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The Effect of Water Harvesting Techniques on Runoff, Sedimentation, and Soil Properties

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Abstract This study addressed the hydrological processes of runoff and sedimentation, soil moisture content, and properties under the effect of different water harvesting techniques (treatments). The study was conducted at three sites, representing environmental condition gradients, located in the southern part of the West Bank. For each treatment, the study evaluated soil chemical and physical properties, soil moisture at 30 cm depth, surface runoff and sedimentation at each site. Results showed that runoff is reduced by 65–85% and sedimentation by 58–69% in stone terraces and semi-circle bunds compared to the control at the semi-humid site. In addition, stone terraces and contour ridges significantly reduced the amount of total runoff by 80% and 73%, respectively, at the arid site. Soil moisture content was significantly increased by water harvesting techniques compared to the control in all treatments at the three study sites. In addition, the difference between the control and the water harvesting structures were higher in the arid and semi-arid areas than in the semi-humid area. Soil and water conservation, via utilization of water harvesting structures, is an effective principle for reducing the negative impact of high runoff intensity and subsequently increasing soil moisture storage from rainfall. Jessour systems in the valley and stone terraces were effective in increasing soil moisture storage, prolonging the growing season for natural vegetation, and decreasing the amount of supplemental irrigation required for growing fruit trees.

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Introduction

Throughout arid and semi-arid regions, water shortage is the major limiting factor for agricultural development and rangeland improvement. Therefore, water harvesting techniques (WHT) have long been utilized as a means to reduce soil erosion and sedimentation and to increase soil water storage and soil fertility (Xiao-yan and others 2004).

Water harvesting can be defined as the process of concentrating rainfall as runoff from a large catchment area to be used in a smaller target area (Oweis and others 1999). WHT consists of two components: the catchment area, where runoff is collected, and the cultivated area, where the runoff is concentrated (Critchley and siegert 1991). Water harvesting may also be used for restoration of the productivity of land which suffers from insufficient precipitation, increasing productivity of rain-fed farming, minimizing risk of drought in areas prone to it and decreasing the threat of desertification through decreasing runoff and increasing infiltration (Prinz and others 1996). The major advantages of water harvesting are that it is simple, cheap, replicable, efficient and adaptable (Reij and others 1988).

Runoff causes erosion of fertile topsoil, resulting in soil degradation and over-exploitation of natural resources for forest and rangeland production (Schiettecatte and others 2005; Gupta 1995).Traditionally, water harvesting practices have been implemented and developed by local farmers in arid and semi-arid areas of the world in order to increase the amount of water available for crop production and tree growth (Oweis and others 1999). Li and Gong

(2002) reported that ridge and furrow rainfall harvesting systems increased water availability for crops and stable agriculture production in many areas of the Loess Plateau in northwest China. In the northern Negev Desert, contour ridges (terraces) are the most common water harvesting technique. *Eucalyptus occidentalis* and *Eucalyptus sagentii* under this technique show more biomass and total height, as a result of the maximum use of the water available to plants (Brunori and others 1995). During the long history of the Palestinian area, farmers built stone terraces in central mountains of the West Bank that were used for soil and water conservation, reducing the negative effect of intense rainfall, resulting in a lower amount of runoff and erosion and significantly increasing the amount of soil organic matter, Mg, Ca, and K (Abu Hammad and others 2006).

Al-Seekh and Mohammad (2008) reported that the amount of runoff and sedimentation were varied under different environmental conditions in the southern part of the West Bank and were mainly affected and controlled by the interaction of different factors, including rainfall characteristics, soil conditions and cover type and percentage of vegetation.

The Palestinian areas, which are located in the eastern Mediterranean region, are characterized by a mountainous topography and fragile semi-arid climate which make the area subject to many environmental problems, such as loss of natural vegetation cover and low and high rainfall intensity. The latter causes soil erosion and overland flow (Retrenberg and Whittles 1947; Zohary 1947). Precipitation is the major water resource for agricultural production, as approximately 95% of agricultural land is rain-fed (MOA 2004 (Unpublished)). The Palestinian water authority (2003) reported that the water deficit is about 88 million cubic meters per year. Moreover, this water demand will increase from 220 million cubic meters per year in 2001 to 360 million cubic meters per year in 2020 due to population increase and higher standard of living expected in the future. Therefore, good soil and water conservation management, such as increasing water storage and using rainfall effectively, is needed to reduce the amount of irrigation water and to maintain good soil quality.

Evaluation of the hydrological processes of runoff, sedimentation and maintaining soil moisture are very important for the successful design and implementation of suitable water and soil conservation practices. Therefore, the objective of this study was to evaluate the effect of water harvesting structures (stone terraces, semi-circle bunds, the jessour stone system and contour ridges) on runoff, sedimentation and soil moisture content in three sites that have different environmental conditions and land use history in southern parts of the West Bank.

Materials and Methods

Study Site

This study was part of a large project entitled Monitoring and Evaluation of Watersheds in the Middle East Region. It was funded by the USDA Forest Service, USAID Middle East Regional Cooperation (MERC) and the US State Department. It was implemented by the College of Agriculture at Hebron University.

The study was conducted in 2005 at the Sorif, Dura and BaniNoem sites in the Hebron District/West Bank (Fig. 1) (Geographic Information System Unit (GIS) 2006). These sites represent different environmental conditions.

BaniNoem is located on the eastern slopes of the West Bank, 15 km east of Hebron city. The geographical position is 35.1° East and 31.4° North. Its topography is mountainous, with elevation ranging from 596 to 704 m above sea level. According to the aridity index, which is the percentage value of evaporation to precipitation in the area, the site is classified as an arid climate with an average precipitation of about 250–300 mm (MOA 2004 (Unpublished)). Most of the precipitation falls in short, high-intensity rainstorms. This precipitation almost always approaches from the west and is influenced by the nearby Sinai and Negev desert climate. The soil bedrock is calcareous, limestone, or hard chalk, with shallow soil. According to Awadallah and Owaiwi (2005) the soil at this site is brown rendzinas and pale rendzinas.

The area of this site is about 50 hectare (ha). It was used for many years as rangelands, but grazing has been

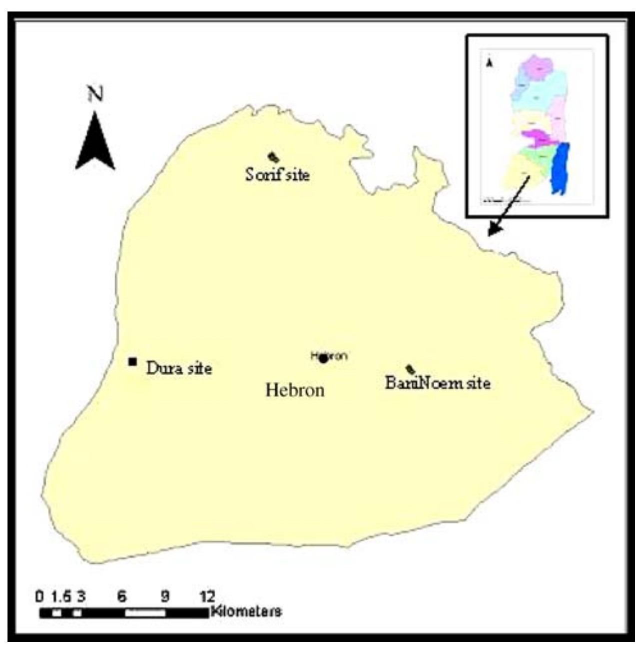

Fig. 1 Location of study sites in Hebron District/West Bank

excluded by fencing since 1995. According to Al-Jubeh (2006) and Mohammad (2005), the dominant plant species in natural vegetation are *Torilis tenella*, *Poa bulbosa*, *Anthemis spp*, *Vivia spp*, *Crithopsis delileana*, *Medicago sp* and *Helianthemum salicifolium*.

The Sorif site is located in the western parts of the central mountain region of the West Bank, 10 km northwest of Hebron city. The geographical position is 35.06° East and 31.62° North. The site's topography is mountainous with steep slopes and elevation ranging from 568 to 727 m above sea level. The area is considered to be a semi-arid to semi-humid Mediterranean climate with a long, hot, dry summer and a short, cool, rainy winter. The average annual rainfall is about 350–400 mm, and occurs during the winter season, from November to April. The soil is classified as terra rossa, brown rendzinas and pale rendzinas (Awadallah and Owaiwi 2005).

The area was once forest, before the deforestation of the last four decades and exposure to overgrazing. The total area, about 15 ha, was fenced and excluded from grazing in 2001. According to Al-Jubeh (2006) and Mohammad (2008), the dominant plant species are *Sarcopoterium spinosum*, *Avena sterilis, Lolium spp, Bromus fasciculatus, Crepis aspera* and *Aegilops binuncialis*.

The Dura site is located 16 km southwest of Hebron city. The elevation ranges from 486 to 535 m above sea level. The geographical position is 34.95° East and 31.46° North and covers an area of about 2 ha. The climate is considered semi-arid, with 300 mm mean annual rainfall (MOA 2004 (Unpublished)). Soil taxonomy includes brown rendzinas and pale rendzinas (Awadallah and Owaiwi 2005). The dominant plant species are *Crupina crupinastrum*, *Avena sterilis*, *Bromus spp, Asphodelus aestivus* and *Onobrychis caput-galli* (Al-Jubeh 2006; Mohammad 2008). The site was used by farmers for cultivation and grazing interchangeably, leading to soil erosion and reduction of vegetation cover.

Treatments

Soil properties, runoff and sedimentation were measured under different water harvesting treatments at three study sites (Table 1).

Stone terraces are constructed along the slope using small stones, in order to slow down runoff, increase infiltration and capture sediment. The technique is widely used in mountainous areas, which have an adequate supply of stones that can be used quickly and cheaply. The jessour system is a type of stone terrace constructed in the wadi (valley between mountains) with earth dikes (tabia) that are often reinforced by stone walls. The sediments that accumulate behind the dikes are used for cropping (Prinz and others 1996). Contour ridges are a microcatchment technique established by constructing earth ridges along the contour; soil is excavated and placed down slope to form ridge.

Measurements and Data Collection

Soil Chemical and Physical Properties

Soil chemical and physical properties were measured once in September of 2005. Three replicate soil samples, 0–10 cm depth, were randomly collected from each treatment and close to runoff plots. The bulk soil samples were air-dried, crushed with a mortar and pestle and sieved to remove coarse (>2 mm) fragments. Soil particle size distribution was determined using the pipette method (Bouwer 1986). Soil pH was determined by using an electrode pH-meter for a saturated soil paste (1:2.5) using distilled water. The electrical conductivity (EC) was also measured in a saturated paste (1:2.5) (Skoog and West 1976; FAO 1980). Organic matter (OM) was determined as organic carbon ratio in the sample by using the Walkey and Black method (Nelson and Sommers 1982). Extractable bases were determined following displacement with 1 M NH_4OAc (Thomas 1982). The Olsen method was used to determine extractable phosphorus using a molybdate reaction for colorimetric detection (Olsen and Sommers 1982).

Runoff and Sedimentation

To evaluate the amount of runoff and sediment yield, replicate 50 m^2 experimental artificial runoff plots (2-runoff plots) were constructed in each treatment at the three study sites, for 18 runoff plots in total. Plots were designed to be the same in size, slope angle and topography in all treatments except those in the jessour system. Each runoff plot was bounded with cement block 20 cm high to prevent run-on from the adjacent area. A plastic pipe was used to convey the runoff water to a 0.7 m^3 tank. After each main rainstorm

Table 1 Water harvesting techniques (treatments) evaluated at each study site

Sorif site	Dura site	BaniNoem site
Natural vegetation (control)	Natural vegetation (control)	Natural vegetation (control)
Stone terraces	Stone terraces	Soil contour ridges
Soil semi-circle bunds	Stone terraces at the bottom of the wadi (jessour system)	Stone terraces

event, the amount of runoff was measured after allowing the sediments to settle. Rainfall was measured by two rain gauges at each study area. The accumulated sediments were measured once, at the end of winter season. Data were measured during the 2004/2005 winter season.

Soil Moisture Content

The gravimetric method was used for soil moisture content. Five replicate soil samples were taken at 30 cm soil depths from each treatment. Samples were taken periodically, on 31-March, 15-April, 2-May, 20-May, 20-June, 25 July, and 10-Sep of 2005. Soil was placed in an aluminum can and taken to the lab, where the can was opened and placed in an oven at 105°C for 48 hours.

Statistical Analysis

One-way ANOVA was used to compare treatment means for soil properties, runoff, and sedimentation within each site. The Fisher LSD (Least Significant Difference) test at $p \leq 0.05$ was used for mean separation utilizing Sigmastat® program.

Results

Soil Properties

The results showed that soil texture is similar between all treatments at each study site. In general, there were no significant differences in almost all tested soil properties between the water harvesting structures and the control. However, significantly higher EC values were measured in semi-circle bunds (0.45 dsm^{-1}) than in other treatments at the Sorif site (Table 2), while pH, available nitrogen (NH^{4+} and NO_3^-) and phosphorous were higher than in the control (natural vegetation). The same trend was observed for pH, available nitrogen (NH^{4+} and NO_3^-) and phosphorous at both the Dura and BaniNoem sites (Tables 3 & 4). At both the Dura and BaniNoem sites, soil organic matter tended to be higher for the control than for soil and water conservation practices. Stone terraces at the Sorif site and the jessour stone system in Dura had significantly higher bulk density than other treatments.

Runoff and Sedimentations

The results represented in Fig. 2 show that at the Sorif site, stone terraces and semi-circle bunds significantly reduced the total surface runoff to 9.7 L/m^2 and 4.8 L/m^2, respectively. Stone terraces and semi-circle bunds reduced sedimentation to 20.6 g/m^2 and 12.1 g/m^2, respectively. The same trend was found in the BaniNoem site, where stone terraces significantly reduced total runoff to 1.2 L/m^2 and contour ridges significantly reduced runoff to 1.6 L/m^2. However, at the BaniNoem site higher sedimentation was measured in the stone terraces (25.7 g/m^2) and contour ridges (12.9 g/m^2) than in the control ($p \leq 0.05$) (Fig. 3).

At the Dura site, data showed that jessour stone terraces constructed in the middle of the wadi had total runoff of

Table 2 Average soil properties in semi-circle, stone terraces, and control (natural vegetation) at the Sorif site in 2005

Treatments	Soil texture					Bulk[a] Density	O.M[*] %	EC[a] (dsm^{-1})	pH[a] (1:2.5)	NH_4^+ (ppm)[a]	NO_3^- (ppm)[a]	P (ppm)[a]
	Coarse sand%	Fine sand %	Silt %	Clay %	Texture class							
Natural vegetation	2.5	29.9	27. 9	38.7	Clay loam	1.38a	5.17a	0.40b	7.02a	6.6a	1.1a	8.1a
Semi-circle	8.5	19.7	26.3	47.1	Clay	1.33a	5.19a	0.45a	7.13a	8.2a	1.7 a	10.1a
Stone terraces	25.5	16.7	23.8	34.2	Clay loam	1.41a	4.38a	0.40b	7.13a	7.2a	1.9 a	8.6a

[a] Means followed by the same letter in the same column are not significantly different according to Fisher LSD test at $P \leq 0.05$

Table 3 Average soil properties in stone terraces, contour ridges, and control (natural vegetation) at the BaniNoem site in 2005

Treatments	Soil texture					Bulk[a] Density	O.M[a] %	EC[a] (dsm^{-1})	pH[a] (1:2.5)	NH_4^+ (ppm)[a]	NO_3^- (ppm)[a]	P (ppm)[a]
	Coarse sand%	Fine sand %	Silt %	Clay %	Texture class							
Natural south	6.1	38.2	30.7	25.9	Loam	1.30b	2.42a	0.27a	7.55a	3.8a	0.5b	4.6b
Stone terraces	6.6	27.8	33.2	30.2	Clay loam	1.55a	2.20a	0.28a	7.56a	4.1a	2.9a	7.1a
Contour ridges	4.0	40.4	33.2	22.3	Loam	1.38b	2.05a	0.26a	7.58a	3.6a	0.6b	3.9b

Means followed by the same letter in the same column are not significantly different according to Fisher LSD test at $P \leq 0.05$

Table 4 Average soil properties in stone terraces, jessour stone system and control (natural vegetation) at the Dura site in 2005

Treatments	Soil texture					Bulk Density[a]	O.M %[a]	EC (dsm^{-1})[a]	pH (1:2.5)[a]	NH_4^+ (ppm)[a]	NO_3^- (ppm)[a]	P (ppm)[a]
	Coarse sand%	Fine sand %	Silt %	Clay %	Texture class							
Natural vegetation	15.6	28.1	31.7	25.8	Loam	1.31b	3.88a	0.32a	7.54a	4.1a	1.6b	7.4a
Stone terraces	11.8	32.5	30.3	28.9	Loam	1.27b	2.86b	0.33a	7.50a	5.0a	2.7ab	8.5a
Jessour stone system	3.8	30.9	28.3	34.5	Clay loam	1.61a	2.09c	0.26b	7.57a	3.4a	3.0a	8.7a

Means followed by the same letter in the same column are not significantly different according to Fisher LSD test at $P \leq 0.05$

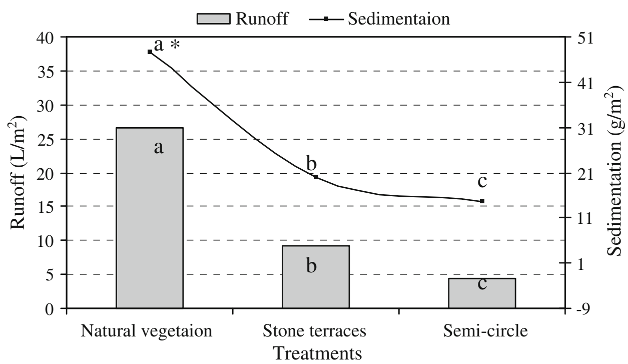

Fig. 2 Total amount of runoff (L/m^2) and sedimentation (g/m^2) in WHT at the Sorif site; *means with the same letters within each variable (runoff, sedimentation) are not significantly different according to Fisher LSD test at $P \leq 0.05$

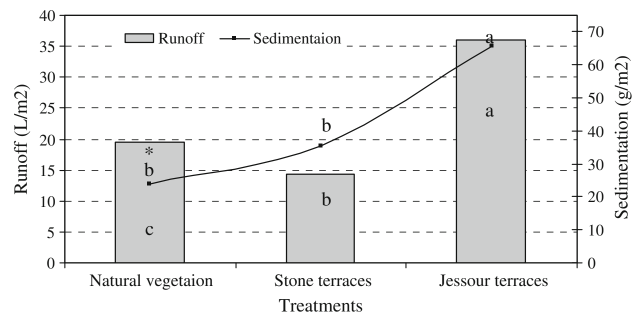

Fig. 4 Total amount of runoff (L/m^2) and sedimentation (g/m^2) in WHT at Dura site; *means with the same letters within each variable (runoff, sedimentation) are not significantly different according to Fisher LSD test at $P \leq 0.05$

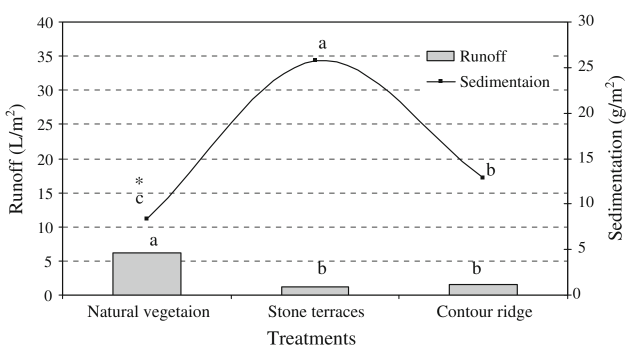

Fig. 3 Total amount of runoff (L/m^2) and sedimentation (g/m^2) in WHT at the BaniNoem site; *means with the same letters within each variable (runoff, sedimentation) are not significantly different according to Fisher LSD test at $P \leq 0.05$

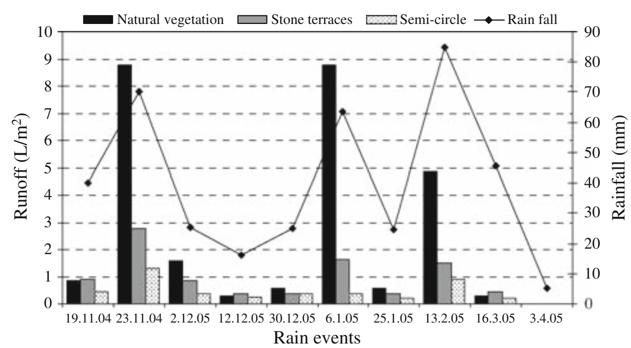

Fig. 5 Distribution of daily rainfall (mm) and runoff (L/m^2) in each rain event at the Sorif site

36.1 L/m^2, which is significantly higher than the 19.6 L/m^2 measured in the control (natural vegetation). In addition, stone terraces in the slope area reduced the runoff to 14.4 L/m^2 (Fig. 4). Moreover, at 64.6 g/m^2 the accumulated sedimentation measured at the wadi (jessour stone terraces system) was significantly higher than the 23.7 g/m^2 measured at the control (natural vegetation) and 35.5 g/m^2 measured at the stone terraces of the slope area (Fig. 4).

During the experimental period, there were ten main rainfall events recorded at the three sites (Figs. 5, 6, and 7). Annual rainfall was 400, 370, and 210 mm at Sorif, Dura and BaniNoem, respectively. The data show that the first main rainfall event was on 19-November and the last was on 3-April of 2005. The amount of surface runoff during each rain event varied between the control and water harvesting structures at the three study sites. At the Sorif and BaniNoem sites, WHT reduced runoff efficiently, compared to the control (Figs. 5 and 7), while the runoff in the jessour system was higher than with other treatments during most of the rainfall events (Fig. 8).

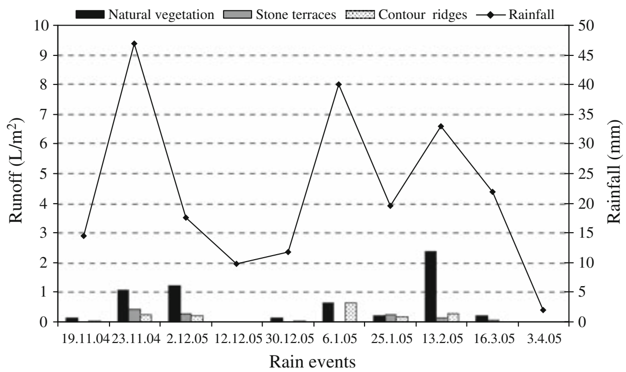

Fig. 6 Distribution of daily rainfall (mm) and runoff (L/m^2) in each rain event at the BaniNoem site

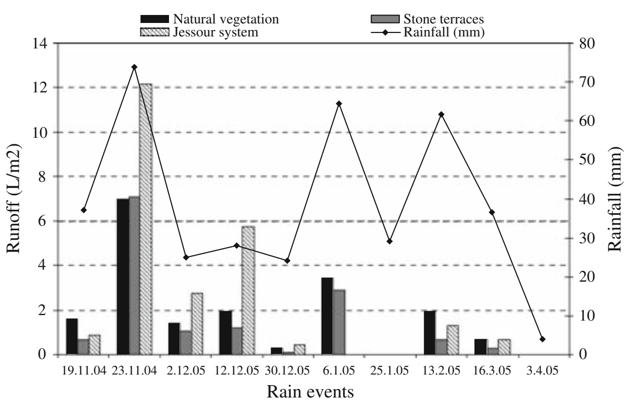

Fig. 7 Distribution of daily rainfall (mm) and runoff (L/m^2) in each rain event at the Dura site

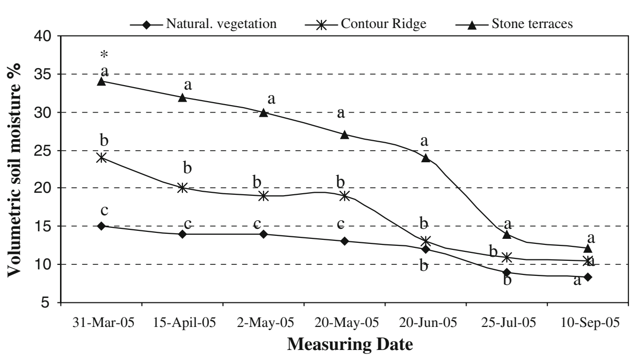

Fig. 8 Temporal change in soil moisture content during the measurements of 2005 in the BaniNoem site at 30 cm soil depth; *means with the same letters for each measuring date are not significantly different according to Fisher LSD test at $P \leq 0.05$

Soil Moisture

Soil moisture exhibited different values under WHT during the study year. Results represented in Fig. 8 show that soil moisture content was significantly higher ($p \leq 0.001$) in the stone terraces and contour ridges than in the control from 31-March to 20-May at 30 cm soil depths. However, stone terraces had significantly more soil water content compared to contour ridges during that period. Soil moisture decreased from 28% to 14% in stone terraces and from 19.5% to 11% in contour ridges from 20-May to 25-July. After the 25-July, the soil moisture was constant and stone terraces had significantly higher soil moisture than other treatments.

Results of the soil moisture content at the Dura site showed that the jessour stone terraces in the wadi had the highest soil moisture content on almost all measurement dates (Fig. 9). Although our results showed that there is a trend of temporal decrease in soil moisture during the periodic measurement dates, the jessour system had high moisture even during the summer months.

The results of soil moisture content measurement at the Sorif site showed that the water harvesting structures, of stone terraces and semi-circle significantly increased the moisture content from that of the control during the first month of the rainy season. The differences between the treatments were small and not significantly different from 20-May to 10-Sept (Fig. 10).

Discussion

Soil Properties

Almost all soil chemical properties that have been taken into consideration in this research exhibit small differences between the treatments. However, The soil has a heavy, fine texture and is classified as clay loam soil in the Sorif site, whereas in both the Dura and BaniNoem sites the loam soil has a light or medium texture according to Kim and Tan (1995) classification. The soil and water conservation practices positively increased the soil nutrients. According to Marx and others (1999), the available

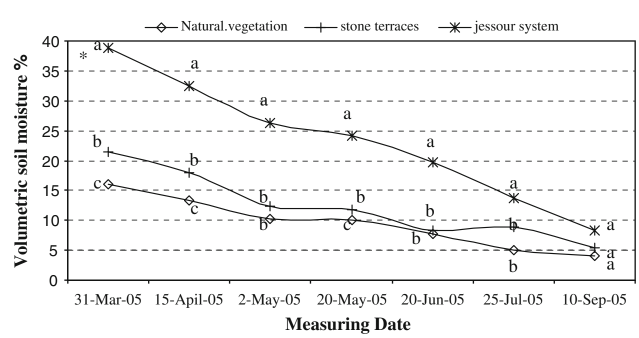

Fig. 9 Temporal change in soil moisture content during the measurements of 2005 in the Dura site at 30 cm soil depth; *means with the same letters for each measuring date are not significantly different according to Fisher LSD test at $P \leq 0.05$

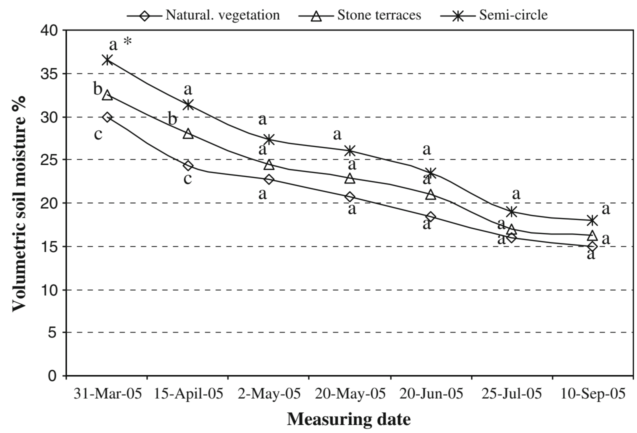

Fig. 10 Temporal change in soil moisture content during the measurements of 2005 in the Sorif site at 30 cm soil depth; *means with the same letters for each measuring date are not significantly different according to Fisher LSD test at $P \leq 0.05$

nitrogen (NH^{4+} and NO_3) and phosphorous were very low in all treatments at the three study sites. Such changes are very small and probably need more years to reveal the actual effects on soil. Natural vegetation had more organic matter than other treatments, which might be due to the construction of the water harvesting structures and the soil disturbance that removed most of the plant residue. On the contrary, in the central mountains of the West Bank, stone terraces increased the amount of soil organic matter, Mg, Ca and K (Abu Hammad and others 2006). Kumwenda (1999) and Holechek and others (1989) reported that in dry land the effect of soil and water conservation management takes a long time to be appreciated. High bulk density in jessour stone terraces at the Dura site (1.61 g/cm^3) (Table 4) and in stone terraces at the BainNoem site (1.55 g/cm^3) (Table 3) is probably due to the disturbance caused by the construction of these terraces and the history of land use at these sites.

Runoff and Sedimentation

The amount of runoff and sedimentation generated was mainly affected and controlled by the interaction between different factors that include surface conditions, the amount of rainfall and soil properties.

The results represented in Figs. 2 and 3 show that the water and soil conservation practices, such as stone terraces, semi-circle bunds and contour ridges, significantly reduced the amount of surface runoff at the BaniNoem and Sorif sites. Similar trends were observed by Al-kharabsheh (2004). Terracing and contour ridges caused an increase in infiltration rate which might be due to water having more time to infiltrate. Schiettecatte and others (2005), in a study under similar conditions and environment, observed that WHT decreased the amount of runoff since it gave more time for water to infiltrate into the soil. In addition, in a study in the central mountains of the West Bank, Abu Hammad (2004) concluded that the average surface runoff was two times higher for the non-terraced plots than for the terraced plots and that sedimentation was 4.5 times higher in non-terraced than in terraced systems.

At the Dura site the picture was reversed for jessour stone terraces in the wadi, which had significantly higher runoff (36.1 L/m^2) and sedimentation (64.6 g/m^2) than the control. These results are probably due to the very large amount of surface runoff from around the steep slopes that are concentrated behind these jessours. The results may also be due to the formation of surface sealing with a low amount of OM% and high clay and bulk density (1.61 g/m^3) (Table 3) that led to a decrease in the infiltration rate and increased surface runoff. Schiettecatte and others (2005), in a study in a semi-arid area in Tunisia under similar conditions, found that large amounts of runoff and sedimentation were collected by the terrace jessour system.

These results represent one season of study under such conditions and provide primary results on the impact of water and soil conservation on soil erosion and runoff. The amount of runoff and sedimentation are influenced and controlled by the interaction of different factors that include the rainfall characteristics, vegetation cover type and percentage, land use and soil conditions (Al-Kharabsheh 2004; Bochet and others 1998; Casermeeiro and others 2004; Andreu and others 1995).

The relationships between monthly values of rainfall and runoff (Figs. 5, 6, and 7) showed. According to Yair and Kossovesky (2002) the Mediterranean climate is characterized by a high year-to-year variability in runoff. This variability is mainly related to vegetation cover and type, soil characteristics and rainfall characteristics (intensity and amount). Rainfall distribution is another factor that plays an important role in such variability. The average intervals between the main rainfall events range from three to 18 days for short and long time intervals, respectively. These periods affect the amount of deep percolation and soil evaporation, which depend on environmental conditions and soil characteristics.

Soil Moisture

Soil moisture is the most important component of the hydrological cycle, particularly in arid and semi-arid areas where rainfall is infrequent and the evaporation rate is high. It has an important role in plant growth, both for rangeland plants and cultivated crops. Soil moisture has an equally important role in influencing the susceptibility of soils to degradation processes, particularly wind and water erosion, and physical degradation. Temporal changes and variability of soil moisture are affected and controlled by topography, soil types, vegetation, land use and management practices (Fu and others 2003; Salve and Allen-Diaz 2001; Al-Kharabsheh 2004; Kutiel and Lavee 1999; Sarah 2002).

Conservation practices such as stone terraces, semi-circle bunds and contour ridges significantly increased soil moisture content, mainly at the BaniNoem (arid climate) and Dura (semi-arid climate) sites (Figs. 8 and 9). Surface soil management reduced the surface runoff which had led to an increase in infiltration and consequently increased soil moisture stored in the soil profile. A similar result was observed by other researchers (Al-Kharabsheh 2004; Mugabe 2004; Brunori and others 1995; Youssef 1998; Al-Ali 1998; Querejeta and others 2000; Li and others 2000; Droppelmann and Berliner 2003; Abu-Zerig and others 2000), who found that water and soil management practices, such as stone terraces, ridges and furrows, significantly increased soil moisture storage over that in untreated areas. In addition, the results of surface runoff in these treatments indicate high moisture storage, since there was a low amount of runoff in stone terraces, semi-circle bunds and contour ridges at the Sorif and BinNoem sites. This means infiltration rate increased and surface runoff decreased. Infiltration and runoff are deeply related, since water that does not infiltrate into soil surface is either evaporated or flows as surface runoff, causing soil erosion (Bradford and others 1987; Remely and Bradford 1989).

The small difference between the water harvesting techniques and the control at the Sorif site, compared to this difference at the Dura and BaniNaoem sites, might be due to the high amount of precipitation (400 mm). In addition, the Sorif site belongs to a Mediterranean climate, which has a low amount of evapotranspiration compared to the BaniNoem and Dura sites. Al-Seekh and others (2009) observed significantly ($p < 0.05$) higher soil moisture content at the Sorif site (23% and 33%) than at the BaniNoem site (10% and 23%) in April of 2004 and 2005, respectively. Furthermore, organic matter and clay were higher in all treatments at the Sorif site (Table 2) than at Dura (Table 3) and BaniNoem (Table 4). Soil moisture increased as clay content (Salve and Allen-Diaz 2001) and organic matter increased (Sarah 2002; Casermeeiro and others 2004; Fu and others 2004, 2003). The factors mentioned above might be the reason for small differences in soil moisture between the water harvesting techniques and the control (natural vegetation) at the Sorif site.

Our results show that soil moisture greatly decreased in the first 15 days after the last rain event. Although it was not significant, water harvesting structures had higher soil moisture than the control during the summer season. This difference was greater in arid and semi-arid areas than in the humid area. Therefore, more attention should be paid to choosing the appropriate time for supplemental irrigation and to management issues such as crop harvesting and the type and varieties of trees to be planted in such regions.

Conclusion

The study demonstrates the usefulness of land management by water harvesting techniques in reducing the amount of runoff and sedimentation and in enhancing soil moisture storage in arid and semi-arid regions. Although stone terraces were found to be effective in increasing soil moisture storage and can be considered an effective practice in soil and water conservation, choosing a particular technique will also be influenced by other factors such as climate, land use and topography.

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References

Abu Hammad A (2004) Soil erosion and soil moisture conservation under old terracing system in the Palestinian Central Mountains. Ph.D Thesis, Agricultural University of Norway, Norway

Abu Hammad A, Borresen T, Haugen LE (2006) Effect of rain characteristics and terracing on runoff and erosion under the Mediterranean. Soil Tillage Research 87:39–47

Abu-Zerig M, Attom M, Hamasha N (2000) Rainfall harvesting using sand diches in Jordan. Agriculture Water Managements 46:183–192

Al-Ali M (1998) Some soil physical properties and soil moisture content relationships, under different soil surface management practices, using diamond shape water harvesting techniques in Jordan. M.Sc theses, University of Jordan, Amman

Al-Jubeh O (2006) Studies of natural vegetation characteristics at different environment and range improvement practices at southern West Bank. M.Sc thesis, Hebron University

Al-Kharabsheh A (2004) Effect of rainfall and soil surface management on soil water budget and erosion in arid areas. M.Sc. thesis, University of Jordan, Amman

Al-Seekh S, Mohammad A (2008) Evaluation of two hydrological processes and soil characteristics under different climatic conditions at West Bank, Palestine. Dirasat 35(2):1026–3764

Al-Seekh S, Mohammad A, Amrou Y (2009). The effect of excluding grazing from Rangeland on soil properties and soil moisture content. Hebron University Research Journal 4(1) (in press)

Andreu V, Rubio LL, Cerni R (1995) Effect of Mediterranean shrub on water erosion control. Environmental Monitoring and Assessment 37:5–15

Awadallah W, Owaiwi M (2005) Spring and dung well of Hebron district. Palestinian Hydrology Group (PHG)

Bochet E, Rubio JL, Poesn J (1998) Relative efficiency of three representative matorral species in reducing water erosion at the microscal in a semi-arid climate (Valencia, Spain). Geomorphology 23:139–150

Bouwer H (1986) Methods of soil analysis part 1–physical and minerlogical methods. American Society of Agronomy, Inc., Madison, Wisconsin, p 844

Bradford JM, Ferris JE, Remley PA (1987) Interill soil erosion processes. 1. Effect of surface sealing on infiltration, runoff, and soil splash detachment. Soil Sciences Society of American Journal 51:1566–1571

Brunori A, Nair PK, Rockwood DL (1995) Performance of two Eucalyptus species at different slope positions and aspects in a contour-ridge planting system in the Negev Desert of Israel. Forest Ecology Management 75:41–48

Casermeeiro MA, Molina JA, Cravaca MT, Costa J, Massanet MI, Moreno PS (2004) Influence of scrubs on runoff and sediment loss in soils of Mediterranean climate. Catena 57:91–107

Critchley W, siegert K (1991) Water harvesting: A manual for the design and construction of water harvesting schemes for plant production. FAO, Rome

Droppelmann K, Berliner P (2003) Runoff agroforestry-a technique to secure the livelihood of pastoralists in the Middle East. Journal of Arid Environments 54:571–577

FAO (1980) Soil and plant testing as a basis of fertilizer recommendations. FAO, Rome, p.78

Fu B, Wang J, Chen L, Qiu Y (2003) The effect of land use on soil moisture variation in Danagou catchment of the Loess Plateau, China. Catena 54:197–213

Fu B, Liu S, Chen L, Yi-He Lu, Qiu Y (2004) Soil quality regime in relation to land cover and slope position across a highly modified slope landscape. Ecology Research 19:11–118

Geographic Information System Unit (GIS) (2006) Hebron University. Data base

Gupta GN (1995) Rain water management for tree planting in Indian Desert. Journal of Arid Environments 31:219–235

Holechek J, pieper R, Herbel C (1989) Range management principles and practices, 2nd edn. Prentice Hall, Englweood Cliffs, New Jersy

Kim H, Tan (1995) Soil sampling, preoeration and analysis. Marcel Dekker, Inc. Madison Avenue, New York, p 90

Kumwenda W (1999) The role of animal traction in soil and water conservation tillage practices among smallholder farmers in Malawi. In: Kaumbutho PG, Simalenga TE (eds). Conservation tillage with animal traction. A resource book of animal traction. Harare, Zimbabwe. (www.fao.org/ag/ags/agse/agse_s/)

Kutiel P, Lavee H (1999) Effect of slope aspect on soil and vegetation properties along an aridity transect. Israel Journal of Plant Science 47:169–178

Li X, Gong J (2002) Effect of different ridge: furrow ratios and supplemental irrigation on crop production in ridge and furrow rainfall harvesting system with mulches. Agriculture Water Managements 54:243–254

Li X, Gong J, Wei X (2000) In situ rainwater harvesting and gravel mulch combination for corn production in the dry semi-arid region of China. Journal of Arid Environments 46:371–382

Marx ES, Hart J, Stevens RG (1999) Soil test interpretation guide. Oregon State University, Oregon

Mohammad A (2008) Growth and Development of Range Plants at Southern West Bank. Hebron University Research Journal 3: 1–21

Mohammad A (2005) Rangeland condition at southern West Bank. Hebron University Research Journal 2:42–54

Mugabe FT (2004) Evaluation of the benefites of infilitrtaion pits on soil Moisture in Semi-arid Zimbabwe. Journal of Agrinomy 3:188–190

Nelson DW, Sommers LE (1982) Total carbon, and organic matter. In: Page AL, Miller RH, Keeny DR (eds) Methods of soil analysis part 2- chemical and microbiological properties. American Socity of Agronomy, Inc. Madison, Wisconsin, pp. 539–580

Olsen SR, Sommers LE (1982) Methods of soil analysis. Part 2. Agron. Monogr. 9, 2nd edn. ASA and SSSA, Madison, WI, pp 403–430

Oweis T, Hachum A, Kijne J (1999) Water harvesting and supplementary irrigation for improved water use efficiency in dry areas. SWIM paper 7. International Water Management Institute, Colombo, Sri Lanka

Palestinian Water Authority (2003) Water resources in Palestine (In Arabic). Rammala, Palestine

Prinz D, Pereria L, Feddes RA, Gilleym JR, Lessaffre B (1996) Water harvesting past and future. University of Karlsruhe, Institute of Hydraulic Structures and Rural Engineering, D-76128 Karlsruhe, Germany. Proceedings of the NATO advanced research workshop. Vimeiro, Portugal, 137–168

Querejeta JI, Roldan A, Albaladejo J, Castillo V (2000) Soil physical properties and moisture content affected by site preparation in the a forestation of a semiarid rangeland. Soil Sciences Society of American Journal 64:2087–2096

Reij C, Mulder P, Begeman L (1988). Water harvesting for plant production. World Bank Technical paper 91. World Bank, Washington, 123 p

Remely PA, Bradford JM (1989) Relationship of soils curst morphology to interrill erosion parameters. Soil Sciences Society of American Journal 53:1215–1221

Retrenberg, Whittles CA (1947) The soil of Palestine. Thomas Murby Co, London, UK

Salve R, Allen-Diaz B (2001) Variation in soil moisture content in rangeland catchment. Journal of Range Management 54:44–51

Sarah P (2002) Special pattern of soil moisture as affected by shrubs, in different climatic conditions. Environmental Monitoring and Assessment 73:237–251

Schiettecatte W, Ouessar M, Gabriels D, Tanghe S, Heirman S, Abdelli F (2005) Impact of water harvesting techniques on soil and water conservation: a case study on a micro catchment in southeastern Tunisia. Journal of Arid Environment 61:267–313

Skoog D, West DM (1976).Fundamental of analytical chemistry. Saunders College Publishing, Philadelphia, p 390

Thomas GW (1982) Exchangeable cations. In: Page AL, et al. (eds) Methods of soil analysis, Part 2 (2nd edn), pp 159–166. Agronomy Monograph 9. ASA and SSSA, Madison, WI, 1159 p

Xiao-yan L, Xie Z, Yan X (2004) Runoff characteristics of artificial materials for rainwater harvesting in the semiarid regions of China. Agriculture Water Management 65:211–224

Yair A, Kossovesky A (2002) Climatic and surface properties:hydrological response of small arid and semi-arid watersheds. Geomorphology 42:43–57

Youssef K (1998) Evaluation of different water harvesting techiques at two different sites of Jordan. M.Sc thesis, University of Jordan, Amman

Zohary M (1947) A vegetation map of western Palestine. Journal of Ecology 43:1–19