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USE OF THE UNIVERSAL SOIL-LOSS EQUATION TO DETERMINE WATER EROSION WITH THE SEMI-CIRCULAR BUND WATER-HARVESTING TECHNIQUE IN THE SYRIAN STEPPE

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Abstract

This research was conducted through the rain season 2009 -2010, in Mehasseh Research Center at (Al Qaryatein), The area is characterized by a hot and dry climate in summer and cold in winter with an annual average rainfall of 114 mm. Three slopes (8%, 6%, 4%) were used in semicircular bunds water -harvesting techniques with bunds parallel to the contours lines at flow distance of 18, 12 and 6 m. The bunds were planted with *Atriplex Halimus* seedlings. Graded metal rulers were planted inside the bunds to determine soil loss and sedimentation associated with the surface runoff, and metallic tanks were placed at the end of the flow paths to determine agricultural soil loss from water runoff. A rain intensity gauge was placed near the experiment site to determine the rainfall intensity that produced runoff. The treatments were done in three replications. The amount of soil erosion (in tons per hectare per year) increased with increasing of the slope, the highest recorded value was 38.66 at slope of 8% and the lowest 0.05 at 4% slope. The amount of soil erosion also increased with increasing of water run distance, which was 38.66 $T.ha^{-1}.yr^{-1}$ at 18 m and 0.05 $T.ha^{-1}.yr^{-1}$ at 6 m . Bunds with different diameter of water harvesting reduced soil erosion by about 65% at slope of 8%, 55% at 6%, and 46% at 4%. The input parameters of Universal soil- loss equation were found to be suitable for determining soil erosion in this arid and semi-arid region.

Key words: bunds, runoff distances, Universal soil -loss equation, water harvesting techniques

Introduction

Water is considered the main limiting factor for agricultural production in arid and semiarid area, Rainfall is the only source of water in such regions, because, as there areas no permanent sources of water such as lakes, river, streams; rain falls irregularly but heavily during the rainy season. Many seasons of drought lead to the degradation of natural resources such as Soil, Water, and Vegetation. Natural resources in rangeland must therefore be managed by water harvesting to ensure adequate production of livestock feed throughout the season and to reduce soil erosion.

Water harvesting is the chemical, physical, and morphological process for concentrating and gathering the runoff of rainfall water for use when necessary to irrigate plants or for drinking water for livestock (Somme et al., 2001). Various techniques are used to collect rainwater from natural terrains or modified areas and to concentrate it for use at smaller sites or on cultivated fields to ensure economic crop yields. Collected runoff is stored in the soil behind dams, terraces, cisterns or gullies or used to recharge aquifers (Oweis, 2004).

In the Syrian Arab Republic, water harvesting is seldom used by farmers, mainly because they are not aware of this traditional system, which is widely adopted in other dry areas, including in Egypt, Pakistan, Tunisia and Yemen. Furthermore, the agricultural research and extension support services in the country lack specific, systematic knowledge about potential areas and suitable locations for water harvesting (De Pauw et al., 2004).

Erosion is the physical process that destroys soil production ability, and runoff leads to loss of organic matter and the entire content of soil. Erosion comprises processes by which earth materials are entrained and transported across a surface, while soil loss is the material actually removed from a particular hill slope or segment. Soil loss may be less than erosion because of on-site deposition in micro-topographic depressions on a hill slope. The sediment yield from a surface is the sum of soil losses minus deposition in macro-topographic depressions, at the toe of a hill slope, along field boundaries or in terraces and channels sculpted into the slope (Terrence and Foster, 1998).

During the past few decades, scientists have devised mathematical models for calculating water erosion of soil. The models include the factors that affect the amount of soil erosion and are used to reduce damage to the soil. The universal soil-loss equation (USLE) is considered to be one of the most significant developments in soil and water conservation in the 20th century and is used on every continent in places where soil erosion caused by water is a problem. It is an empirical equation based on the work of many individuals that has evolved over the past 60 years and is still being revised(Laften and Moldenhauer, 2003).The equation first published in Agriculture Handbook No. 537 of the United States Department of Agriculture (Wischmeier and Smith, 1978) is:

$$SE= R*K*LS*C*P$$

where *SE* is the long-term average annual soil loss (usually expressed in $t.ha^{-1}.yr^{-1}$),*R* is rainfall erosion potential in $J.ha^{-1}$, *K* is soil erosion susceptibility in $t.ha^{-1}$, *LS* is the dimensionless impact of slope length and steepness, and *C* and *P* are the dimensionless impacts of cropping and management systems and of erosion control practices. The USLE has become the standard tool for predicting soil erosion by water throughout the world (Meyer, 1984).

The objective of this study was to use the USLE to determine the effectiveness of semi-circular bunds of different diameters (18, 12, 6m) in reducing soil erosion, the influence of runoff distances of 18, 12 and 6 m in reducing soil erosion and to determine all the factors that affect the USLE in order to find a suitable form for calculating soil erosion in arid and semi-arid areas.

Material and Methods

Site: The site studied is located in the Syrian steppe 120 km northeast of Damascus. It covers about 7000 ha and is at 850–950 m altitude, 37.20 ° longitudes, and 34.08º latitude, with a rainfall of 114 $mm.yr^{-1}$ (Figure 1).

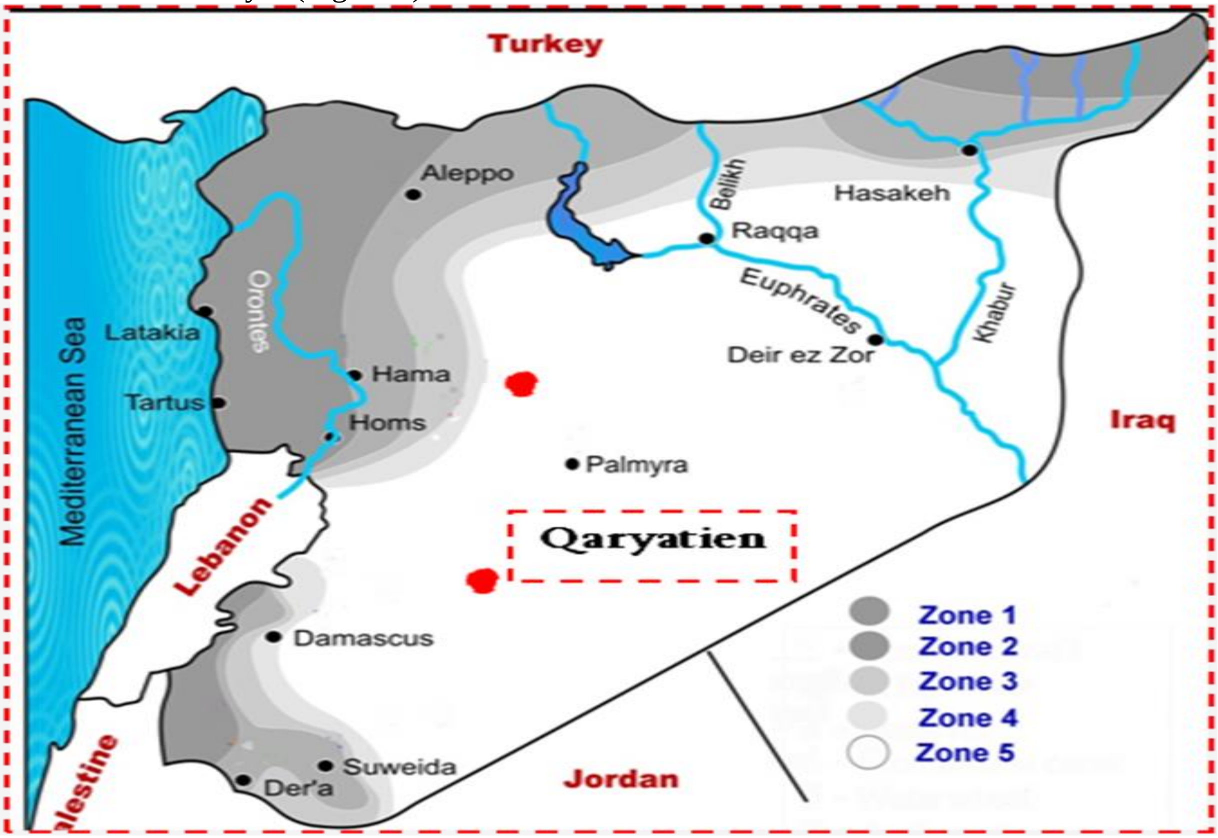

Figure 1. Site of the experiment (Qaryatien)

The area is considered to be arid to semi-arid area. It is very hot in summer and very cold in winter, with low rainfall (an annual average of 114 mm) and an evaporation rate of 1750 mm. Climate characteristics are recorded tan electronic climate station (Table 1).

Table 1. Climatic characteristics of studied site

Climatic element	Jan	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Rainfall (mm)	27.7	14	26	18.5	1	0.0	0.0	0.0	0.3	4.4	**0**	4.5	96.4
Rainfall density $mm.h^{-1}$)(	11.89	-	-	-	-	-	-	-	-	-	-	-	-
Air temperature (ºC)	6.5	6.4	8.9	13.2	21.4	23.9	26.2	25.1	23	17.6	12.1	6.9	15.9
Max. temperature (ºC)	10.3	12.5	14.1	22.1	28.9	32.7	34.1	33.9	31	25.4	18.2	13	23.0
Min. temperature (ºC)	0.65	-0.2	2.1	6.4	11.5	14.3	17.2	16.7	13.3	7.9	6.1	1.3	8.1
Relative humidity (%)	74.1	64.2	57.9	51.4	35	44.2	45.3	49.1	48.7	50.3	68	73.1	55.1
Wind speed ($m.s^{-1}$)	3.4	3.8	3.6	4.1	4.3	4.6	6	4.4	3.6	3.2	3.1	4.5	4.05
Evapotransportation(mm)	42	61	86	136	223	222	217	224	196	143	80	41	1671

The chemical properties of the soil were the same on the three slopes. The average proportion of total carbonates was very high (41.96%); the pH was7.69, and the organic matter content was 0.534% (Table 2).The percentages of sand, silt and clay and the bulk density differed by slope; however, the real density was the same (Table 2)

Table 2. Chemical and Physical properties of soil according to slope

Slope (%)	chemical properties			physical properties				
	organic matter (%)	pH	total carbonates (%)	Real density $g.cm^{-3}$	Bulk density $g.cm^{-3}$	clay (%)	silt (%)	sand (%)
8	0.554	7.65	40.26	2.65	1.28	22	5	73
6	0.587	7.76	41.48	2.65	1.28	20	11	69
4	0.462	7.68	41.96	2.65	1.28	19	11	70

Field structure

The study was conducted on three slopes (8%, 6%, 4%), which were chosen with a Nevo device. Contour lines were drawn on the three slopes at 18, 12 and 6 m to serve as runoff distances. Then, semi-circular bunds with diameters of 18, 12 and 6m were dug on the contour line. A control system had the same diameter contours (18, 12, 6 m) but no bunds. The bunds and the blanks were planted with the livestock feeding shrub *Atriplex Halimus*. All treatments were distributed randomly on three replicates for each slope (Figure 2).

The rainfall during the season studied was recorded at an electronic climate station installed at the site. Rainfall gauges were used to measure the amount of rainfall, and graded pins and metal tanks were planted in the water catchment area to measure accumulated and eroded soil with the USLE (United States Department of Agriculture, 2008). A rain intensity gauge was placed near the site to determine the rainfall intensity that produced runoff.

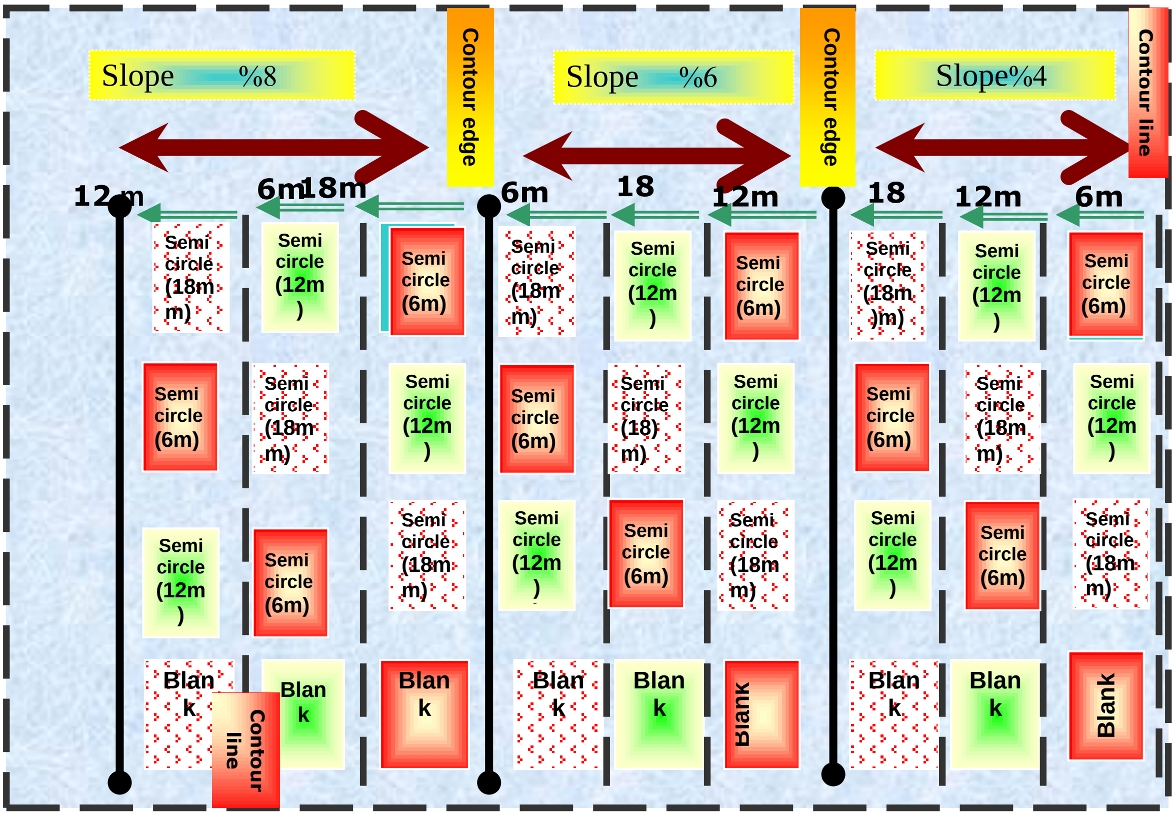

Figure 2.Position of treatments in the experiment (one replication)

Result and discussion

The highest rainfall during the rainy season was27.7mm in December 2009, with a rainfall density during that month of 11.89 mm.h^{-1} (Table 1). The runoff of rainwater in this season was compared with erosion of the agricultural soil on the three slopes and at the three runoff distances. Soil erosion was calculated for *R*, *K*, *LS*, *C* and *P* of the USLE.

The *R* coefficient represents rainfall and is determined from the amount of rainfall and the quantity of runoff. Its value is therefore related to rainfall density, which can be calculated from:

R (J.ha^{-1}) $=\sum EI30$

Where, $E = (118.9+87.3)\log^{10}/I_{30}$, and I is the highest rainfall intensity during half an hour during a rain storm. I is calculated by plotting the amount of rainfall during1 month (Figure 3).

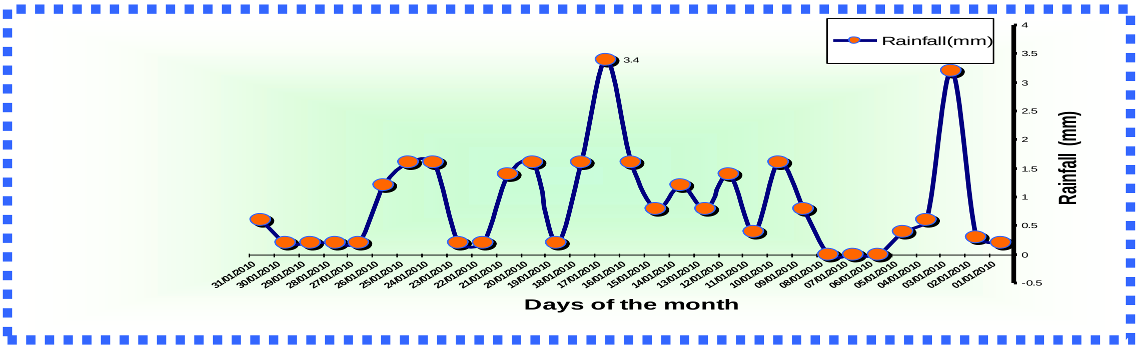

Figure 3. Value of *I* in the USLE

The *K* coefficient is calculated (Fredrrich et al., 2003) as follows:

$K= \{(2.1 \times 10^{-4})* (12-OM)\ M^{1.14}+3.25(S-2) +2.5(P-3)\}/100$

where *OM* is the soil content of organic matter (%), *M* is{(silt+sand)*(silt + fine sand)}, *S* is the coefficient of the class of soil texture, related to the diameter of the soil aggregates(Table 3) and *P* is the infiltration of soil in cm.day^{-1} (Table 4).

Table 3.Value of coefficient *S* in calculating *K* in the USLE

Coefficient S	(sDiameter of soil aggregate (mm
1	< 1
2	2–1
3	10–2
4	> 1

Table 4. Value of coefficient *P* in calculating *K* in the USLE

P	Infiltration of soil (cm.day^{-1})
1	< 1
2	1–10
3	10–40
4	40–100
5	100–300
6	> 300

After calculating the coefficients of the equation for the *K* factor in the USLE, we determined the erosion potential of the soil due to water runoff (Table 5). The value of *K* was < 0.09, which is in agreement with the results of Ferreira et al., (1995),who found a value of 0.09 when the organic matter content of soil was less than 2%.

Table 5. Calculated *K* coefficient in the USLE

Slope (%)	Runoff distance(m)	Total Organic Matter %	Silt (%)	Sand (%)	Coefficient of soil texture(s)	Infiltration (cm.day^{-1})	*K*
0.08	18	1.623	0.20	0.525	1	6	0.043
0.08	12	0.913	0.20	0.525	1	6	0.043
0.08	6	0.71	0.20	0.525	1	6	0.043
0.06	18	0.403	0.25	0.500	1	4.8	0.018
0.06	12	0.71	0.25	0.500	1	4.8	0.018
0.06	6	0.913	0.25	0.500	1	4.8	0.018
0.04	18	0.811	0.20	0.525	1	3.6	0.018
0.04	12	0.51	0.20	0.525	1	3.6	0.018
0.04	6	0.51	0.20	0.525	1	3.6	0.018

The *LS* coefficient of the USLE represents the length, slope and shape of the catchment area (Troeh et al., 2004). We first determined the coarseness of the surface by accurately surveying the surface of the catchment area and recording topographic elements such as boulders, cobbles, gravel (fine, medium and coarse) and plant roots on the three slopes. We then calculated the average percentage of each topographic element per square of catchment area, to derive the coarseness of the land (Table 6).

Table 6. Coarseness of study site

Slope (%)	Length (m)	Catchment area (m^2)	Coarse gravel (%)	Medium gravel (%)	Fine gravel (%)	Roots (%)	Coarseness (%)
8	18	127.17	15	12	5	3	0.0875
8	12	56.52	10	8.7	2	1.85	0.0564
8	6	14.13	4.6	5.5	5	0.8	0.0397
6	18	127.17	9.5	8	4.9	2	0.0610
6	12	56.52	8.2	8	4.6	1	0.0545
6	6	14.13	6.5	7	4.5	0.6	0.0465
4	18	127.17	6.8	4.5	4.5	1	0.0420
4	12	56.52	5.8	2.5	2.5	1	0.0295
4	6	14.13	4.2	2.2	2.3	1	0.0243

We determined the *LS* coefficient in the USLE by multiplying the value for coarseness by the length of the catchment area (18, 12, 6 m) and by the slope (8,6,4%)(Table 7).The value of *LS* was < 1, which is in agreement with the results of Stone(2000).

Table 7. Calculated *LS* coefficient in the USLE

Coarseness (%)	Slope (%)	Length(m)	*LS*
0.0875	0.08	18	0.126
0.0564	0.08	12	0.054
0.0397	0.08	6	0.019
0.0610	0.06	18	0.066
0.0545	0.06	12	0.039
0.0465	0.06	6	0.023
0.0420	0.04	18	0.060
0.0295	0.04	12	0.0141
0.0243	0.04	6	0.0058

The *C* coefficient corresponds to the vegetation cover in the catchment and target area. Vegetation plays an important role in fixing the soil and thus reducing soil erosion by rainfall. The value of this coefficient is affected by the percentage of planted shrub cover.

The coefficient is calculated from:

C= (area of vegetation * percentage of successful shrubs) / catchment area

In this study, C increased with increasing slope and increasing diameter of the water harvesting bunds (Table 8). The vegetation cover in the bunds was greater than in the controls on all three slopes. The value of this coefficient in the USLE was < 1, in agreement with the results of Foster (2000), who found values of 0.02–0.04on pastureland.

Table 8.Calculated *C* coefficient in the USLE

Treatment	Slope (%)	Diameter (m)	Dimensions of shrubs			Successful shrubs (%)	Catchment area (m^2)	*C*
			Plant coverage (m^2)	Length (m)	Width (m)			
Bund	8	18	0.075	0.30	0.25	70.56	127.17	0.0416
Blank	8		0.019	0.16	0.12	19.22	127.17	0.0029
Bund	8	12	0.036	0.20	0.18	52.56	56.52	0.0335
Blank	8		0.013	0.12	0.11	19.02	56.52	0.0044
Bund	8	6	0.008	0.10	0.08	37.66	14.13	0.0213
Blank	8		0.000	0.01	0.01	18.95	14.13	0.0001
Bund	6	18	0.055	0.25	0.22	65.75	127.17	0.0284
Blank	6		0.011	0.11	0.10	19.12	127.17	0.0020
Bund	6	12	0.034	0.19	0.18	49.56	56.52	0.0300
Blank	6		0.011	0.11	0.10	19.02	56.52	0.0037
Bund	6	6	0.013	0.12	0.11	33.26	14.13	0.0310
Blank	6		0.011	0.11	0.10	18.78	14.13	0.0013
Bund	4	18	0.029	0.18	0.16	32.90	127.17	0.0075
Blank	4		0.011	0.11	0.10	19.10	127.17	0.0017
Bund	4	12	0.012	0.12	0.10	29.39	56.52	0.0062
Blank	4		0.011	0.11	0.1	18.88	56.52	0.0031
Bund	4	6	0.002	0.05	0.04	29.15	14.13	0.0041
Blank	4		0.001	0.10	0.10	18.75	14.13	0.0013

The *P* coefficient represents the ability of the water-harvesting technique to reduce soil erosion. We determined ***P*** by measuring the amount of erosion inside the metal tanks at runoff distances of 18, 12 and 6m on the three slopes. We determined the accumulated soil behind the bunds after taking readings from the metal pins and obtained P by dividing the amount of erosion by the accumulated soil and multiplying the result by 100. The results (Table 9) agreed with those of Renard et al.(1997), who found values of 40–70% in farmland with the contour line technique.

Table 9. Calculated *P* coefficient in the USLE

Slope (%)	Treatment	Soil erosion ($t.ha^{-1}.yr^{-1}$)	Runoff distance (m)	*P*(%)
8	Accumulated pins	80.7	18	65.028
	Erosion tank	124.1		
	Accumulated pins	33.8	12	61.735
	Erosion tank	54.8		
	Accumulated pins	22.4	6	61.370
	Erosion tank	36.5		
6	Accumulated pins	60.2	18	55.005
	Erosion tank	109.5		
	Accumulated pins	23.7	12	54.110
	Erosion tank	43.8		
	Accumulated pins	17.7	6	52.249
	Erosion tank	33.8		
4	Accumulated pins	25.2	18	46.069
	Erosion tank	54.8		
	Accumulated pins	17.8	12	44.337
	Erosion tank	40.2		
	Accumulated pins	4.6	6	42.009
	Erosion tank	11.00		

Having determined all the coefficients of the USLE, we estimated the amount of soil erosion on the three slopes (Table 10). The amount of soil erosion on slope 8%at a runoff distance of 18 m was greater than that with the other treatments.

Table 10.Amount of soil erosion obtained with the USLE

Slope %	Runoff distance m	*R*	*K*	*LS*	*C*	*P*	Bulk density $g.cm^{-3}$	Soil erosion	
								$m^3.ha^{-1}$	**$t.ha^{-1}.y^{r-1}$**
8	18	72.29	0.043	0.126	0.0416	0.650	1.28	1.06	38.66
	12	72.29	0.043	0.054	0.0335	0.617	1.28	0.35	12.66
	6	72.29	0.043	0.019	0.0230	0.613	1.28	0.08	3.04
6	18	72.29	0.018	0.066	0.0284	0.550	1.28	0.13	4.90
	12	72.29	0.018	0.039	0.0300	0.541	1.28	0.08	3.01
	6	72.29	0.018	0.023	0.0310	0.522	1.28	0.03	0.99
4	18	72.29	0.018	0.060	0.0075	0.460	1.28	0.03	0.98
	12	72.29	0.018	0.014	0.0062	0.443	1.28	0.01	0.18
	6	72.29	0.018	0.006	0.0041	0.420	1.28	0.00	0.05

Conclusion

The amount of soil erosion increased with increasing slope, with the highest value on the 8% slope (38.66 $t.ha^{-1}.yr^{-1}$) and the lowest on the 4% slope (0.05 $t.ha^{-1}.yr^{-1}$).The amount of soil erosion increased with increasing water runoff, reaching 38.66 $t.ha^{-1}.yr^{-1}$ at 18 m, while it was only 0.05 $t.ha^{-1}.yr^{-1}$at the shortest distance (6 m).

Use of water harvesting bunds with different diameters led to reductions in soil erosion of 65% at a 8%slope, 55% at a 6%slope and 46% at a 4% slope.

For the first time in the region, the input parameters for the USLE have been determined, and a suitable means for calculating soil erosion in this arid and semi-arid region has been obtained.

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