Evaluation of Applied Erosion Practices in a Semi-Arid Area

Mamoun Gharaibeh, Yaser Mohawesh, and Hafsa Al-Zubi

Abstract**—**Water erosion is considered a serious problem in arid and semi arid areas, mainly due to infrequent heavy rainfall events, low native plant density, and mismanagement of agricultural lands. The Universal Soil Loss Equation (USLE) was adopted to predict the annual soil loss and to evaluate the efficiency of conservational practices to control rainfall soil erosion in six sites of Wadi Ziqlab catchment, northeastern parts of Jordan. Soil loss and thickness of A horizon were estimated in sites applying soil conservation practices (SCP) and compared with a nearby sites with no SCPs. The thickness of A-horizon and the organic matter content were increased and stabilized with applied SCP's. Conserving the land was effective in reducing soil loss to the tolerance level in most of sites. Average annual erosion rate was reduced from 25 t $ha^{-1}.yr^{-1}$ (severe erosion risk) to 7 t $ha^{-1}.yr^{-1}$ (low risk) when SCP were applied.

Keywords**—**Water erosion, soil, A horizon, USLE.

I. Introduction

SOIL erosion is considered as a serious eco-environmental problem that threatens sustainable development in arid and semi-arid regions. Erosion degrades soil structure, and causes soil compaction, poor internal drainage, and salinization. About 85% of global soil degradation is associated with soil erosion, causing a reduction in crop productivity and environmental damage [1].

The topography and climate of any region is conducive to accelerate soil erosion. Existing local conditions such as soil erodibility (vulnerability of soil to erosion), rainfall erosivity (the potential of rainfall to cause erosion), topography, and type of vegetation cover will cause variations in the degree of erosion. The topographic factors that influence soil erosion processes are slope steepness, length and shape. The upland erosion is greater on steeper, longer land and convex slopes than on gentle, short, and concave hillsides. The steep land is more vulnerable to water erosion than flat land because of the erosive forces such as splash, scour, and transport [1].

The process of soil erosion is highly dependent on human actions. Natural erosion rates are lower for soils with a good vegetative cover than those with bare soil. In fact, any human actions that uncover soil (e.g., farming, logging, building, overgrazing, off-road vehicles, fires, etc.) greatly enhance soil erosion rates.

Soil erosion also reduces both the quantity (soil depth) and the quality (water holding capacity and other physical, chemical and biological properties) of soil. Within a slope landscape, water erosion plays an important role in redistributing soil materials and nutrients through changing the depth and properties of surface layer. In the long term, erosion alters topsoil and consequently affects nutrient availability, organic matter content, and crop yield. In general, erosion affect the first 12 cm of the top soil, which implies the loss of the first soil horizon (A horizon) [2]. The A horizon (topsoil) is made up of decomposed organic matter (humus) mixed with mineral particles. Plant seeds germinate and plant roots grow in this layer.

Water erosion lowers soil quality by transporting soil organic matter, soil nutrients, and soil particles of the A-horizon from the upper to lower slope positions. The removal of the A-horizon decreases vegetative cover, changes the physical properties of the remaining soil, and prevents the re-establishment of grasses [3]. The reduction of erosion can be attributed to the stabilization of soil surface layer (A-horizon), the increase of organic matter and the accumulation of crop residues [4].

Proper evaluation of the erosion process in any area provides the first step in choosing effective methods for soil erosion control. The most common models used to assess annual soil loss by water erosion are the Universal Soil Loss Equation (USLE) and the Revised Equation (RUSLE) [5]. The USLE is simple and can be applied on a regional scale.

Moreover, proper management practices minimize many related erosion problems such as loss of fertile topsoil siltation of streams and lakes, eutrophication of surface water bodies and loss of aquatic biodiversity. Such practices can be effectively carried out if the magnitude and spatial distribution of soil erosion are known. Therefore, it is necessary to establish soil conservation measures to reduce land degradation and to ensure development of a sustainable management of soil resources. The implementation of

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effective soil conservation measures has to be preceded by a spatially distributed erosion hazard and risk assessment.

The soils of Wadi Ziqlab area are particularly susceptible to erosion due to the natural or human interference. Human actions can be easily upset the natural balance and lead to rapid removal of soil through improper land use or improper agricultural practices. Therefore, erosion of surface soils in these regions should receive a particular concern since land is characterized by low native plant density and high intensity storms.

This study aimed to evaluate potential water erosion in Wadi Ziqlab, summarize currently used control practices, quantify the effectiveness of the applied soil conservation practices, and determine the best control practices required to reduce soil erosion to acceptable level using USLE.

II. Materials & Methods

A. Location & Description of Study Area

The area of Wadi Ziqlab catchment extends from the highlands of northern parts to eastern mountains bordering the Jordan Valley, located between coordinate’s latitudes 32° 23" to 32° 34" north and longitudes 35° 33" to 35° 50" east (Fig. 1). The elevations of this area are highly variable; ranging between 200m below sea level in the Jordan Valley in the west to more than 1075m above sea level at the upper south-east side of the catchment.

Wadi Ziqlab catchment is characterized by limited amount of rainfall during wet cold winters and long hot dry summers. The annual average temperatures range from 14.3º to 17.9 º C. Most of the precipitation occurs between the months November and March with average annual precipitation between 350 and 550 mm. Since the area is characterized by low native plant density and high intensity storms; erosion of surface soils should receive a particular concern.

The classes of land use in the study area are: bare soil, bare rock, olive, grape and pomegranate orchards, open forest, wheat fields. Most of the studied areas contained a mixture of pervious land uses. Conservation practices were applied in several fields, plowing was parallel to the longest field axis, and downslope tillage is the most common.

B. Collection & Analysis of Soil Samples

Soil samples were collected from 6 sites within Wadi Ziqlab catchment. Each site contained a field applying soil conservation practice (SCP) and a nearby land with no SCP. Both locations have the same topographical features (slope length and gradient), and same land use. Six A-horizons from each site were studied with a total of 36 A-horizon samples. Erosion control practices were applied by the government in the six chosen sites. Field with no applied erosion control practices was chosen as the control. From each field; three soil samples were taken along a transect line and the depth of A-horizon in cm was recorded. Soil texture was determined by the hydrometer method [6] and total organic matter by the Walkley-Black method [7].

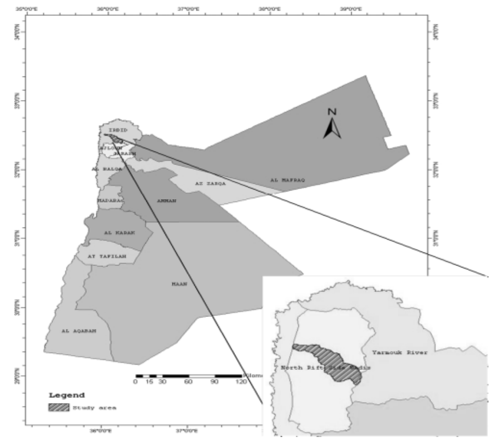

Fig. 1 Location of study area.

C. Soil Conservation Practices in Wadi Ziqlab Catchment

Soil and water conservation practices (SCP) had been applied at Wadi Ziqlab catchment since early 1960’s. Recently, the same practices have been applied while new ones are adopted when machinery became available (e.g. terraces). Most of the SCPs in Jordan were carried out by the government because they are quite costly to implement. The main conservation practices that can be found in studied area are: stone tree basins, contour stone walls, terraces: a new SCP used recently in studied catchment, contour lines, and wadies controls.

In this study, USLE was used to estimate soil loss in Wadi Ziqlab and compared with the estimated soil loss tolerance (T). Soil loss tolerance (T) is the maximum amount of soil loss in tons per acre per year, which can be tolerated and still permit a high level of crop productivity to be sustained economically.

D. Determination of USLE Factors

The Universal Soil Loss Equation (USLE) is used to predict how much erosion by water will occur in specific area. The estimation of long-term average annual erosion rate is based on rainfall pattern, soil type, topography, crop system, and management practices.

USLE predicts soil loss resulting from sheet or rill erosion on a single slope, soil loss from gully erosion is not included in this equation. This model is applied in selected cropping and management systems, and could be applied to non-agricultural conditions. The USLE compares soil losses from a particular field with a specific crop and management system to “tolerable soil loss” rates. Alternative management and crop systems may also be evaluated to determine the adequacy of conservation measures in farm planning.

Five major factors are used to calculate the soil loss for a given site. Each factor is the numerical estimate of a specific condition that affects the severity of soil erosion at a particular location. The erosion values reflected by these factors can vary considerably due to varying weather conditions. Therefore, the values obtained from the USLE more accurately represent long-term averages.

The USLE soil loss equation is:

$$A = R \times K \times LS \times C \times P \qquad (1)$$

Where A is the computed soil loss per unit area, expressed in the units selected for K and the period selected for R, R is the rainfall and runoff factor, K is the soil erodibility factor, L is the slope-length factor, S is the slope-steepness factor, C is the cover and management factor; and P is the support practice factor. Soil loss here is determined in t $ha^{-1}.yr^{-1}$.

Rainfall Runoff Factor R

The numerical value used for R in USLE must show the quantifiable effect of raindrops impact and reflect the amount and the rate of runoff associated with the rain. The R value incorporates total precipitation, intensity and duration pattern of rainfall, which means that large numbers for the R factor reflect more erosivity caused by weather condition. The R value can be derived from isoerodent maps, tables or it can be calculated from long term weather data [8].

The R calculated as follows:

$$R = \sum EI_{30}/100 \qquad (2)$$

Where R in hundreds of foot tons inch $acre^{-1}\ h^{-1}\ yr^{-1}$, and EI30 is the total storm energy (E) in hundreds of foot tons $acre^{-1}$ multiplied by the maximum 30-min intensity (I_{30}) in inches $hour^{-1}$. EI_{30} calculations differ in the equation used to express the relationship between the kinetic energy and the intensity of the storm calculated as follows:

$$e = 916 + 331\log_{10} i \qquad (3)$$

Where (e) is the kinetic energy in foot tons $acre^{-1}$ $inch^{-1}$, and (i) is the intensity in inches h^{-1}.

Erodibility Factor K

K is assumed to be constant throughout the year. A widely used relationship for predicting erodibility is a nomograph by Wischmeier et al., which was developed from data collected from 55 midwestern agricultural soils. Soil erodibility in the nomograph is predicted on a function of five soil profile parameters. An analytical relationship for the nomograph is

$$K = \frac{\left[2.1\times10^{-4}(12-a)M^{1.14} + 325(b-2) + 2.5(c-3)\right]}{100} \qquad (4)$$

Where K is soil erodibility in tons per acre per unit rainfall index (tons.acre.hr $hundreds^{-1}.acre^{-1}.ft^{-1}.tons^{-1}.in^{-1}$), M is the percentage of the standard classification of the very fine sand (0.1 – 0.05 mm) plus the silt (0.05 – 0.002 mm) multiplied by the percent of all soil fractions other than clay [(% very fine sand + % silt)(100 - %clay)], a is soil organic matter content (%), b is the soil structure code used in soil classification, c is the soil profile-permeability class. Permeability codes range from 1-6. A value of 6 is assigned for fine textured soils, 4 for medium textured soil, and 1 for coarse textured soils [5].

Steepness & Slope length Factors LS

The effects of land topography on soil erosion are determined by dimensionless L and S factors. Slope length (L) is the slope distance from the point of overland flow to the point of concentrated flow or until deposition occurs. The slope steepness factor (S) is used to predict the effect of slope gradient on soil loss. To computed factors LS use the following equation:

$$\mathrm{LS} = (\lambda/72.6)^{m}\,(65.41\sin^2\theta + 4.56\sin\theta + 0.065) \qquad (4)$$

Where λ is slope length in feet, θ is the angle of the slope in degrees, and m is 0.5 if the percent slope is 5 or more, 0.4 on slope of 3.5 to 4.5percent, 0.3 on slope 1 to 3 percent and 0.2 on less than 1 percent slope uniform gradient. The equation was derived from the data with slopes between 3-18%. For slope length greater than 5m, the S factor was modified significantly after extensive evaluation of the original USLE data base [9]. The modified version is

$$\mathrm{S} = 10.8(\sin\theta) + 0.03 \qquad (5)$$

$$\mathrm{S} = 16.8(\sin\theta) - 0.5 \qquad (6)$$

Where S is the slope and θ is the angle of the slope in degrees.

Cover Factor C

The simplest approach to define the C factor is to use tabulated values. The selected C values in USLE for cropland were presented by [5]. Complete listings of C values are given in Agriculture Handbook number 537. Cover crop factor changes with land-use cover, resulting in varying erosion rates over the course of season, even with invariant month-to-month rainfall energy. The C factor is given a value of 0.003 for undisturbed, 0.5 for undisturbed land, 0.26 for olive tree fields, 0.22 seasonal horticultural crops, and 1 for bare land.

Conservation Support Practices Factor P

The P factor was used to evaluate the effect of contour tillage, strip-cropping, terracing, and others. The lower the P value the better the practice is for controlling soil erosion. The factor P is estimated using the procedure outlined in [5]. The P factor is given a value of 0.5-0.6 for land slopes below 12%, 0.7 for slope ranging from 13-16%, and 0.8 for slope ranging from 17-20%, and 0.9 for slopes ranging from 21-25%.

III. Results & Discussion

The study represents the first field attempt to quantify and predict erosion in northern parts of Jordan and to evaluate the efficiency of current SCP's in reducing erosion.

The implementation of SCP's showed great benefits for developing the land and improving soil properties. Organic matter content and the thickness of A horizon were increased significantly with the presence of stone walls (Fig. 2 and 3).

Thickness of A Horizon

Fig. 3 shows that the thickness of A-horizon was higher with construction of stone walls (SCP's) compared to fields where no stone walls (no SCP's). The thickness of A-horizon in all studied fields applying SCP remained unchanged and therefore the fertility status of soil. On the other hand, the thickness of A horizon was changed significantly with the slope fields with no SCP's; indicating less organic matter and nutrients.

The thickness of A horizon ranged from 19 to 27 cm in sites applying SCP's, and from 15-22 cm in sites with no SCP's. About 50% of A horizon thickness values were in the range of 20-23 cm and 18-22 cm in both sites, respectively. Average thickness of A horizon in sites applying SCP's was 22 cm, and 20 cm for sites with no SCP"s.

The A-horizon is the uppermost zone of soil where most nutrients (including soil organic matter) are stored and cycled. It is also the most important soil zone in agricultural soils because crops and grasses are usually shallow rooted. The related changes in eroded topsoil in areas with no SCP's are reflected on decreased soil fertility and decreased productivity of cultivated land compared to those applying SCP's.

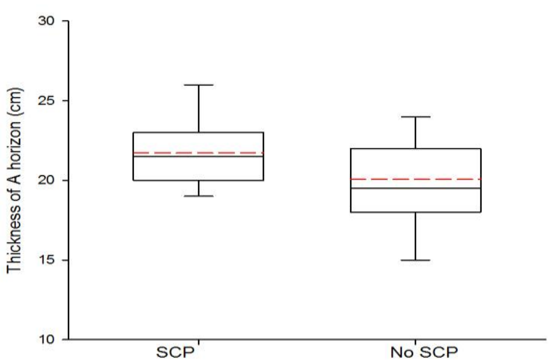

Fig. 2 Thickness of A horizon (cm) in sites applying soil conservation practice (SCP) and sites without SCP

Organic Matter content

The data are represented by box plots, and dotted line in both graphs represents the mean value. The bottom whisker represents the lowest obtained value (min) and the top represents the highest value (max). The bottom, middle, and top horizontal lines in each box represent the lower (25%), middle (50%) and upper quartile (75%), respectively.

Fig. 2 shows that OM content was higher in soils applying SCP's compared to those with no SCP's. OM values ranged from 0.9 to 2.2% in sites applying SCP's, and from 0.7-1.45 in sites with no SCP's. Most of OM values (75%) were in the range of 1.7-1.65% and 0.9-1.4% in both sites, respectively. Average OM content in sites applying SCP's was 1.35%, and 1.15% for sites with no SCP"s.

Estimation of Soil Loss Amount by USLE

Soil loss in sites adopting SCP's were predicted and compared to those lacking SCP's using USLE. The erosivity factor (R) in USLE was obtained from the Iso-erodents map of north Jordan published by [10]. The mean value of R-factor in the study area was 350 MJ.mm/ha.hr.year. R factor represents the erosive potential of rainfall; the numerical value of R in USLE must quantify the raindrops impact effect on soil and must also provide information on the amount and rate of runoff likely to be associated with rain.

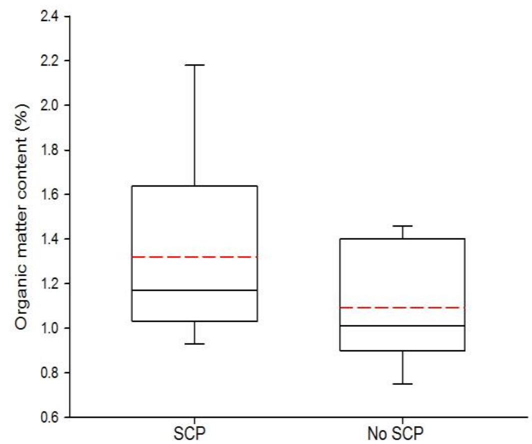

Fig. 3 Organic matter (OM) content (%) in in sites applying soil conservation practice (SCP) and sites without SCP

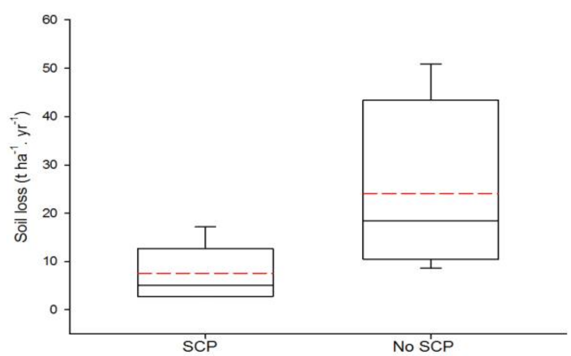

Fig. 3 Average annual soil loss (t ha^{-1}.yr^{-1}) in sites applying soil conservation practice (SCP) and sites without SCP

The soil erodibility factor (K) indicates soil susceptibility to water erosion. Basic soil properties that tend to increase K values include: high contents of silt and very fine sand (a tendency to form surface crusts), presence of impervious soil layers, and block, platy, or massive soil structure. Soil properties that tend to make the soil more resistance to erosion (low K values) include: high soil organic matter content, and strong granular structure. Soil textural classes varied among different samples with clay fraction dominating over other soil fractions. Permeability and structure codes were assigned for each location, permeability classes were in the high permeability code 6. Soil structure was found to be fine granular type; soil structure code used for all samples was 2. Soil erodibility factor was then calculated using the US customary units (tons acre hr per hundreds of acre ft ton in) then was converted to SI units (t ha h $ha^{-1}.MJ^{-1}.mm^{-1}$). The conversion was done by dividing the results by a factor of 7.59. The average value of K factor was 0.014 in t ha h ha^{-1} $MJ^{-1}.mm^{-1}$ which is considered as low soil erodibility. The slope length and steepness substantially affect sheet and rill erosion estimated by USLE. The effect of these factors can evaluated separately using uniform-gradient plots, however in erosion prediction, considering the factors L and S may be evaluated as a single topographic factor, LS, is more convenient. The ratio for specified combinations of field slope length and uniform gradient may be obtained directly from the slope-effect chart in the agricultural Handbook number 537. The LS values varied depending on the slope steepness, LS had a high values in high slope area. Values for C factor varied depending on the land use. The vegetative cover prevents the soil from erosion through: (1) holding the soil together through plant root system, (2) slowing down the water as it flows over the land and allowing much of rainfall water to soak through the soil particles, and (3) decreasing the impact of the raindrops before it hits the soil surface. The supporting practice factor (P-factor) represents practices and measures that are used to control soil loss by water. The value of P depended on soil management practices related to the slope of the field. The lower the P value, the more effective the conservation practices. P values attributed as 1 in fields without erosion control practice. The C and P factors are estimated using procedure outlined in [5]. These five major factors are generally used to calculate soil loss for any site, each factor is the numerical estimate of specific condition that affects the severity of soil erosion by rainfall water. These factors were combined to estimate the approximate values of soil loss in Wadi Ziqlab. Soil loss tolerance (T) is the maximum average of annual soil loss expressed in tons per hectare per year that will permit current production levels to be maintained economically and indefinitely. Many researchers assigned various values of T for each soil condition. For example; 5 t $ha^{-1}.yr^{-1}$ is recommended for thin slow forming soils and 2 t/ha/yr where soils are highly erodible [1]. Naturally any value of acceptable loss will depend on the soil conditions.

Application of SCP's significantly reduced soil erosion. Soil erosion ranged from 2-17 t ha^{-1}. yr^{-1} in sites adopting SCP's, whereas it ranged from 9-52 t ha^{-1}. yr^{-1} in sites lacking SCP's (Fig. 3). Average erosion was reduced from 25 to 7 t ha^{-1}. yr^{-1} with applying SCP's. About 50% of erosion value lied below 5 t ha^{-1}. yr^{-1} in in conserved sites, whereas 75% of erosion values lied between 20-45 t ha^{-1}. yr^{-1}. In addition, Fig. 3 shows that higher variability in erosion values in sites lacking SCP's and mostly occurring above 20 t ha^{-1}. yr^{-1}.

The erosion risk increases in particular from high slope areas to gentle areas. Erosion risk occurs in areas with steep slope, poor vegetation, high soil erodibility, and no soil conservation practices. Moreover, land use and management practices are the deciding factor in determining the extent of soil erosion and erosion induced degradation. Rangelands with poor vegetation cover, stony surface, poor fertility status and arid conditions need SCP not just to control soil movement but also to improve the vegetation by reducing the runoff and increase infiltration. The severity of soil loss is judged relative to the rate of soil formation, if soil properties such as nutrient status, organic matter content, texture, and thickness remain unchanged through the time, it is assumed that the rate of erosion balances the rate of soil formation. Soil erosion risk in most sites was found to be tolerable, however, in the high slopes erosion was moderate with applied SCP, and severe in fields with no soil conservation practices.

IV. Conclusion

Applying SCP's reduced soil erosion in most of the studied sites to tolerable level. Conserving the soil increased and stabilized thickness of A-horizon and increased SOM content. Increasing both soil OM and the thickness of A horizon preserved soil fertility and increased crop yields in fields adopting SCP.

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