

## **Soil and water losses in a low intensity rainfall region in Iraq**

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**Abstract** The rainfed region of northern Iraq experiences moderate to severe water erosion. The area is characterized by low intensity rainfall, so erosion characteristics in the region may differ from those of regions with high intensity rainfall. Data from two natural runoff plots in the region were used to derive preliminary rainfall-runoff and soil erosion relationships. Runoff was found to vary linearly with rainfall. Interrill or sheet erosion was the dominant erosion type on the plots. Soil loss varied exponentially with rainfall intensity and values of the exponent obtained were within the range observed in other rainfall regions. Average soil erodibility measured on each plot varied with plot surface conditions.

### **Pertes en sol et en eau dans une région à faible pluviométrie en Irak**

**Résumé** Le Nord de l'Irak, région arrosée, est affectée par une érosion pluviale qui va de modérée à importante. La région est caractérisée par des chutes de pluie de faible intensité, aussi, les caractères de l'érosion dans cette zone sont différents de ceux des régions où les chutes de pluie sont beaucoup plus intenses. On a utilisé les données provenant de deux parcelles de ruissellement dans cette région pour en tirer des conclusions concernant les rapports entre la pluviométrie, l'écoulement et l'érosion du sol. On a trouvé que l'écoulement variait de façon linéaire avec les chutes de pluie. L'érosion "en nappes" a été considérée comme le type d'érosion dominant sur ces parcelles. Les pertes de terre ont varié de façon exponentielle avec l'intensité pluviométrique et l'ordre de grandeur du rapport exponentiel obtenu est du même ordre que celui observé dans des régions à hauteur de précipitation différente le degré moyen d'érosion mesuré sur chaque parcelle variait avec les conditions de la surface de la parcelle.

## **INTRODUCTION**

Water erosion in the mountain and foothill regions of northern Iraq is still occurring at an alarming rate (FAO, 1973). However, research information

about the rate of soil and water losses under different soil, cropping and management conditions in the region is scarce. Such information is essential for assigning erosion control measures suitable for the region.

Except for short duration spring showers, rainfall intensity in the region seldom exceeds  $10 \text{ mm h}^{-1}$ . Most research reports concerning soil and water losses on natural runoff plots have been for higher intensities (Olson & Wischmeier, 1963; Lal, 1976; Ulsaker & Onstad, 1984). The purpose of this study was to measure soil and water losses from tilled and untilled natural runoff plots located at the Hijran basin in northern Iraq. Measurements of this type from several locations in the region can be combined and used to develop erosion prediction and control methods for northern Iraq.

## SITES AND METHODS

The Hijran basin is located along the main road between Arbil and Shaqlawa and lies between  $36^{\circ}0'$  and  $36^{\circ}30'N$  and between  $44^{\circ}15'$  and  $44^{\circ}30'E$ . The climate of the area may be classified as semiarid with average annual rainfall of about 900 mm. Rainfall occurs mainly during the months October to May. Occasional snow showers occur in the winter. Figure 1 gives the average rainfall pattern in the region (FAO, 1973).

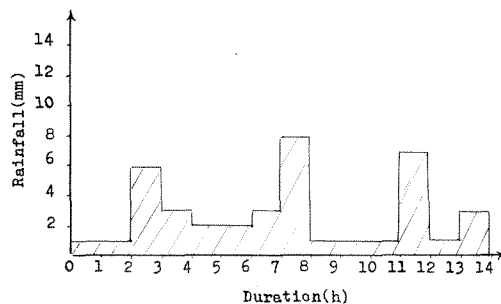


Fig. 1 Common rainfall pattern in the region (FAO, 1973).

The area is primarily used as grazing land. The grass species are mostly annual. Perennial grasses like wild almond (*Prunus amygdalus*) are also common in the region. Grass cover in the spring may reach 80%.

Two  $20 \times 4 \text{ m}^2$  plots were established in the autumn of 1980 on a fenced area of 17% uniform slope. The soil at the site is Mollisol (Al-Taie *et al.*, 1969). Information on the soil is given in Table 1.

One of the plots was tilled by hand tools in the autumn of 1980. The other plot was left undisturbed throughout the study. The tilled plot was cleared from weeds in the autumn of 1981. Data collection was terminated at the end of the second rainfall season in May 1982.

After each rainstorm, the runoff volume in a collecting tank at the plot outlet was measured. The runoff was mixed thoroughly and a sample was

Table 1 Soil description at the experimental site

Soil order	Soil particle size distribution:				Saturated conductivity (cm h <sup>-1</sup> )	USLE K* [(g m <sup>-2</sup> )/(N h <sup>-1</sup> )]
	% Clay	% Silt	% Sand	% Organic matter		
Mollisols	40.67	45.00	14.33	1.87	8.25	27.90

\*Estimated from the soil erodibility nomograph (Wischmeier & Smith, 1978).

taken for sediment concentration determination. Sediment concentration was determined using the evaporation method (Guy, 1975). Sediment yield was calculated from sediment concentration as follows:

$$\text{Sediment yield (g m}^{-2}\text{)} = \text{runoff depth (mm)} \times \text{sediment concentration (ppm)} \times \text{density of sediment mixture (g cm}^{-3}\text{)}/1000 \quad (1)$$

No recording raingauge was available at the time of the studies so total rainfall in each storm was recorded using a simple raingauge located at the experimental site.

## MATHEMATICAL ANALYSIS

Erosion in runoff plots may be classified into rill and interrill soil erosion (Foster *et al.*, 1977). Interrill erosion is caused primarily by rainfall while rill erosion is caused primarily by runoff. In areas with low intensity rainfall like northern Iraq, interrill erosion becomes the dominant erosion type on most agricultural soils, since such areas are characterized by low runoff rate.

Interrill erosion rate (mass per unit area per unit time) may be expressed (Park *et al.*, 1982) as:

$$D_I \propto i^\psi \quad (2)$$

where  $i$  is the rainfall intensity and  $\psi$  is an exponent which depends on the soil properties and the rainfall pattern.

To simplify the solution of equation (2), it was assumed that the natural rainstorm can be replaced by a hypothetical storm of constant intensity. We further assumed that the maximum 30-minute intensity ( $I_{30}$ ) of the natural storm is the constant intensity of the new storm (Neto, 1979). Therefore, the rainfall depth ( $V_r$ ) is given by:

$$V_r = I_{30}T \quad (3)$$

where  $T$  is the characteristic rainfall duration for the new storm.

The next step was to simplify the runoff hydrograph. A characteristic runoff rate,  $\sigma$ , was chosen such that:

$$\frac{\sigma}{I_{30}} = \frac{D}{T} \quad (4)$$

where  $D$  is the characteristic runoff duration. Therefore, runoff depth ( $V_u$ ) is given by:

$$V_u = \sigma D \quad (5)$$

The above steady-state assumption is reasonable for low intensity rainfall due to a long storm duration.

Total soil loss (mass per unit area) due to the interrill erosion rate  $D_i$  will be:

$$A = \int_0^T D_i dt = \phi I_{30}^\psi T \quad (6)$$

where  $\phi$  is a proportionality constant. Equation (6) can be written as:

$$A = \phi I_{30}^{\psi-1} V_r \quad (7)$$

An expression for  $\phi$  is (Foster *et al.*, 1977):

$$\phi = BKSCP \quad (8)$$

where  $B$  is a coefficient,  $K$  is the soil erodibility factor (mass per unit area per erosivity unit),  $S$  is the sine of the slope angle,  $C$  is the soil loss ratio and  $P$  is the contouring factor in the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978).

Not all sediment detached on the plot is transported downslope to the collecting tank. Without a transporting agent (i.e. runoff), it was assumed that detached sediment becomes reattached to the soil surface. Interactions of detachment, sediment transport and deposition on agricultural land were discussed by Hussein (1982).

The sediment yield reaching the tank,  $S_y$ , can be expressed as:

$$S_y = A d_r \quad (9)$$

where  $d_r$  is the sediment delivery ratio. Sediment yield can also be expressed as:

$$S_y = \phi I_{30}^\psi D \quad (10)$$

From equations (4), (6), (9) and (10),  $d_r$  can be expressed as:

$$d_r = \sqrt{(V_u/V_r)} \quad (11)$$

A recording raingauge was not available in these studies. Therefore,  $I_{30}$  had to be estimated from available measurements.

Several studies (Neto, 1979; Richardson & Foster, 1980) indicated that it is possible to express  $EI_{30}$  (storm kinetic energy  $\times$  maximum 30-minute intensity) in terms of the rainfall amount:

$$EI_{30} = aV_r^b \quad (12)$$

where  $a$  and  $b$  are parameters which depend on the rainfall pattern. The four years (1983–1987) of recorded raingauge data available in Aski-Kalak weather station near Arbil were used to find a tentative estimate for  $a$  and  $b$  in the region. A power equation (equation (12)) fitted the data better than linear, exponential and quadratic equations. The value of  $b$  in the power equation was near  $3/2$ . The data were refitted to equation (12) with the exponent  $b$  fixed at  $3/2$ . The resulting equation was:

$$EI_{30} = 0.0175 V_r^{1.5} \quad (13)$$

where  $EI_{30}$  is in  $\text{N h}^{-1}$  and  $V_r$  is in mm. Using  $b = 3/2$  in equation (12) lowered the coefficient of determination ( $r^2$ ) to 0.68 compared with 0.76 in the original power equation. However, we preferred the use of  $b = 3/2$  to simplify the mathematics.

To find  $I_{30}$  from equation (13), we need an expression for  $E$ , the rainfall kinetic energy. The average kinetic energy per unit mass of rain is:

$$E_m = \frac{1}{2} V_t^2 \quad (14)$$

where  $V_t$  is the terminal velocity of the drops. The total kinetic energy for the storm expressed in  $\text{MJ ha}^{-1}$  is:

$$E = 0.005 V_r V_t^2 \quad (15)$$

where  $V_r$  is in mm and  $V_t$  is in  $\text{m s}^{-1}$ . Equation (15) gave reasonable results when tested against the Wischmeier rainfall energy equation (Wischmeier & Smith, 1978) using rainfall data from northern Iraq. Equation (15) also gave reasonable results when tested against the Kowal and Kassam data (Kowal & Kassam, 1977) for the high intensity storms of northern Nigeria where rainfall energy was measured by a specially designed instrument (Kowal *et al.*, 1973).

From equations (13) and (15),  $I_{30}$  ( $\text{cm h}^{-1}$ ) can be expressed as:

$$I_{30} = 3.5 \sqrt{(V_r)/V_t^2} \quad (16)$$

For low intensity rainfall, an average value of  $5.5 \text{ m s}^{-1}$  for  $V_t$  seems reasonable (Laws, 1941; Gunn & Kinzer, 1949). Substituting for  $V_t$  in equation (16),  $I_{30}$  ( $\text{mm h}^{-1}$ ) can be expressed as:

$$I_{30} = 1.16 \sqrt{V_r} \quad (17)$$

## RESULTS AND DISCUSSION

Since the treatments were not replicated, the results reported here can be considered as no more than a guideline for future runoff and erosion

experiments in the region. A criterion for runoff and erosion prediction techniques in the region is established. Several data points were deleted because they represented extreme values in the data which bias the fitting of relationships. Data points with runoff and sediment concentration which are greatly different from those resulting from storms of nearly equal rainfall depth on the same plot were also deleted. Runoff and sediment concentration data were recorded for the 37 rainfall events which occurred during the studies in which a measurable quantity of runoff occurred. Table 2 shows some of the rainfall, runoff and sediment yield data.

**Table 2** Rainfall, runoff, sediment concentration and sediment yield for some rainfall events

Julian date	Rainfall (mm)	Runoff (mm):		Sediment concentration (ppm $\times 10^4$ ):		Sediment yield (g m <sup>-2</sup> ):	
		tilled	untilled	tilled	untilled	tilled	untilled
81061	4	0.05	0.03	0.56	0.49	0.28	0.147
81108	21.5	0.10	0.12	0.14	0.25	0.14	0.30
81346	9	0.02	0.02	6.02	6.98	1.25	1.45
81362	18	0.13	0.13	3.24	4.52	4.30	5.99
82028	48	0.59	0.53	6.39	3.85	39.21	20.81
82107	21	0.33	0.36	6.17	6.87	21.18	25.72

### Rainfall and runoff

Knowledge of the relationship between rainfall and runoff for different land uses is essential for watershed planning and erosion control. Plots of runoff vs. rainfall for all storms are shown in Figs 2 and 3 for the tilled and the untitled plots respectively.

The mathematical analysis in this study suggests the following type of relationship between rainfall and runoff:

$$V_u = \left(\frac{D}{T}\right)^2 V_r \quad (18)$$

which indicates a linear relationship between rainfall and runoff for a given storm, with runoff occurring regardless of the amount of rainfall.

Two other formulae that mostly represent the trend in the rainfall-runoff data in this experiment were also included in the statistical analysis. The first formula is a linear relationship between rainfall and runoff but with a nonzero intercept:

$$V_u = \bar{a} (V_r - V_{rc}) \quad (19)$$

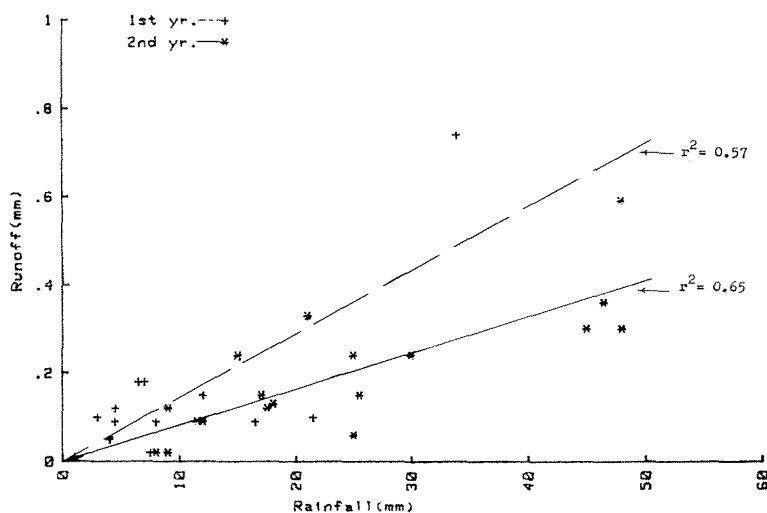


Fig. 2 Runoff vs. rainfall on the tilled plot.

where  $\bar{a}$  is a coefficient and  $V_{rc}$  is the threshold rainfall amount below which no runoff occurs. The second formula is a power relationship between rainfall and runoff:

$$V_u = a_1 V_r^{b_1} \quad (20)$$

where  $a_1$ ,  $b_1$  are a coefficient and an exponent respectively.

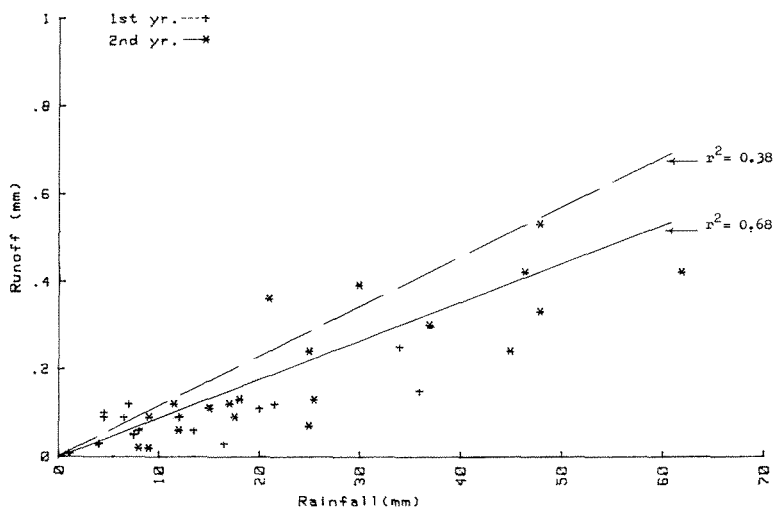


Fig. 3 Runoff vs. rainfall on the untilled plot.

Table 3 gives parameter values and the goodness of fit results when the above three equations were fitted to the rainfall-runoff data in the experiment. All correlations mentioned in Table 3 are significant at the 95% level. Table 3 indicates that equation (18) gave a fair fit to the rainfall-runoff data and equations (19) and (20) improved the fit only slightly. The first year rainfall-runoff data for the untilled-plot were affected by one extreme data point which was not deleted because deletion gave a positive intercept in equation (19) which is contrary to the hydrological facts on such runoff plots. From this it was concluded that equation (18) satisfactorily describes the rainfall-runoff relationship within the range of the data in this experiment. In the following discussion only equation (18) will be considered.

**Table 3** Parameter values of the rainfall-runoff equations

Equation	Plot	Year	Coefficient	Exponent or intercept	Coefficient of determination ( $r^2$ )
$V_u = \left(\frac{D}{T}\right)^2 V_r$	tilled	1st	0.0148	-	0.57
		2nd	0.0083	-	0.65
	untilled	1st	0.0106	-	0.38
		2nd	0.0079	-	0.68
$V_u = \bar{a}(V_r - V_{rc})$	tilled	1st	0.0160	-0.0118	0.62
		2nd	0.0084	-0.0023	0.66
	untilled	1st	0.0162	-0.0859	0.58
		2nd	0.0080	-0.0030	0.69
$V_u = a_1 V_r^{b_1}$	tilled	1st	0.0195	0.7941	0.48
		2nd	0.0036	1.2271	0.62
	untilled	1st	0.0134	0.7981	0.59
		2nd	0.0028	1.2866	0.72

For both plots, there was no significant difference between the best fit regression lines for first and second year data at the 95% level. Within either of the two years, there was no significant difference between the best fit regression lines for the tilled and the untilled plots at the 95% level. For this reason, a single equation can be used to describe the rainfall-runoff relationship in this experiment. The following equation was obtained by fitting equation (18) to all the rainfall-runoff data collected:

$$V_u = 0.0092 V_r \quad (21)$$

Equation (21) has a coefficient of determination ( $r^2$ ) of 0.50. The approximately steady-state nature of rainfall-runoff events in the region due to the long storm durations may be the principal factor causing no significant difference in runoff between the tilled and the untilled plots.

In Fig. 2, the runoff ratio decreased during the second year after tillage. According to Edwards (1977), tillage increases the immediately available pore space near the surface but decreases the amount of infiltrating water moving



deeper into the profile due to the reduction in the plough layer porosity. Furthermore, the bare tilled plot during the first year after tillage was more susceptible to surface sealing which reduces the infiltration rate (Morin & Benyamini, 1977). This effect decreases with time and the tillage effect usually disappears after four to five years (Foster *et al.*, 1980).

In Fig. 3, runoff ratios are relatively close for the first and the second years on the untilled plot. However, the effect of seasonal changes in rainfall may become more noticeable if the treatments were replicated and data were collected for longer periods of time.

### Soil loss

Sediment yield and sediment concentration data for some of the storms are listed in Table 2. To estimate parameter values, equation (7) was fitted to soil loss data using the least-squares method (Steel & Torrie, 1960). The values of  $K$  and  $B$  obtained are listed in Table 4. In the regression analysis for each plot, data from both years were grouped to increase the degrees of freedom and reduce the standard error. Coefficients of determination ( $r^2$ ) for the fitted relationships were 0.25 on the tilled plot compared with 0.48 on the untilled plot. Both correlations were significant at the 95% level.

**Table 4** Parameter values of the erosion equation

Plot	$\psi$	$K$ $\left[ \frac{g \ m^{-2}}{mm(mm \ h^{-1}) \psi^{-1}} \right]$	$K$ $\left[ \frac{g \ m^{-2}}{N \ h^{-1}} \right]$	Average $K^*$ $\left[ \frac{g \ m^{-2}}{N \ h^{-1}} \right]$	$B$
tilled	1.8	0.84	38	52	10.25
untilled	2.6	0.29	62		11.40

\*Obtained by combining data from both plots.

As indicated in the mathematical analysis,  $B$  is dimensionless. The effects of rainfall, slope, soil, cover and conservation practices on soil loss are all accounted for as shown in equations (7) and (8). Therefore  $B$  should remain approximately constant for a particular region and this was the case in this experiment as shown in Table 4.

The difference in  $\psi$  between the tilled and the untilled plots evident in Table 4 is further clarified by Fig. 4, the plot of soil loss  $A$  vs.  $I_{30}$ . At low  $I_{30}$  values (i.e.  $I_{30} < 3.5 \text{ mm h}^{-1}$ ) soil loss on the untilled plot was lower than on the tilled plot due mainly to the canopy cover on the untilled plot. This is reflected by a lower  $\psi$  value in the fitted equation on the untilled plot in comparison with the tilled plot (Steel & Torrie, 1960). However, at higher  $I_{30}$  values, the relative effect of canopy cover on soil loss is reduced as shown in Fig. 4. Therefore, the exponent  $\psi$  on the untilled plot must be

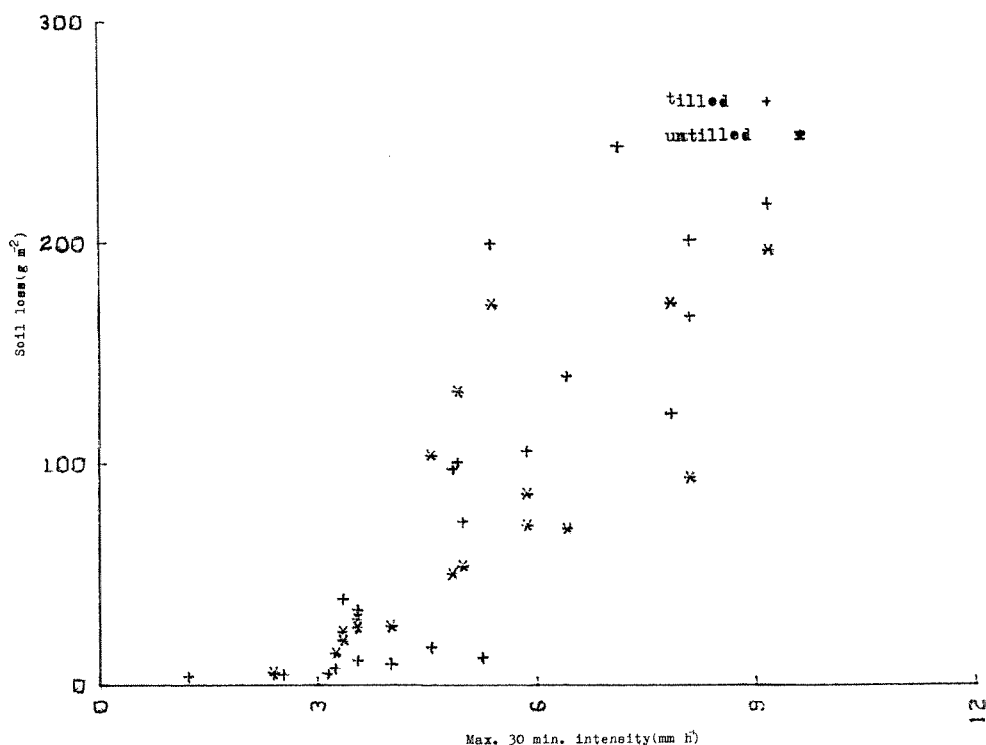


Fig. 4 Soil loss ( $A$ ) vs. maximum 30 minute intensity ( $I_{30}$ ).

larger, so that soil losses estimated by the two regression equations become close at higher intensities.

Values of  $\psi$  obtained in this experiment were within the range observed by most researchers (Ekern, 1954; Meyer, 1981; Watson & Laflen, 1986).

Values of soil erodibility,  $K$ , measured in  $\text{g m}^{-2}$  per erosivity unit and listed in Table 4 were computed by dividing the sum of the soil losses adjusted to unit plot conditions (Wischmeier & Smith, 1978) by the sum of the corresponding erosivity factor.

Table 4 shows that soil erodibility measured on the untilled plot is almost twice that measured on the tilled plot. No apparent reason is found for this large variation. Therefore, further investigations are recommended and for longer periods of time.

## CONCLUSIONS

Data were gathered for two rainfall seasons from two natural runoff plots located in the Hijran basin. One of the plots was tilled while the other was left undisturbed. Erosion and runoff analysis showed that:

- The ratio of runoff to rainfall indicates no significant variation with the seasonal changes in rainfall or with soil surface condition.

- (b) The dominant erosion type is interrill erosion. The rainfall erosivity term is the product of rainfall amount and maximum 30-minute intensity raised to some power.
- (c) Average soil erodibility measured on the tilled plot differed significantly from that measured on the untilled plot.

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