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DESIGN AND FEASIBILITY OF TERRACES IN THE RAINFED REGION IN IRAQ

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ABSTRACT

The rainfed region in Iraq comprises an area of more than 5 millions ha of forest, grazing and farmland areas. Except the plains, the region suffers from moderate to severe water erosion due mainly to overgrazing and land mismanagement. Due to population growth and the shortage in water resources, an expansion in land used for agriculture in the region is expected. Terracing is an option when utilizing sloping land for agricultural production. A terrace design criterion was developed for the region in which terrace spacing was determined using the Revised Universal Soil Loss Equation (RUSLE); terrace channel specifications were determined using conventional hydraulic computations. Analyses showed that terracing is feasible on rolling and hilly sloping land in the high rainfall zone (seasonal rainfall > 600 mm) on the condition that high value cash crops are grown to offset the high cost of terrace construction and maintenance. In the medium and low rainfall zones (seasonal rainfall 400- 600 mm and < 400 mm), terracing for water erosion control is generally not needed on cultivated land less than 10% in slope where wheat and barely crops are normally grown; however, pioneer research projects are need to assess the feasibility of terraces of the level (detention) type to conserve rain water in these two zones for a more successful rainfed farming venture-

INTRODUCTION

Declining soil productivity and contamination of surface water resources are two major outcomes of cropland erosion by water. Research is often need to establish erosion control measures suitable to a particular region.

Terracing for water erosion control may become necessary when farming moderate and steep slopes; this practice has increased recently due to population growth in regions with limited land resources (32). Soil erosion modeling and economic analysis may be used to explore the necessity for terrace farming in agricultural areas (7, 33). Terraces are also used for water conservation on all types of slopes. Lu et al. (26) reported that development of narrow terraces on lands that sloped 5 and 10 degrees reduced soil losses by 57.9% and 89.8% and nutrient losses by 89.3% and 95.9% respectively in a semiarid region in China; additionally, soil bulk density was reduced by 4%, soil moisture increased by 20.7%, soil fertility increased by 42.4% and yield increased by 22.4-37.3%. In another study, Yang et al. (40) found that the average annual sediment yield from a watershed decreased exponentially with the increase in flow diversion terrace protection.

Most developing countries lack the necessary data base to establish a suitable terrace design criterion. Terrace design formulas derived elsewhere (e.g. 10, 30) are often valid only within the region where they were developed. The Universal Soil Loss Equation (USLE) (38) its revised version (RUSLE) (35) are being used to find terrace spacing in regions where an estimation of the

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equation parameters is available. Since the values of this equation parameters in the rainfed region in Iraq are generally available (17, 20, 19) we will use the RUSLE to obtain a first approximation for terrace spacing in the region. Basic hydraulic principles for channel flow will be used to estimate terrace channel specifications. Terraces are generally expensive to build and maintain, hence the feasibility of any proposed terrace system should be determined.

BACKGROUND

Terraces are embankments or a combination of embankments and channels constructed across the slope to control erosion and/or conserve water by diverting and temporarily storing surface runoff instead of permitting it to flow uninterrupted down the slope (36). Terraces may be classified by their alignment, gradient, outlet and cross section. Alignment may be parallel or nonparallel. Gradient may be level or graded. Outlets may be soil infiltration only, vegetated water ways, tile outlets or combination thereof. Cross section may be narrow base, broad base, bench and steep backslope (4).

On gently to moderately sloping land (i.e. slope < 12%), the broadbase type of terraces (Fig.1a) may be used. On moderately steep land (i.e. 12% < slope < 20%), the steep backslope type of terraces (Fig.1b) may be used; in this type of terraces, the backslope is usually kept in grass. Both types can be farmed; for the narrow base type of terraces, the entire cross section is frequently seeded to permanent vegetation. On steep land, the bench type of terraces (Fig.1c) may be used (4, 10, 23); however, the high cost of bench terraces limits their use for commercial agriculture in rainfed regions (34).

The graded type of terraces is primarily used for water erosion control mainly by reducing the field slope length. The level (detention) type retains runoff and it is primarily used for water conservation. Both types can be farmed. Terraces are preferably constructed parallel to facilitate farming operations. It was found (1) that terracing significantly increases the water use efficiency of plants (the ratio of total plant dry weight to the difference between total precipitation and total runoff).

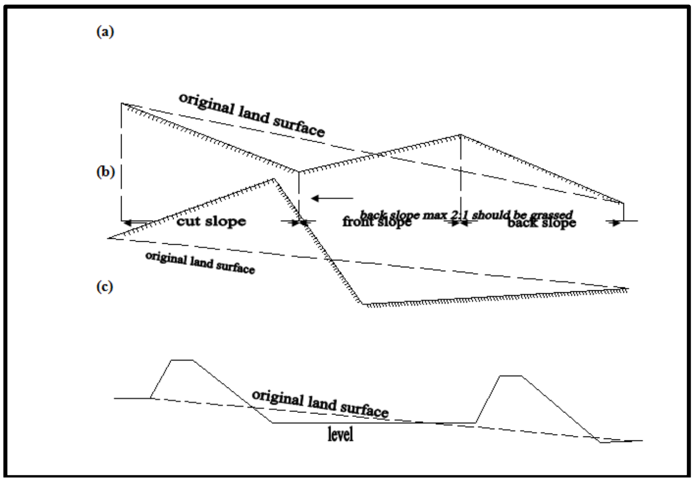

Fig.1: Typical terrace cross section; a- broad base, b- steep backslope, c- bench.

Terraces cannot be used effectively on sandy areas, on stony land or on shallow oils. They are not practical in fields with complex topography and become too expensive for mechanized agriculture on slopes that exceeds 8-12%, but are sometimes used on very steep slopes when crops are grown with hand labor and animal traction (37).

The rainfed region in Iraq (Fig. 2) experiences moderate to severe water erosion (9, 19, 24). Terraces are needed when cultivating sloping land in the high rainfall zone

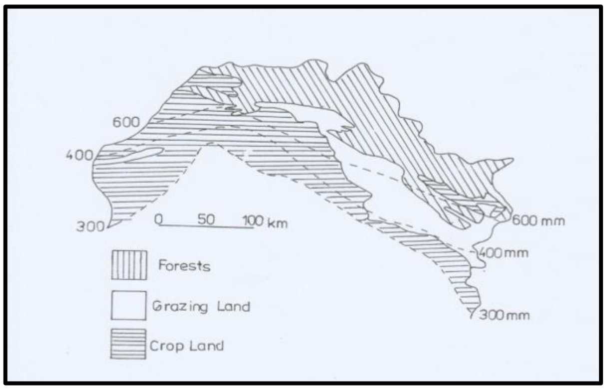

Fig.2: The rainfed region in Iraq.

(seasonal rainfall > 600 mm). The primary objective of terracing in this zone is water erosion control. In the medium and low rainfall zones (seasonal rainfall 400-600 mm and < 400 mm), terraces, if needed, are to be used mainly for water conservation.

ESTIMATING TERRACE SPACING IN THE REGION

Terraces for water erosion control may be spaced by simulating erosion and sediment yield on the targeted land slope using a suitable erosion/sediment yield model (29). However, most of these models require extensive input data not readily available in sites where terracing is needed. An alternative, is using the USLE/RUSLE to obtain a reasonable first approximation for terrace spacing in a region. The slope length used when checking soil loss for a proposed terrace spacing is the distance from the terrace ridge to the next lower terrace channel measured along the natural flow direction (Fig. 3) (31). In the past few decades, the USLE/RUSLE was applied in

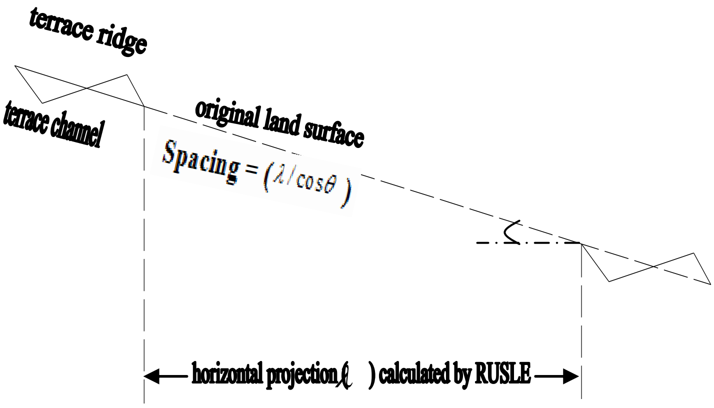

Fig.3: Terrace spacing (after NRCS, 2010).

many regions of the world where an estimation of their factors became available. When the RUSLE is used to obtain terrace spacing, the terrace spacing should not exceed the slope length limit for contour cultivation by using a soil loss tolerance limit, the most intensive use expected for land and the expected level of management. On gently sloping land, anticipated runoff and the economical terrace cross section size may determine spacing rather than soil loss tolerance between terraces (4).

The RUSLE is:

$$A = RKLSCP \qquad (1)$$

where A = mean annual (seasonal) soil loss (t/ha/yr), R = rainfall-runoff erosivity factor [(MJ/ha)(mm/h)], K = soil erodibility factor [t h/(MJ mm)], L = length of slope factor, S = steepness of slope factor, C = cover-management factor and P = supporting practice factor taking as the contouring factor (Table 1). The horizontal terrace spacing λ (horizontal projection of the slope length parallel to the soil surface) is calculated from:

Table 1: Regression equations for the contouring factor in the RUSLE[1,2].

$$P_b = a(s_m - s_c)^b + P_{mb} \qquad s_c \prec s_m$$

$$P_b = c(s_c - s_m)^d + P_{mb} \qquad s_c \geq s_m$$

$$P_b = 1.0 \qquad s_c \geq s_e$$

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[1] Foster et al. (12).

[2] P_b = base value for the P factor for contouring, s_m = slope (expressed as sine of the angle θ) at which contouring has its greatest effectiveness, s_c = slope (sin θ) for which a value of P_b is desired, s_e = slope (sine θ) above which contouring is ineffective, P_{mb} = the minimum P value for a given ridge height with base conditions. For a moderate ridge height (8-10 cm), a = 23132 b = 4 c = 12.26 d = 1.5 s_m = 7% s_e = 20% P_{mb} = 0.45

Table 2: Slope length exponent (m) values for the condition of low rill/interrill ratio[1].

Slope (%)	1	2	3	4	5	6	8	10	12	14	16	20	25	30	40
m	0.08	0.14	0.18	0.22	0.25	0.28	0.32	0.35	0.37	0.40	0.41	0.44	0.47	0.49	0.52

[1]McCool et al. (27). The low rill/interrill ratio was selected according to Hussein and Othman (21).

Table 3: Critical slope length values for the effectiveness of contouring[1].

Slope (%)	Critical slope length for effective contouring (m)[2].
1-2	305
3-5	117
6-8	61
9-12	38
13-16	24
17-20	18
21-25	15

[1]Foster et al. (12).

[2]Moderate ridge height (8-10 cm), hydrologic soil group C, no cover or minimum roughness or both, EI_{30} for 10 yr frequency storm = 17.02 [(MJ/ha) (mm/h)].

$$L = T / RKSCP = (\lambda / 22.1)^m \qquad \textbf{(2)}$$

From which terrace spacing x can be calculated:

$$x = \lambda / \cos\theta \qquad x \le x_{eff\ contouring} \qquad (3)$$

where T = soil loss tolerance limit (t/ha/yr) and m = slope length exponent (Table 2),
θ = slope angle and $x_{eff\ contouring}$ = critical slope length value for the effectiveness of contouring (Table 3). In equation 2, the overland flow area between two adjacent terraces is assumed of uniform slope. After terraces operate, P values for terraces (Table 4) should be used in RUSLE applications.

Table 4: Terrace P-factor values for conservation planning[1,2].

Horizontal terrace interval (m	Closed[3] outlets	Open outlets, with percent grade of[4]		
		0.1-0.3	0.4-0.7	≥ 0.8
Less than 33	0.5	0.6	0.7	1.0
33-42	0.6	0.7	0.8	1.0
43-54	0.7	0.8	0.9	1.0
55-68	0.8	0.8	0.9	1.0
68-90	0.9	0.9	1.0	1.0
More than 90	1.0	1.0	1.0	1.0

[1]Foster and Highfill (11). Use P factor for terraces after terraces have been constructed and operational not at the design stage.
[2]Multiply these values by other P-subfactor values for contouring or other support practices on interterrace interval to obtain composite P-factor value.
[3]Values for closed-outlet terraces also apply to terraces with underground outlets and to level terraces with open outlets.
[4]Channel grade is measured on the 90 m of terrace closet to outlet or 1/3 of total length, whichever distance is less.

DESIGN SPECIFICATIONS FOR TERRACE CHANNELS

Graded terraces are usually designed to handle runoff from a 10 yr 24 h frequency storm (31). A triangular channel cross section (a reasonable approximation to most field channels) with side slope Z (cotangent of side slope angle) between 5 and 10 is usually chosen. Such side slope is easily farmed and incorporated with the land slope. Since the terrace channel is farmed, a free outlet is assumed. The outlet depth is considered critical which is given by:

$$y_c = [\sqrt{2\beta}\ Q_e\ /(Z\sqrt{g}\ )]^{0.4} \qquad (4)$$

where y_c = the critical depth (m), β = energy coefficient, $Q_e = \sigma_p$ A and σ_p = characteristic peak discharge per unit area (m/s), A = area drained by the terrace channel (m^2), and g = acceleration due to gravity (m/s^2). If the hillslope is the only watershed element contributing to the terrace channel, an expression for σ_p is given (21) by:

$$\sigma_p = I_5 \sqrt{V_u} / \sqrt{V_r} \qquad (5)$$

where I_5 = maximum 5 min intensity (m/s) for the design storm and V_u and V_r are respectively design storm runoff and rainfall depths (mm).

Level terraces and graded terraces with underground outlet that impound runoff water on the field should be designed to hold the runoff volume from a 10 yr 24 h storm (4). Flow depth (y) is estimated by setting V_u A = Zy^2L and simplifying:

$$y = (V_u \ x / Z)^{1/2} \tag{6}$$

where A = x L, x = terrace spacing (m) and L = length of terrace channel (m).

Average channel depth (d) is estimated by adding 0.15 m free board to the flow depth estimated by equations 4 and 6. Width of channel side should be no less than 4 m so as to enable machinery of all types to be used. For the triangular cross section, width of channel side (W) is estimated from:

$$W = d(Z^2 + 1)^{1/2} \quad W \geq 4\, m \tag{7}$$

Field conditions often determine the convenient length of terrace channel. However, channel length of graded terraces should not exceed 500 - 600 m because of the danger of overtopping during intense storms (6, 10, 37). For level terraces, the length should not exceed about 1000 m to reduce the potential risk of failure (31).

Flow in graded terrace channels is spatially varied with increasing discharge (8). For this reason, a convex channel slope is preferably chosen to handle the increasing discharge downstream. The chosen channel slope should not result in a flow shear stress greatly in excess of the critical flow shear stress for detachment of soil or channel bed materials. Slope at the upstream end of channel is assumed zero; the channel slope at the outlet may be obtained by using the following equation:

$$S_f = \tau_c /(\gamma \ R_c) \tag{8}$$

where τ_c = critical flow shear stress below which no detachment occurs (Pa), S_f = friction slope assumed equal to channel bed slope for kinematic channel flow (5) and γ = specific weight of sediment-water mixture. R_c is channel hydraulic radius for the critical flow given by:

$$R_c = [Z /(2\sqrt{Z^2 + 1}\,)]\ y_c \tag{9}$$

The following equations may be used to estimate the critical flow shear stress for detachment (3):

For cropland surface soils containing ≥ 30% sand:

$$\tau_c = 2.67 + 6.5\, clay - 5.8\, vfs \tag{10}$$

where clay, vfs are respectively fractions of clay and very fine sand contents in the surface soil and τ_c expressed in Pa. In equation 10, vfs is set equal to 0.4 when vfs < 0.4 and clay is set equal to 0.4 if clay > 0.4. For soils containing < 30% sand, equation 10 becomes:

$$\tau_c = 3.5 \tag{11}$$

Critical shear stress given by equations 10 and 11 is the shear stress acting on the soil or channel bed materials. Grass and mulch reduce this stress. When the terrace channel is covered with grass, total shear stress is divided into that acting on the vegetation or mulch and that acting on the soil using sediment transport theory (14, 18).

Soil infiltration may be used as the outlet for level terraces. Soil infiltration rate, under average rainfall conditions, must permit infiltration of the design storm from the terrace channel within the inundation tolerance of the planted crops. Vegetated outlets are suitable for graded and open-end level terraces. Underground outlets are suitable for both graded and level terraces; the outlet consists of an intake and an underground conduit. Combination of different outlet types may be used in the same terrace system.

Life of terrace systems is normally considered 20 years (16). Deposition in terrace channels may shorten the economic life of a terrace system. Due to tillage

operations in terrace channels, a uniform deposition depth may be assumed. The density of deposited sediment may be assumed equal to the bulk density of the tilled layer (13).

RESULTS AND DISCUSSION

Table 5 shows the application of RUSLE to obtain typical terrace spacing for 19 sites distributed among four soil orders in the rainfed region. Soil erodibility factor (K) at these sites was determined by taking surface soil samples from a representative location at the site; the samples were then analyzed for the factors in the soil erodibility nomograph (39). The obtained nomograph values were divided by 10 to obtain an estimate for soil erodibility factor in the region (2, 22).

Table 5 indicates that terracing is needed only on rolling and hilly slopes in the region high rainfall zone regardless of the soil order. Values between parentheses in column 11 of Table 5 indicate no need for terracing unless the slope length exceeds the critical value for contour cultivation given in Table 3. No terracing for water erosion control is normally needed on gently sloping land and nearly level land. On rolling and hilly slopes, terrace spacing is small due to the relatively high seasonal soil loss rate. Certainly, a terrace system with a small spacing value would be expensive to build and maintain and the land has to be used to grow high value cash crops. Economic feasibility becomes an important factor when terrace spacing is less than 30 m (37).

Hence for a terrace system to control water erosion on rolling and hilly slopes in the region, spacing can be calculated using the RUSLE. In this respect, the R-factor values are readily available for nearly all locations in the region (17, 19). The K-factor can be obtained from the region soil erodibility map (19) or by analyzing a representative surface soil sample at the site then applying the soil erodibility nomograph with the result divided by 10 (Table 5). Measurement of a representative land slope at the site is also needed. Terrace channel specifications can be obtained using equations 4 through 11.

For example, the horizontal terrace spacing (λ) for a wheat field near the Duhok city ($36^0\ 51'\ 56''$ N $42^0\ 59'\ 58''$ E) has a Vertisol soil with 20% sand, an average land slope of 12%, soil loss tolerance limit of 5 t/ha/yr (Table 5), C = 0.5 (20) and P = 0.59 (Table 1), is estimated as follows:

R = 1600 MJ/ha mm/h (Fig. 4).

K = 0.0045 t h/(MJ mm) (Fig. 5).

m = 0.37 (Table 2).

$\theta = \tan^{-1}0.12 = 6.84^0$, S = 16.8 sin 6.84 – 0.5 = 1.5 (Table 5).

Applying equations 2 and 3:

$\lambda = [5/(1600\times0.0045\times1.5\times0.5\times0.59)]^{2.7} \times 22.1 = 74.62$ m

$x = \lambda/\cos\theta = 75.15$ m

From Table 3, the slope length limit for effectiveness of contouring = 38 m.

Hence, spacing = 38 m.

Table 5: Optimum terrace spacing for water erosion control in the rainfed region of Iraq using the RUSLE.

Soil Order	Location	Common slope (%)	Present Land use	Soil loss[1] tolerance (t/ha/yr)	R factor[2] (MJ/ha). Mm/h	Typical[3] nomog. K [th/(MJ mm)]	Mean[4] S factor	Typical[5] C factor	Typical[6] contouring P factor	Typical[7] terrace spacing (m) ($x=\lambda/\cos\theta$)
	Zako	0 -5	Wheat	10	2535	0.0691	0.30	0.5	0.55	117)[8](
	Hareer	10 – 15	=	5	5000	0.0337	1.58	=	0.61	6.4
	Bakrajo	0 – 5	=	10	2560	0.0234	0.30	=	0.55	(117)
Vertisol	Arbil	5 – 10	=	=	1062	0.0684	0.84	=	0.46	(61)
	Alton Kopry	5 – 10	=	=	900	0.0592	0.84	=	0.46	(61)
	Hamdania	0 – 5	=	=	780	0.0547	0.30	=	0.55	(117)
	Hijran	5 – 20	Grazing	2	3920	0.0281	1.58	0.3	0.61	6.7
Mollisol	Halabcha	0 – 5	Wheat	10	2044	0.0198	0.30	0.5	0.55	(117)
	Saraw	0 – 5	=	10	1900	0.0271	0.30	=	0.55	(117)
	Shikan	5 – 10	Wheat	10	1844	0.0262	0.84	0.5	0.46	(61)
Entisol	Aqra	10 – 15	=	5	4773	0.0395	1.58	=	0.61	4.7
	Shaqlawa	10 – 15	=	5	4496	0.0289	1.58	=	0.61	12.6
	Sordash	15 – 25	Grazing	2	4000	0.0291	2.79	0.3	1.0	0.7
	Kabyae	0 – 10	Wheat	10	1500	0.0474	0.57	0.5	0.45	(117)
	Sinjar	0 – 10	Barely	=	772	0.0447	0.57	=	0.45	(117)
	Tellafar	5 – 10	=	=	519	0.0568	0.84	=	0.46	(61)
Aridisol	Debaka	5 – 10	Wheat	=	980	0.0528	0.84	=	0.46	(61)
	Qadir Karam	5 – 15	Wheat	5	1700	0.0417	1.17	=	0.51	(38)
	Taza	0 – 10	Barely	10	690	0.0458	0.57	=	0.45	(117)
	Kifry	0 - 10	=	10	540	0.0460	0.57	=	0.45	(117)

[1]McCormack et al. (28). [2]Figure 4. [3]This value is divided by 10 for RUSLE application in the region (19). [4]S= 10.8sinθ+0.03 for slope<9%, S=16.8sinθ-0.5 for slope≥9% (length of slope >3.75 m) (27). [5]Assuming continuous cropping; for grazing land, poor condition was assumed (20). [6]Table 1. [7]Using equation 2 and Fig. 3. [8]Terracing for water erosion control is only needed when field slope length exceeds the critical slope length for contouring given between parenthesis (Table 3); however, level type terraces may be used at desired intervals for water conservation.

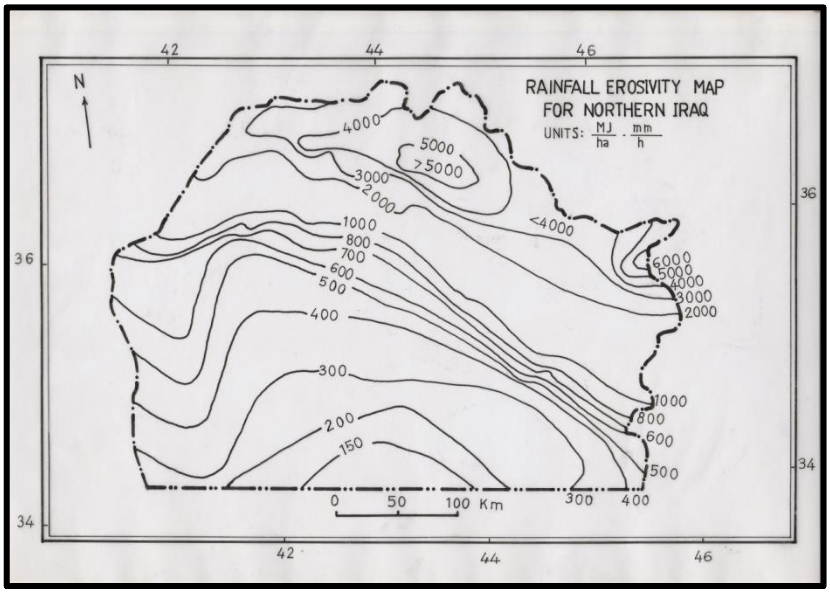

Fig.4: Rainfall erosivity in northern Iraq (19).

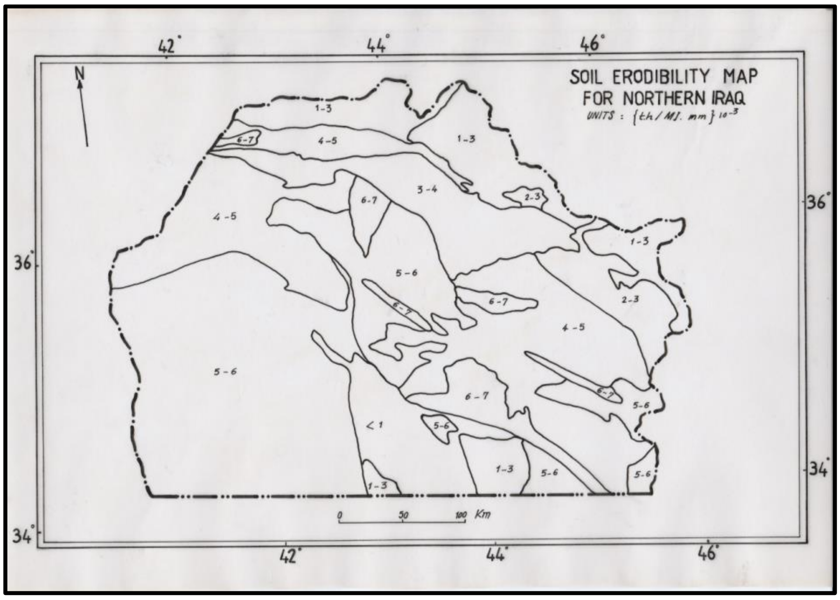

Fig.5: Soil erodibility in northern Iraq (19).

Channel specifications:

For Duhok city, the 10 yr 24 h storm produces about 70 mm of rainfall (V_r) and 50 mm of runoff with maximum rainfall intensity ($I_{max} = I_5$) of 100 mm/h = 2.7777×10^{-5} m/s (25).

1- *Level terraces option:*

For Z = 5

channel depth = $d = (0.05\times38/5)^{1/2} + 0.15 = 0.77$ m

width of channel side = $W = 0.77\ (5^2+1)^{1/2} = 3.93$ m ~ 4 m.

2- *Graded terraces option:*

$\sigma_p = I_{max}\ (V_u/V_r)^{1/2} = 100(50/70)^{1/2} = 84.5$ mm/h = 2.35×10^{-5} m/s.

For a bare channel bed at the design stage, $\beta \approx 1$, assuming Z = 5 and length of terrace channel = 600 m:
$A = 38 \times 600 = 22800\ m^2$

$y_c = [\sqrt{2}\ \sqrt{1} \times 2.35 \times 10^{-5} \times 22800/ (5 \times \sqrt{9.81})]^{0.4} = 0.30$ m (Eq. 4).

channel depth = d = 0.30 + 0.15 = 0.45 m

width of channel side = $W = 0.45\ (25+1)^{1/2} = 2.29$ m. (W < 4 m)

$R_c = 0.49 \times 0.3 = 0.15$ m (Eq. 9)

Slope of channel bed at channel end, $\tau_c = 3.5\ N/m^2$ (Eq. 8), hence

$S_f = 3.5/ (9800 \times 0.15) = 0.0024 = (0.24\%)$.

Hence, for the graded terraces option, Z may be increased so that $W \geq 4$ m. However, such terraces would be expensive to build.

Technology is currently available for terrace design and layout using GIS with an automated guidance system (15). Such procedure incorporates the spatial analysis capability of GIS and the accuracy of the automated guidance system in terrace layout. Such procedure is cost effective, efficient and flexible especially when terracing large areas.

CONCLUSIONS

The main conclusions of the study can be summarized as follows:

- **In the rainfed region of Iraq, terracing for water erosion control may be needed on rolling and hilly land slopes in the high rainfall zone.**
- **The USLE/RUSLE can be used to obtain terrace spacing in the region.**
- **Specifications of terrace channels in the region can be obtained using conventional hydraulic computations.**
- **Research is needed to develop suitable terrace systems for the rainfed region in Iraq for both water erosion control and water conservation.**

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تصميم و جدوى المصاطب في منطقة الزراعة الديمية في العراق

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الملخص

تضم المنطقة الديمية في العراق مساحة تزيد عن 5 ملايين هكتار من الغابات و المراعي الطبيعية و الأراضي الزراعية. فيما عدا السهول تعاني أراضي هذه المنطقة من تعرية مائية متوسطة إلى شديدة. بسبب الزيادة السكانية و شحة الموارد المائية يتوقع حصول ازدياد في استغلال أراضي المنطقة للأغراض الزراعية مستقبلا. تعد المصاطب أحد الخيارات المتاحة عند استغلال الأراضي المنحدرة للإنتاج الزراعي. تم وضع دليل لتصميم المصاطب في المنطقة حيث تحدد المسافة بينها باستخدام المعادلة العامة لفقد التربة و تحدد مواصفات قناة المصطبة باستخدام الحسابات الهيدروليكية الاعتيادية. تم حساب المسافة بين المصاطب في مواقع منتخبة تغطي المناطق المضمونة و شبه المضمونة و غير المضمونة الأمطار. تبين من النتائج أن المصاطب يمكن إنشائها بجدوى اقتصادية في المناطق مضمونة الأمطار ذات الانحدارات المتوسطة للسيطرة على التعرية المائية شرط إنتاج محاصيل زراعية ذات قيمة سوقية عالية يمكن من خلالها تغطية تكاليف إنشاء و إدامة المصاطب. في المناطق الأخرى لا توجد في العادة حاجة إلى إنشاء المصاطب للسيطرة على التعرية المائية عند استغلال أراضي زراعية بانحدار أقل من 10% لإنتاج محاصيل مثل الحنطة و الشعير. إلا انه في هذا المناطق هناك حاجة للبحث من خلال مشاريع رائدة في إمكانية استخدام المصاطب المستوية لحفظ مياه الأمطار لزيادة فرص نجاح الزراعة الديمية فيها.

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