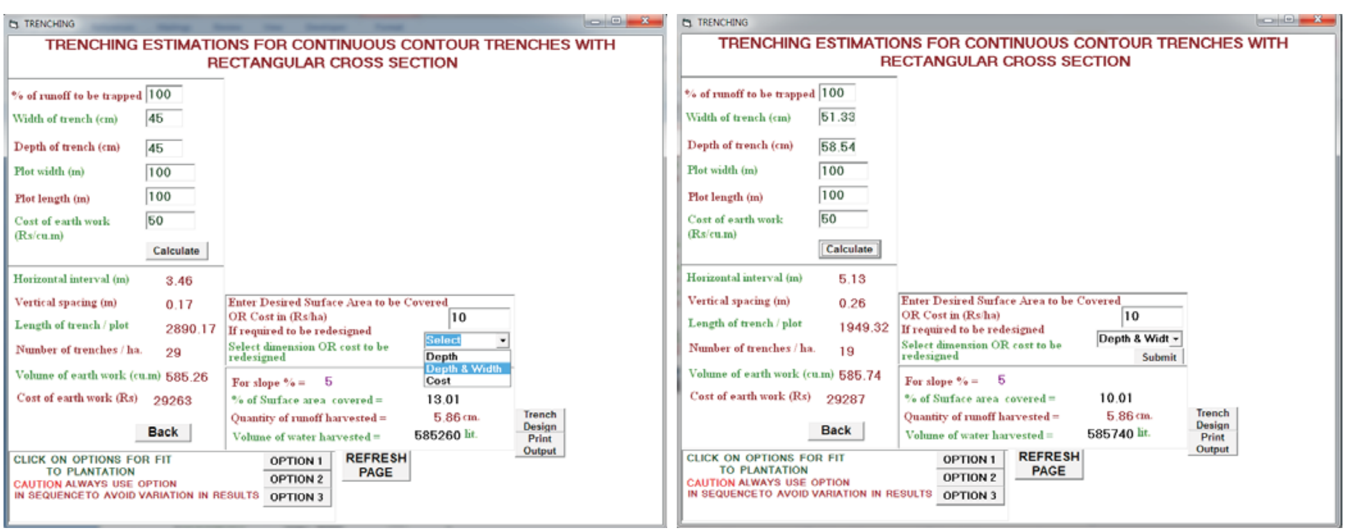


Fig. 9. Procedure for changing surface area by modifying both depth and width dimension

required interval to utilize the moisture conserved through trenches. To solve this problem the software is provided with a fit to plantation option. The user can choose the best option for his location (Fig. 10). The software will suggest the user regarding lowest surface area covering option. In the above example the estimated horizontal interval is 3.46 m and the plantation has to be carried out at 8 m interval. Under this condition the user can use fit to plantation option to modify trench dimensions. On clicking on option 1, the revised dimensions to accommodate plantation at 8 m interval are generated *i.e.* 39.06 cm for depth and 60 cm for width of the trench with 4 m horizontal interval so that plantation can be accommodated at alternate trenches with 15% surface area coverage under trenches. By clicking option 2 the software will modify the width and depth dimensions to 48.41 cm to accommodate 100% runoff at 4 m horizontal interval with 12.1% surface area coverage. By clicking on option 3, the revised dimensions to accommodate plantation at 8 m interval will be generated *i.e.* 39.07 cm for width and 60 cm for depth of the trench with 4 m horizontal interval so that plantation can be accommodated at alternate trenches with 9.77% surface area coverage under trenches. Among three options, option 3 is the best option as it occupies least surface area under trenches for harvesting 100% runoff. Similarly, this option can be used for fit to plantation for other type of trenches.

Availability of funds (cost constraint)

In cases where there is constraint of funds the user can decrease the runoff to be harvested. The user can furnish information and submit to reduce the quantity of runoff to be trapped by construction of trenches within available funds. In the above example the cost of trenching is

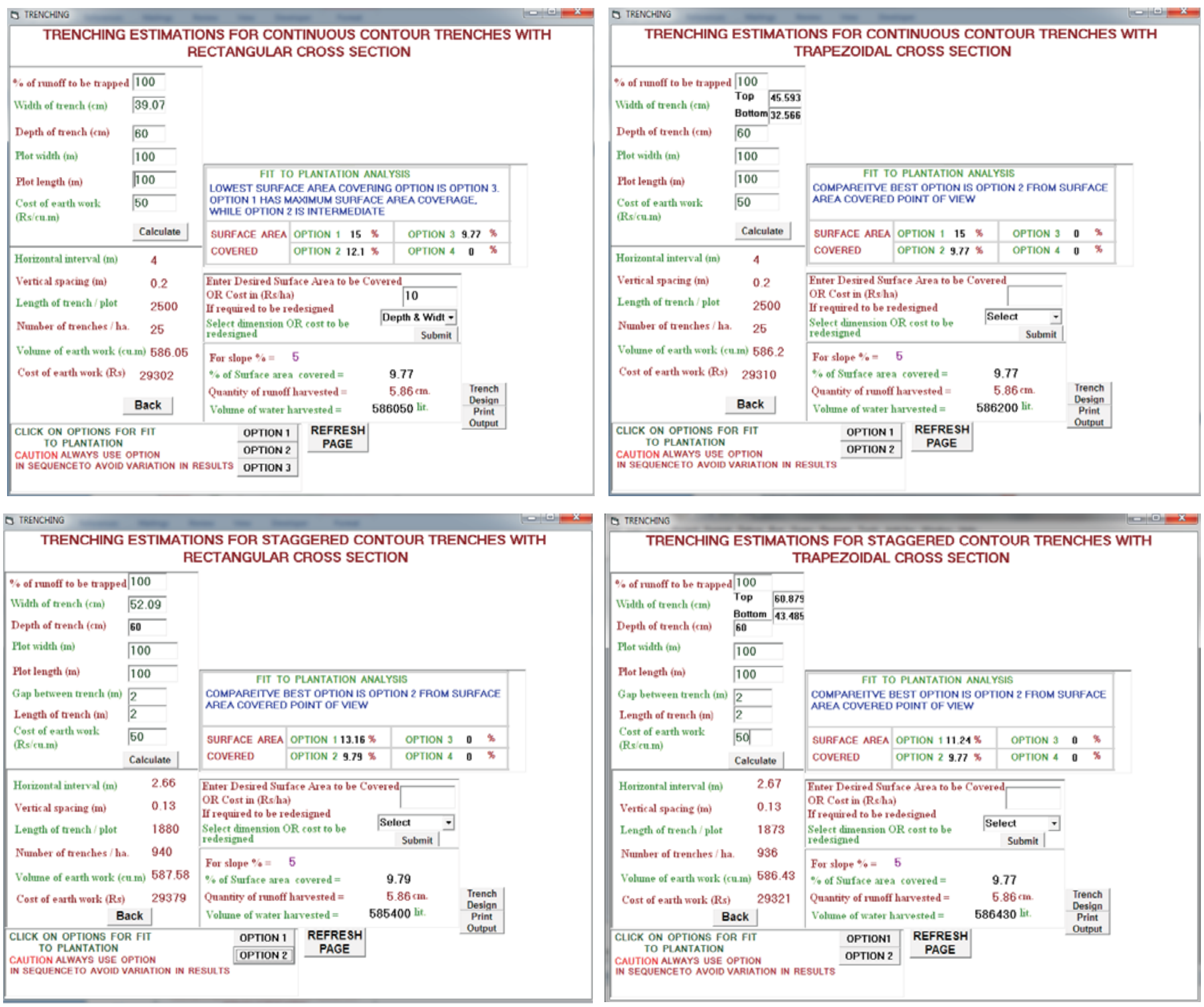


Fig. 10. Procedure for redesigning trenches for desired plantation spacing

₹ 29263/- for harvesting 100% of the direct runoff and if the available fund is ₹ 25000 then he has to submit this information in the window along with the parameter to be modified *i.e.* cost. On submission the revised quantity of runoff that can be stored by construction of trenches with available funds will be generated in the respective window (*i.e.* 85.43% of runoff instead of 100%) and on pressing the calculate button revised estimates for other parameters will also be generated as shown in Fig. 11.

Alert systems for critical input data

The decision support system is equipped with a warning system for crucial input data that will become automatically active every time the user furnishes unsuitable trench dimensions. Similarly DSS will guide the user to redesign trenches, if calculated dimensions exceed the critical values.

4. CONCLUSIONS

Trenching is the most efficient practice for in situ conservation of moisture, soil and nutrients for restoration of degraded non-arable lands. A user friendly software has been developed using visual basic programming language, written in very simple and user friendly manner. so that any person with little computer knowledge, having required data can easily run the programme and obtain desired results. It is possible to make accurate estimates of trench design parameters (horizontal interval, vertical interval, density of trenching, cross section, earth work, cost *etc.*) for construction of continuous and staggered trenches under different conditions without wasting time in search for literature and tedious calculations involved. It is expected to be of immense importance and practical use for persons working in State government agencies, NGOs and forest departments implementing watersheds development programmes.

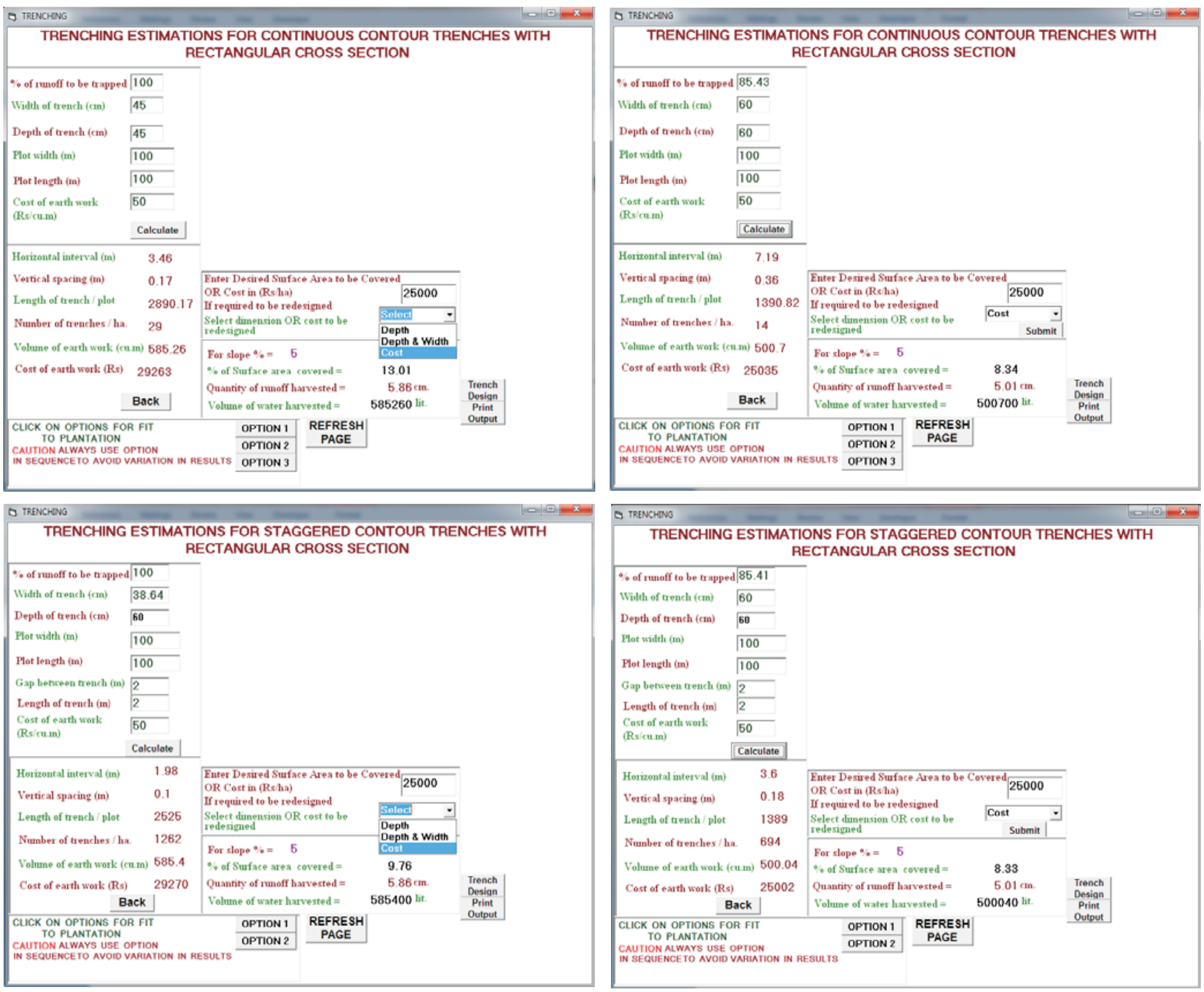


Fig. 11. Procedure for redesigning under cost constraint

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