效率的인 農業機械 運用을 위한 테라스 營農시스템의 適正化

Optimization of Row-Crop Production System on Terraced Lands.

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摘　要

테라스 農耕地의 機械化營農에 대한 問題點은 여러 學者들에 의해서 論議되어 왔으나 費用에 依한 具體的인 措置는 거의 試圖된 바 없다.

本硏究에서는 適正한 테라스 營農 시스템을 究明하기 위하여 土壤流失費用, 農業機械利用費用 및 테라스 築造費用을 包括的으로 다루었다. 이를 위하여 테라스 斷面의 設計와 그 築造費用의 推定, 土壤流失의 豫測 및 農業機械의 作業性能과 그 利用費用의 評價가 可能한 디지탈 콤퓨터 模型을 開發하였다.

例示의 테라스 豫定地에 대하여 反復技法을 利用하여 콤퓨터 模型을 試驗한 바 테라스 營農시스템의 適正化에 滿足하게 使用될 수 있음이 立證되었다.

Introduction

Altough many investigators have described the problems of mechanically farming terraced fields and have developed parallel terrace systems to facilitate operations of modern farm equipment, little quantitative measures of the cost and difficulty of farming point rows and of mismatch of machine width to terrace base width have been attempted. Point row areas as shown in Figure 1 are areas required to be doubly processed. They result in the loss of seed, fertilizer, insecticide and herbicide. The aim of this study is to provide help for the terrace designer in analyzing the effects of terrace type, terrace layout and terrace base width on costs in order to select the best terrace system.

In order to evaluate various terrace systems for efficient use of machinery and proper soil conservation, it is necessary to develop a method for optimizing the overall costs. Soil loss estimation with Universal Soil Loss Equation and the cost of sediment damage and yield reduction due to topsoil loss have been studied by Lee Swanson (1974). Evaluation of field machine operation costs based on the distance actually traveled by a machine has been described by Scarborough and Hunt (1977). Similarly, a method for evaluating the costs of earthmoving operations for terrace construction based on scraper travel could be developed for this study.

The model describing the objective function

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and its constraints cannot be described wholly analytically due to the complexity of terrace design criteria and of machine operations in irregularly shaped fields. But, a computer model could be developed to aid in the design of terrace sytem, to evaluate its construction cost, and to predict economic and energetic performance of field machines.

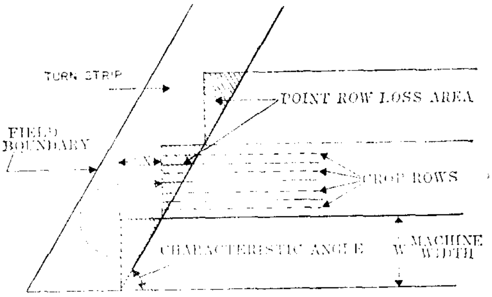


Fig 1. **Point row loss area due to angled turn srtip**

Development of the Problem

In order to evaluate the system, it is necessary to make a mathematical model in terms of the pertinent parameters involved. The appropritate objective function describing the model in this study is

Net profit = Gross return − cost

The gross return is the dollar value of the crop after harvest. The gross return of the crop production system is determined as follows:

Gross return($) = planted area × Yield per area × Price per yield

The expected yield of crop is determined by the productivity loss due to top soil loss which was reported by Odell and Oschwald (1970).

The cost of crop production for different terrace systems are divided into three cost categories: these associated with soil erosion, with field machinery operations and with terrace construction.

Soil Erosion

The costs associated with soil erosion can be expressed as

$$SEC = ASL \times DR \times DS$$

where SEC = the cost of sediment damage due to soil erosion in dollars
ASL = annual average soil loss in tonne by Universal Soil Loss Equation
DR = sediment delivery ratio
DS = sediment damage in dollars per tonne

Machine Operation

The costs of machinery operations are related to travel distance. To determine machine travel distance, a continuous pattern with a turn strip at each end as defined by Hunt (1977) is assumed. For regular-shaped fields such as rectangular, triangular and trapezoidal, a precise mathematical model of theoretical travel distance and turning travel distance can be found if the field dimensions and the effective machine width are known. For irregularly shaped fields the theoretical travel distance of a machine is determined from dividing the area of the field by the machine width.

An approximate method of determining turning travel distance for irreuglar-shaped fields was developed in terms of the characteristic width and of characteristic angles of a field. The characteristic width of a field is the sum of the dimensions perpendicular to the direction of machine travel in the various tracts of land processed. As shown in Figure 2, tract boundaries are first approximated as straight lines and the direction of machine operation is specified. Tract widths and tract angles are weighted as in Table 1.

o produce a characteristic width and characteristic angles for the whole area. Both the sine and the tangent functions are used in weighting. The tangent function of the tract angles produces a characteristic angle used to compute turn travel and point row areas. The sine function is necessary to determine turn travel when processing the turn strips.

The number of turns for irregular-shaped fields are determined from dividing the characteristic width by the effective machine width. The increase in turning travel distance, Δx as shown in Figure 1, is determined from dividing the machine width by the tangent of the weighted characteristic angle.

The length of the turn strip is determined from dividing the charcteristic width by the sine of the weighted characteristic angle. The annual costs of machine operation are divided into fixed costs and variable costs. The fixed costs of each implement per unit of travel distance are determined by the purchase price, the fixed cost percentage and the total travel distance of a machine in a year. The variable costs include machine repair and maintenance costs, operator wages, timeliness charges, fuel and oil costs, and tractor costs. The fuel and oil costs are determined by the PTO power required.

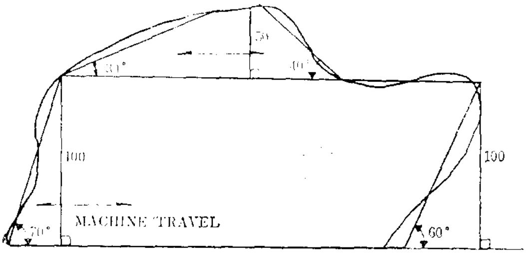


Fig 2. Approximated field boundaries to determine the characteristic width (cw) and the characteristic angles weighted as the tangent and sine function.

Table 1. Example of computing the characteristic width and the characteristic angles weighted by the tangent and sine function (for the field inFig.3)

tract width (tw)	tract angles (ϕ)	$1/\tan\phi$	$tw/\tan\phi$	$1/\sin\phi$	$tw/\sin\phi$
100	70	0.364	36.40	1.064	106.42
50	30	1.732	86.60	2.000	100.00
50	40	1.192	59.59	1.556	77.79
100	60	0.577	57.74	1.155	115.47
total 300			240.33		399.38

characteristic width(cw):

$cw=\Sigma tw/2=300/2=150$

characteristic angle as weighted by the tangent function (ϕ_1):

$\phi_1=\tan^{-1}(1/(\Sigma(tw/\tan\phi)/\Sigma tw))$

$=\tan^{-1}(1/(240.33/300))=51.3°$

characteristic angle as weighted by the sine function(ϕ_2):

$\phi_2=\sin^{-}{}_{1}(1/(\Sigma(tw/\sin\phi)/\Sigma tw))$

$=\sin^{-1}(1/(399.38/300))=48.7°$

The tractor costs are the sum of the fixed costs and repair costs. They are related to the time spent in field work and in other operations.

Terrace Construction

The costs of terrace construction were developed from the movements of scrapers and motor graders. Broad-base and grassed-backslope terraces with both underground tile and grassed-waterway outlets were analyzed. It was assumed that a proposal for a terrace system would include the location of the terraces, designation of stations at appropriate intervals, and proposed channel elevations as derived from a contour map.

A computer program to design a tile outlet terrace using balanced cuts and fills was developed by Forsythe and Pasely (1969), but their concept of raising and lowering the entire channel often does not fit the reality of terrace construction due to the diversity of field conditions. In many cases it is not desirable to cut in an area of depression.

Furthermore, terraces may be built with a combined outlet systm having both tile outlets and grassed-waterways. In which case, a lowering of the channel elevation at the outlet to the grassed-waterway is not feasible due to the existing elevation of the grassed-waterway. A computer program to design the balanced cuts and fills for terraces was developed to handle these problems.

This computer program takes the channnel and outlet specifications provided by the engineer, and computes cuts and fills for both broad-base and grassed backslope terraces. Before finding cuts and fills it establishes ridge heights, checks for channel adequacy and compares terrace slopes against established constraints.

Using SCS standard procedures, each individual tile outlet terrace is designed to store for up to 24 hours runoff from a 10-year frequency storm. Computations of available storage begin with a water depth of 30cm at its tile outlet. The cross sectional area of the channel required to store water at each station is computed for this initial depth. Total storage for the tile outlet terrace is then determined using the average-end area method. After computing the storage available at the initial depth, a check is made to see if it satisfies the storage requirement. If it does not, the depth of water in the terrace is increased by raising the ridge elevation a predetermined distance, and new computations are made to determine the available storage with the new water depth. This procedure continues until the computed storage meets the required storage.

Each gradient terrace with a grassed waterway outlet is designed to drain off runoff water without overtopping the terrace ridge. An attempt to predict the design channel peak flow at a given point of terrace in terms of the terrace spacing and length was made satisfactorily by a technique of 3rd order polynomial regression of design channel peak flow date reported by a local SCS office (1977). The resultant formula of design peak flow is:

$$Y=AX+BX^2+CX^3$$

where $A=-0.007151+0.099664Z$
$-0.081379Z^2+0.034196Z^3$
$B=0.001722-0.019443Z+0.025412Z^2$
$-0.012701Z^3$
$C=-0.000060+0.001291Z$
$-0.002116Z^2+0.001263Z^3$
X = terrace length(m) divided by 100
Z = terrace space (m) divided by 100
Y = design peak flow (m^3/min) per unit runoff (cm)

At a given point of the terrace, the ridge height is initially assumed to be 30 cm high. The outflow capacity of the terrace channel is computed using the cross sectional area and the water flow velocity by Manning's formula. If the channel capacity does not meet the design peak flow, the ridge height is incremented until the computed outflow meets the design paek flow.

Once the ridge heights are determined, the program computes the volume of cuts and fills for the entire terrace by the geometry of terrace cross sections developed by Larson(1966). All the terrace slopes for broad-base terrace are kept at less than 6:1 slope. The base width of the front slope is maintained at the same width for the entire terrace. The widths of the cut slope and the backslope can be increased over the given base width of the front slope if it is necessary to keep terrace slopes from exceeding the slope constraints. For grassed-backslope terraces the grassed backslope is constrained to a 2:1 slope or less while all other slopes are limited to slopes no greater than 6:1. The bases of the front slope and backslope are maintained at the same widths for the entire terrace.

After the total volume of cuts and fills has been found, the computer next determines if they balance. If not, broad-base terraces are balanced using an iterative process. The entire channel is lowered or raised. But, should a new channel elevation exceed the depth constraint, the channel elevation is established at the constrained value. New computations are made to determine ridge heights with new channel elevations and to compute cuts and fills. This procedure continues until cuts and fills balance. Grassed-backslope terraces differ from broad-base terraces in that cuts are made only on the downhill slope after the ridge heights are established. The balancing is done by increasing or decreasing the depth of the downhill cut. Where the new depth of cut exceeds the maximum allowable depth of cut suggested by the engineer, the cut is limited to that maximum.

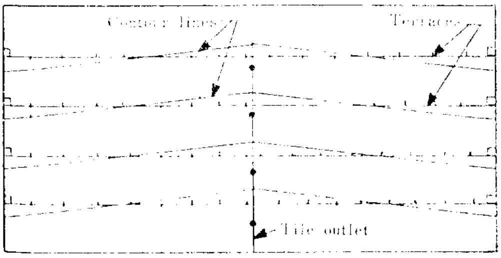
The costs of terrace construction are divided into three categories: the cost of earthmoving, the cost of finish work on the terrace slopes and the cost of the outlet systems. It was assumed that soil is moved solely by a self-loading scraper and that finishwork on terrace slopes is done by a moter grader. A method of estimating the earthmoving cost by scraper was developed based on scraper travel. The scraper travel is determined in terms of a scraper cycle consists of the travel while loading, turning and unloading. The guiding principle for a scraper cycle is to avoid unnecessary travel as the scraper proceeds to construct the terrace ridge. A scraper cycle may be established over several station intervals. The distance of the cycle is equal to or greater than the distance required to fill or unload the capacity of the scraper. The cost of earthmoving is then determined by the total hours and hourly cost of scraper use. The travel distance of the motor grader to finish the terrace slopes is determined by the base widths of the slopes ,the width of the blade and the length of the terrace. The cost of finish work is also computed from hours of use and cost per hour. The cost of the outlet system is determined by the number of inlet tubes and their cost per piece, the lengths of the tile outlets and the grassed-waterways, and their unit costs.

Computer Model And Search Technique

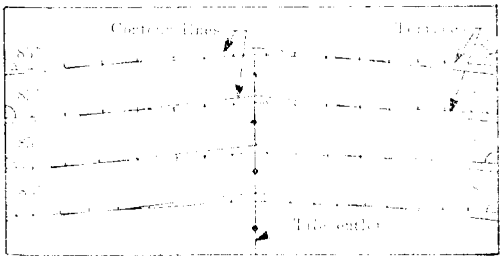
A computer program was written in FORTRAN language to search for the optimum system of terrace farming. The most important factors or variables in the analysis of terrace farming systems are the layouts of terraces, the size of implements, the base widths of terraces and the types of terrace cross sections. It was assumed that an experienced engineer first proposes possible layouts (location of terraces and channel planning) of a terrace system. For each different terrace layout, the computer designs all the terraces in the system to meet the design criteria within the constraints of channel requirements and the maximum allowable terrace slopes. It analyzes the overall system in terms of costs and returns. A number of trials varying the type of cross setion and the widths of terrace bases are made automatically by the computer for each terrace layout. The outputs of the computer are examined to see if minor changes in the channel or further changes in the layouts are necessary to improve the return. New computations are made for the new layouts. The optimum system is the one which gives the maximum net return but also includes considerations of the tolerable amount soil loss and the views of the farm manager.

Application of the Computer Model

The computer model was tested using typical input data. A field as shown in Figure 3 was chosen as an example problem. Two different terrace layouts were compared. Terrace System I was laid out to form straight terraces for better machine operation while Terrace System Ⅱ was laid out closer to the contour-lines in order to reduce the cost of terrace construction. Each system has four tile-outlet terrace which are identical. The field dimensions of the two different terrace layouts are listed in Table 2. Table 3 lists the machine constants used in this analysis. The wage of operator was set at a constant value of 4 dollars per hour. It was assumed that the implements listed in Table 3 were also used



(a) TERRACE SYSTEM I Ⅰ



(b) TERRACE SYSTEM Ⅱ Ⅱ

Fig 3. Terrace layouts for example field.

Table 2. Field dimensions for machine operation analysis

system	land	top lenght (m)	bottom length (m)	space or cw* (m)	φ_1 ** (deg)	φ_2 *** (deg)
Terrace Ⅰ	1	360.00	360.00	36.00	90.00	90.00
	2	360.00	360.00	36.00	90·00	90.00
	3	360.00	360.00	36.00	90.00	90.00
	4	360.00	360.00	36.00	90.00	90.00
		360.00	360.00	36.00	90.00	90.00
Terrace Ⅱ	1	—	361.37	50.33	17.05	15.37
	2	361.37	361.37	36.00	85.00	85.00
	3	361.37	361.37	36.00	85.00	85.00
	4	361.37	361.37	36.00	85.00	85.00
	5	361.37	—	43.64	13.50	12.11
unterraced	1	360.00	360.00	180.00	90.00	90.00

Note : *=characteristic width
**=characteristic angle weighted by the tangent function
***=characteristic angle weighted by the sine function

for 81 ha in addition to the field under study and the tractor was also used for 200 hours in operations other than those analyzed. The costs of fertilizer, seed, insecticide and herbicide for the point row loss areas were assumed to be \$94/ha, \$25/ha, \$10/ha and \$20/ha, respectively, for growing a continuous corn crop on silt loam soil. The depth of topsoil at the start of the planning period was assumed to be 25cm.

Table 3. Constants used for field machine operation costs

implement	width (m)	force factor (N/m)	speed (km/hr)	purchase price (\$)	fixed cost (%)	repair cost (%/hr)	timeliness factor (hr^{-1})
plow	3.0	12400	5.0	3200	17.0	0.07	0.0003
disk	6.0	4100	8.0	4400	17.0	0.05	0.0004
planter	6.0	1600	8.0	4400	14.0	0.07	0.0003
cultivator	6.0	3500	5.6	2500	14.0	0.06	0.0002
combine	6.0	—	4.8	18000	17.0	0.07	0.0004
tractor	—	—	—	18750	17.0	0.012	—

Earthmoving Cost Comparisons

Example solutions using typical input data reveal some general conclusions about the costs of production on the two terraced fields.

Table 4 compares the earthmoving costs of the two terrace layouts each having three different base widths. The results show that the total cost of earth-moving increases as the base width increases regrardless of the type of layout. Also, the total cost of earthmoving for Terrace System Ⅰ is always greater than that for Terrace System Ⅱ with the same base width. For the example contour map used, the terraces in System Ⅰ need more cuts and fills due to a deep depression area in the middle of the field.

Table 4 also shows that the methods of estimating the cost of earth-moving by either the volume of earthwork or the length of terrace are not appropriate since there are significant differences in the cost per volume or the cost per length between the two different layouts. The method of estimating the earthmoving cost based on scraper travel is considered to be satisfactory since it takes into account both the volume of earthwork and the topography of the field in its algorithm.

Table 4. Comparison of the earthmoving costs with 4% land slope

system	base width (m)	terrace length (m)	earthwork volume (m^3)	total cost (\$)	cost per length (\$/m)	cost per volume (\$/m^3)
Terrace Ⅰ	4.5	360.00	424	449.08	1.2474	1.0592
	6.0	360.00	562	559.28	1.5536	0.9952
	9.0	360.00	926	868.00	2.4111	0.9374
Terrace Ⅱ	4.5	361.37	390	300.83	0.8325	0.7714
	6.0	361.37	518	381.72	1.0563	0.7369
	9.0	361.37	868	615.03	1.7019	0.7086

Effects of Field on Terrace Layouts

Table 5 shows an analysis of the overall system with 4% land slope. Three base widths were assumed for each terrace system. The results show that the costs of machine operation and the costs of terrace construction are the major costs in overall system analysis. The costs of sediment damage and the reduction in the gross return due to soil erosion for the unterraced system are substantially more than for either terraced system, and would be even more significant as the ground slope increases. There is a significant increase in machine operation costs for System Ⅱ over System Ⅰ due to the increases in the number of turns and in the point row loss area.

The straight terrace system produced the greater returns. The net return of System Ⅰ with terrace bases of 4.5m and 6.0m are greater than those of System Ⅱ despite the increases in the terrace construction costs. However, another test using the same field size as shown in Figure 3 with 6% land slope revealed that System Ⅱ produced the greater returns because the decrease in terrace consturction costs was greater than the increase in machinery operation costs.

Table 5. Overall system analysis with 4% land slope

system	base width (m)	gross return ($)	terrace cost ($)	machine cost ($)	sediment cost ($)	net return ($)	soil loss (T/ha)
Terrace Ⅰ	4.5	3203.70	241.30	433.12	6.00	2523.28	3.36
	6.0	3203.70	273.32	390.15	6.19	2534.04	3.48
	9.0	3203.70	375.59	426.66	6.78	2394.67	3.81
Terrace Ⅱ	4.5	3203.70	200.23	478.41	6.07	2518.98	3.41
	6.0	3203.70	223.74	439.87	6.14	2533.95	3.45
	9.0	3203.70	304.14	474.60	6.75	2418.22	3.79
unterraced		3152.78	0.00	389.96	90.04	2672.78	50.53

A mismatch of machine width to the base width of a terrace increases the costs of machine operation significantly. Each terrace system with the base of 4.8m resulted in the lowest costs of machine operation. An explanation is that all the implements except the plow exactly match the width of the terrace base. A base width other than an integer number of impl-ement width results in a large increase in machine operation cost. As could de expected, the machine operations were done most efficiently on the conventional unterraced system.

In summary, careful layout of a terrace to keep both machinery operation costs and terrace construction costs as low as possible is very important to optimizing the return. Among the terrace systems analyzed, System Ⅰ with 6m base appears to be the optimum system with the greater annual net return and a moderate soil loss.

Summary

Although many investigators have described the problems of mechanically farming terraced lands, little quantitative measure of the cost has been attempted. An investigation toward the optimization of a terrace farming system included costs of soil loss, machinery operat-

ions and terrace construction. A computer model was developed to design terrace cross-sections, estimate their construction cost, predict soil loss and evaluate the economic and energetic performance of field machines. Solution of an example problem using an iterative optimization technique with a digital computer showed satisfactory modeling of terrace farming system.

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