Chapter 2

Effect of water harvesting techniques on water productivity and soil erosion

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M. Mudabber, T. Oweis, M. Suifan, N. Shawahneh, Y. Sattar, F. Ziadat, A. Bruggeman and M. Karrou

2.1 Introduction

The Jordan Badia is representative of the vast drier environments of the West Asia and North Africa (WANA) region. Pasture rangeland covers the majority of the Badia, although the vegetative cover is not dense. The vegetation in the Badia includes shrubs and short grasses. Barley is the main field crop in dryland farming, although irrigated forage, vegetables, and fruit orchards are also found in the *Badia*. Most of Jordan's livestock (70%) is produced in the *Badia* (Oweis et al., 2006).

Rainfall water is the most important natural resource limiting land productivity of the Badia. Water harvesting techniques (WHTs) are an important land management practice that can improve water availability for plants by concentrating runoff water from unplanted areas into targeted planted areas – known as on-farm water harvesting (WH). WHTs can improve soil structure and decrease soil erosion rates by intercepting runoff water at relatively short-distance intervals; however, this requires proper design and implementation of the WHTs. WH can also reduce the impact of drought, which is a frequent consequence of rainfall variability in the Badia. WH, if integrated within production systems, in addition to other helpful management techniques, can play an important role in the efficient use of rainwater. Implementation of WHTs will automatically imply no frequent plowing of the land, and thus no more destruction to soil structure, no reduction of soil organic matter, and improvement of soil water holding capacity.

Many WHTs have been successfully tested over many years, including small-scale WH with contour furrows and microcatchments of different shapes and sizes (Hatten and Taimeh, 2001). Drought tolerant forage shrubs (most commonly *Atriplex* spp) have been successfully tested under these water-harvesting systems.

Microcatchment WH is recognized as a useful technique in improving vegetation and reducing land degradation. However, its performance in improved water productivity has not been widely quantified.

The objectives of the research were as follows:

- Assess the effect of different WHTs on runoff and soil erosion under field conditions
- Evaluate the water productivity of the implemented WHTs

2.2 Background

The term 'Badia' historically refers to the region where Bedouins live. The annual rainfall of the Badia is 50–150mm (Figure 2.1). The Badia represents the drier environment of WANA, and is considered home for a substantial proportion of the region's rural population. Sheep are an integral part of the Bedouins' life, representing a source of food and clothing, and a symbol of wealth and pride.

The Badia encompasses a wide and significant part of the Hashemite Kingdom of Jordan. It covers approximately 72,600 km^2, or 81% of the total country area. The Jordanian Badia is sub-divided into three

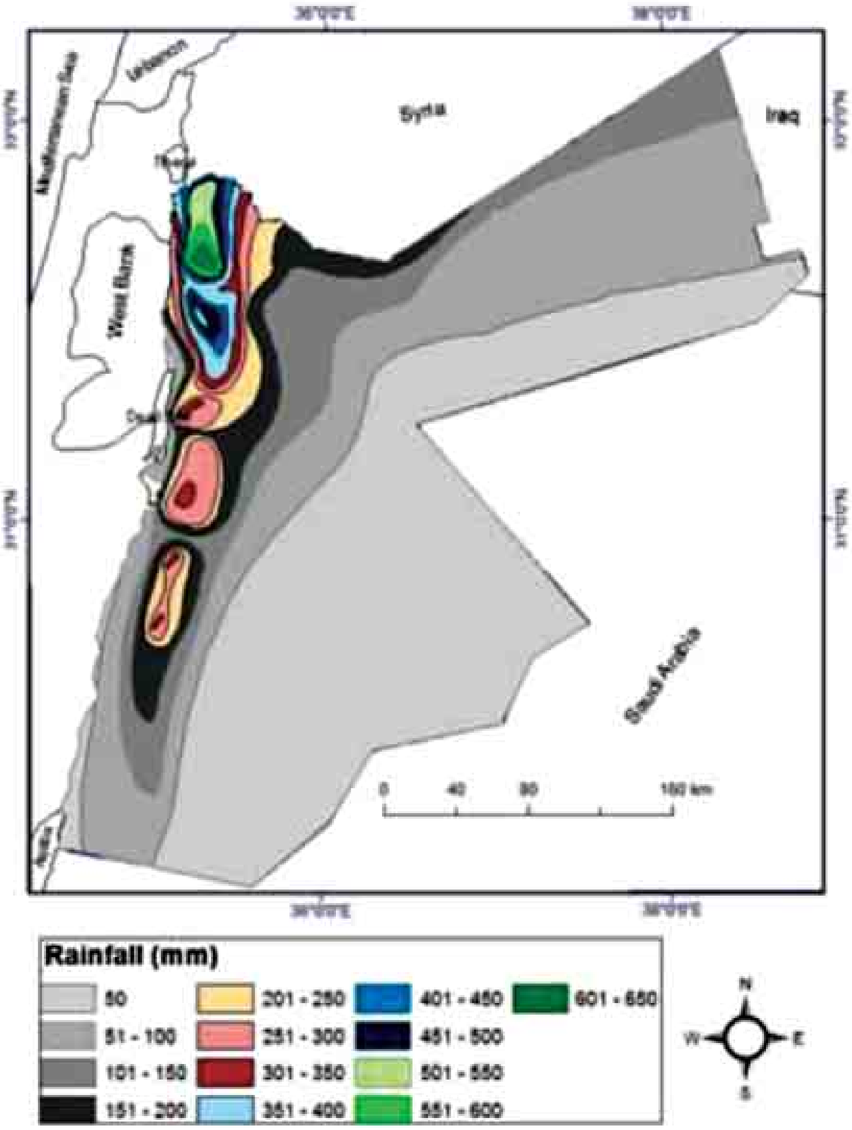

Figure 2.1. Annual rainfall of the Badia.

geographical areas (Allison et al., 1998): Northern Badia with an area of 25 900 km^2 (about 35% of the Badia total area); Middle Badia with an area of 9600 km^2 (about 13%); Southern Badia with an area of 37,100 km^2 (about 51%).

Grazing in the Badia used to be sustainable. Modern socioeconomic changes gradually turned grazing into overgrazing and, among other outcomes, causing deterioration and degradation of traditional rangelands. Nevertheless, as rangelands gradually degraded, the number of herds grew constantly. Over-cutting of shrubs further exacerbated the degradation problem, exposing soil to the danger of water and wind soil erosion. Furthermore, the use of agricultural machinery and the introduction of new and environmentally unsuitable crops at the expense of the natural rangelands, destroyed soil structure and accelerated degradation processes (Allison et al., 1998; Oweis et al., 2006).

How is it that the Bedouins were able to live in the Badia for thousands of years? The nomadic Bedouins inherited the means to coexist with steppes and the Badia, and throughout history have established socioeconomic systems compatible with the surrounding environmental ecosystems, water, and rangelands. Human communities were nomadic and semi-nomadic, searching for water and pasture. This lifestyle induced a set of values and laws and formed an environment-friendly system based on the principles of sustainability and self-sufficiency. Generally, where people in arid lands are truly dependent on their environment for life, they tend to treat it with great respect. Communities evolve a deep and practical sense of responsibility for the environment, based on an awareness of their long-term self interest. Local custom and law ensures, for example, that pastures are not overgrazed, trees are not cut, and sources of water are not fouled (Dutton, 1998).

Today, although some Bedouins retain their traditional lifestyle of full mobility with their sheep and goats, most are only mobile for parts of the year, or have adopted a fully settled way of life and are dependent on grain-based concentrates for their herds during much of the year. The nomadic grazing system is beginning to diminish due to trucking and mobilization of feed and water. There is a shift in the livestock production towards semi-intensive systems. Recently, feed prices increased rapidly and had a negative impact on livestock production. In addition, native pastures can no longer satisfy the livestock feed requirements, and supplemental feeding with barley grain, straw, bran, and other crop by-products has become essential. Attempts to meet the widening 'feed gap' have led to an expansion of the area planted to barley, achieved by cultivating previously uncultivated marginal land and by replacing the traditional barley–fallow rotations with continuous barley cropping.

Importantly, the growing power of urban communities has increasingly impinged upon both the local Badia communities and the Badia physical environment. Ideas and technologies in the urban centers have created new demands for arid land resources, or generated new services and products that have become integrated into the lifestyle of the population of arid areas, thus altering their relationship to the Badia. This has encouraged a desire for a lifestyle that cannot be supported by the Badia physical environment. Of the Jordanian Badia population, > 85% is settled in areas with well-established basic infrastructure such as roads, water, electricity, and telephones. The relative dependence on the Badia has decreased,. Land prices rose sharply in recent years and so people are treating the land differently. This loss of the traditional sense of responsibility has created physical instability, e.g. flash floods, increased soil erosion, and the squandering of already scarce resources (Dutton, 1998).

Over time the natural resources have been subjected to various processes that caused their deterioration, partly as a consequence of natural factors such as drought and climatic variability, and partly due to the demands of an increasing human population. Land degradation is a process that threatens the arid and semi-arid ecosystems, thus displacing people, and degrading biodiversity. The government is increasingly focusing on restoring the productivity of the Badia.

2.3 Materials and methods

2.3.1 Research site selection

The selection of a Badia research watershed followed a three-step procedure whereby selection criteria at each of the steps helped to focus on the most suited site satisfying the study requirements. The approach followed was inter-disciplinary and included discussion meetings and field visits to ensure that the requirements of each discipline were met. The use of GIS tools and analysis was an indispensable part of this process (Ziadat et al., 2006). The watershed selection process was divided into the following components:

- Scoring and weighting of the selection criteria
- Selection of potential watersheds (three stages)
- Rapid rural, hydrological, and environmental appraisals of the most promising watersheds
- Data management and manipulation
  The criteria used in the first selection

stage were: (1) rainfall, (2) presence of communities, (3) soil, (4) watershed area, and (5) topography. The second stage used revised criteria of stage one, together with field visits to screen the selected watersheds. For the final stage selection, the results of a rapid rural appraisal hydrological, and environmental assessments were used together with the outcome of the field visits.

2.3.2 Site description

The selected 60-km^2 watershed is located 65 km southeast of Amman and covers part of the lands of the Mharib and Majidiyah communities (Figure 2.2), with respective populations of 300 and 120 people. The 35-ha research site is located 2–3 km west of Mharib village. Land use is mainly rangeland and barley, and the research site was already planted with barley when selected. The site has an altitude range of 820–846 m and topography comprises a gentle slope (north-eastern), a moderate slope (south-western), and a flood plain and main gully between the two slopes – the slope has a range of 2–30%. Soil texture is silty loam to silty clay loam, with soil depth range of 0.35–1.50 m. The soil is generally poor in structure with moderate permeability, and is friable, fragile, and highly calcareous, forming a thick surface crust when wetted; and highly affected by erosion. The cover of native vegetation is fair especially on the banks of waterways. Plants such as *Poa bulbosa*, *Anabasis syriaca, Haloxylon articulatum* dominate the native vegetation. Barley cultivation has been long practiced. Previously, sheep and goat flocks grazed the cultivated barley and associated native vegetation in a destructive manner.

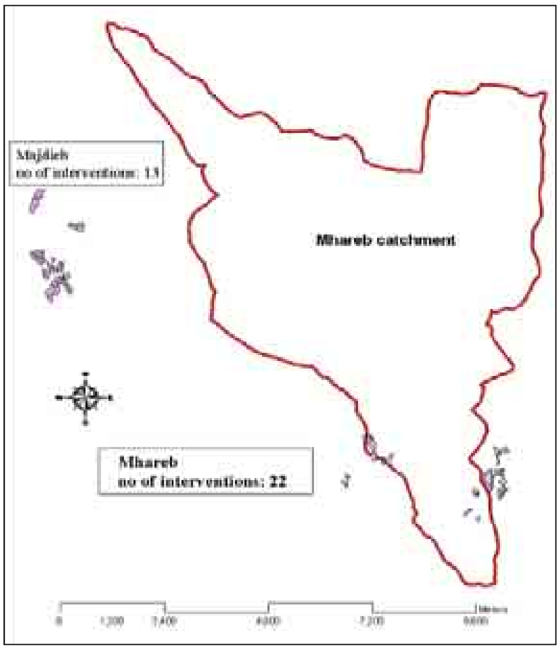

Figure 2.2. Selected watershed with intervention sites at both Mharib and Majidiyah.

Land tenure is 80% private (locally owned), 15% governmental, and 5% private (owned from outside the community). The average size of a holding is 7.5 ha. The average household size is about eight members. Parts of the population are nomads who travel with their flocks a far distance from the community. The average flock size is around 200 heads per holder: 67% of farmers own a small flock and 28% a medium-sized flock, and only 5% own large flocks. However, medium-sized flocks compose > 50% of the total small ruminant number and large flocks about 30%. The grazing period is 2–5 months according to annual precipitation and rangeland situation.

Climate

The Badia falls in an arid climatic zone characterized by a Mediterranean semi-arid to arid climate with a dry summer. Rainfall is erratic both spatially and temporally, with a maximum of 200 mm annually (100–150 mm average annual rainfall). Rainfall distribution is erratic both within and between years. Rainfall frequently occurs in sporadic intense storms thus resulting in surface runoff.

The moisture regime is transitional Xeric–Aridic and the temperature regime is Thermic. Average daily air temperature is 17.5 °C, with a daily mean minimum of 10°C and maximum of 24.5 °C. Occasionally, absolute minimum and maximum air temperatures reach –5 and 46 °C, respectively (Taimeh, 2003).

The evaporation rate is very high, and can exceed rainfall by several fold. As a result, the greater portion of precipitation is lost to the atmosphere by evaporation. Rain mostly falls during December–March with a chance of rain during both November and April.

Soil

The physiography is described as a very finely dissected limestone and chert plateau on Umm Rijam Chert and Muwaqqar Chert and Marl formation, forming a watershed of drainage flowing southwest to Wadi Walla, and north east to Azraq Depression. Rounded hill crests give way downslope to steep, rocky upper slopes of major valleys. Middle and lower slopes are colluvial. Broad valley floors are filled by silty alluvium, and active wadis have gravelly channels often rectangular or V-shaped.

The surface of the soil is moderately hard when dry, often with a root mat of depth 3–10 cm when soil is untilled, which protects the soil surface from wind and water erosion. When the soil surface is tilled the surface has a relatively high cover of stone and gravel, and sometimes cobbles, which is dominant in Mharib village, and is relatively less in Al-Majidyya.

The dominant soil types in the study area are (Dr. Wa'el Sartawi, 2006):

Xerochreptic Camborthids, Loamy, Carbonatic, Thermic, Deep.

The topsoil is a yellowish brown color, with a gravelly fine silty clay loam texture. Structure is strong fine sub-angular blocky, usually with common chert or limestone. Soil reaction with HCl acid is moderate–strong. The subsoil is a strong brown color, with silty clay loam texture and little to common limestone gravel. Structure is moderate medium-fine sub-angular blocky. Some calcium carbonate ($CaCO_3$) concretions can occur throughout the profile, with strong–violent reaction with HCl. There is a slightly saline Cambic horizon within 12–40 cm deep. The soil formed on a slight–moderate alluvial and colluvial slope of < 5%, within limestone materials at a depth > 75 cm. The surface is sometime capped, causing runoff and slight–moderate rill or gully erosion. Surface stone or gravel cover is slight.

Xerochreptic Calciorthids, Fine-silty, Carbonatic, Thermic, Deep.

The topsoil is light yellowish brown to brown in color, with silty loam to silty clay loam texture and silt content > 50%. Structure is moderate medium sub-angular blocky with common limestone and gravels. Soil reaction is strong with HCl. Subsoil is strong brown to brownish yellow, moderate to strong sub-angular blocky, heavy silty loam to silty clay loam. Gravel content is low in the upper subsoil, but chert and limestone fragments can restrict effective root depth to 45 cm. $CaCO_3$ concretions are common and there is a Calcic horizon at 15–50 cm. Soil reaction is strong–violent with HCl. The soil is saline. Soil is formed on gentle–moderate slopes within limestone hill areas of slope 5–10%. The parent material is colluvial limestone, usually with a strong capping due to high silt contents that enhance surface runoff and lead to sheet erosion. The average soil depth is 70 cm.

Xerochreptic Paleaorthids, Shallow, Fine-silty, Carbonatic, Thermic.

The soil is formed on colluvial limestone materials with Aeolian admixture and depth is limited by a petrocalcic layer, with depth < 45 cm. The topsoil is a light yellowish brown color, and of stony silty clay loam texture. Soil structure is moderate–medium fine sub-angular blocky. When the soil is dry, the surface is moderately hard. Surface gravel cover is common; and the soil has a strong reaction with HCl. Subsoil is dark yellowish brown in color, often becoming paler with depth as $CaCO_3$ content increases. Texture is silty clay loam with little to common limestone gravel to boulders. Structure is weak, medium to fine sub-angular blocky, with strong–violent reaction with HCl. Common to many concretions of $CaCO_3$ indicate the petrocalcic layer.

Runoff and soil erosion

Badia soils have high silt and high $CaCO_3$ content, and so have low soil infiltration rates of 4–20 mm/h. The soil surface is often crusted leading to high runoff flows. Runoff coefficients are within the range 0.21–0.36, and under certain topographic conditions > 0.6 following intense thunderstorms.

Soil erodibility is affected by texture, organic matter, and permeability. Soil erosion is relatively highly associated with poor soil structure and high runoff flows over bare or plowed land (no vegetative cover). The surface soil crust further aggravates the situation. Most runoff water flows along concentration paths creating rills and gullies. Annual soil loss over relatively flat terrain is within tolerable soil loss levels. However, in the case of hilly topography where most runoff is inside rills and gullies, soil loss occurs at a much higher rate – exceeding tolerable levels and causing a serious soil erosion problem. Soil loss and degradation of natural vegetative cover result in reduction of soil organic matter content and soil water holding capacity, as well as the deterioration of other soil properties, leading to further land degradation.

2.3.3 Climate stations

An automatic weather station (Photo 2.1) was installed in a fenced area at the middle of Mharib village (31º 40’ 27.1’’ North; 36º 13’ 13.8’’ East; 879 m.a.s.l) on 27 December 2005. A tipping bucket rain gauge had been installed during late 2004. The data loggers of both the weather station and the rain gauge were programmed to log data every 10 min. The weather station faced several technical problems that prevented a continuous logging of data during the first season. Additionally, the wind speed sensor also broke and there was other damage and problems for the station during 2008.

Logged weather parameters included: air temperature, relative humidity, wind speed and direction, solar radiation, and soil temperature at 10 cm depth.

Photo 2.1. Hobo automatic weather station at Mharib site.

Rainfall

Rainfall was measured using a tipping-bucket rain gauge installed in Majidiyah village inside the fence of the farmer house during October 2005. The logging interval was set at 10-min interval. No other weather data was collected at Majidiyah village.

2.3.4 Community meetings and selection of farmer field sites for interventions

The Badia Benchmark Project is a community-based project. The community approach is suitable and directly relevant in natural resource management for water and rangeland resources, which are the main issues addressed by the project. The project team organized several meetings and activities with the two communities, starting from summer 2004. A visit was organized for community members to the University of Jordan Muwaqqar experimental station, located about 10 km from Mharib, to show them the different WH interventions which have been evaluated in similar environments: e.g. storage earth dams, water spreading techniques, and contour ridges for shrub and fruit tree plantations.

Many community members showed interest in participating in the proposed activities. The project team approached farmers who showed interest in project activities and visited their land to determine the suitability for certain activities. Several sites were selected and WH plans were made and implemented in each field.

2.3.5 Characterization of intervention sites

Site characterization was done following the USDA key to Soil Taxonomy (1996) and the FAO guidelines of soil profile description (1977). Soil sampling was done during November 2004, and laboratory analysis included soil texture, pH, EC, organic matter content. Soil core samples were collected for bulk density. Infiltration rate tests were performed for the different sites using the double-ring infiltrometer method. Soil moisture, runoff, and soil erosion were measured only for the experimental site at Mharib.

2.3.6 Collection of data from intervention sites

The shrub biomass data used in this report was only that for the experimental site at Mharib. For the methodology followed and additional information please refer to Chapter 4 of this report.

2.3.7 Experimental sites

Two additional experimental sites in Mharib and Majidiyah were established in October 2005 and November 2006, respectively.

Mharib site

The Mharib site had the following treatments:
Land slope: S1 = 2–8%, S2 = 10–20%
Spacing: 4 and 8 m as follows:

- 1 = 4-m spacing with 8 m^2 per Atriplex shrub (4-m spacing between ridges and two shrubs per 4-m length of ridge).
- 2 = 8-m spacing with 11 m^2 per Atriplex shrub (8-m spacing between ridges and three shrubs per 4-m length of ridge).

Land management:

- Continuous contour ridges (CRVC)
- Intermittent contour ridges (CRVI)
- Without intervention (Control).

Replication: three replicates.
Each treatment contained at least four contour ridges each approximately 100 m long.

The selected site was divided into three parts, forming the three replicates of the experiment. The treatments and intervention levels were distributed within each replicate. Each replicate contained 12 plots (Table 2.1).

Width of furrow: 80 cm
Depth of furrow: 15 cm
Ridge height: 35 cm
Ridge slope length (upstream side): 65 cm.
Ridge slope length (downstream side): 50 cm.
Intermittent ridges: width of furrow with range 50–80 cm.

Table 2.1. Experiment treatment.

Slope (%)	Spacing between contours (m)	Intervention	Number of shrubs per 4-m length along contour
10–20	4	CRVC	2
		CRVI	2
	8	CRVC	3
		CRVI	3
	4	Control	2
	8	Control	3
2–8	4	CRVC	2
		CRVI	2
	8	CRVC	3
		CRVI	3
	4	Control	2
	8	Control	3

Continuous ridges: capacity for runoff = max. 540 L/4-m length
(i.e. 0.8 × 0.168 × 4.0 × 1000)

For CRVC-4 is max. 270 L/shrub

For CRVC-8 is max. 180 L/shrub

Intermittent ridges: capacity for runoff = max. 330 L per 2.8-m length
(2.8 × 0.168 × 0.7)

For CRVI-4 is max. 165 L/shrub

For CRVI-8 is max. 110 L/shrub

Measurements

Fodder Shrub Production

The survival percentage of fodder shrubs was recorded monthly, while fresh production per shrub was estimated using the reference unit technique during May (Andrew et al., 1981). Five shrubs from each replicate were randomly selected and cut to ground level. Weights of browse (leaves and small twigs < 0.5 cm in diameter) and wood were recorded for each shrub – considering that a branch forms about 20% of shrub size, and shrub biomass was estimated according to the reference unit method. The branches were weighed, and the browse parts were separated, weighed, and dried in an oven at 72°C for 72 h and weighed again after drying. Fresh, browse, and dry shrub production were calculated, as was productivity (kg/ha).

Fresh yield (FY): Total shrub biomass (leaves and wood) production above ground level.
Browse yield (BY): Total shrub fresh biomass (including leaves and twigs < 5 mm in diameter) production above ground level.
Dry yield (DY): Total shrub dry matter (including leaves and twigs < 5 mm in diameter) production above ground level.

Soil Moisture

A TDR instrument (model Trime-FM version 2/3 from IMKO Micromoduletechnik Gmbh) was used for easy and direct measurement of volumetric soil moisture. Access tubes were installed in each plot of the field in both the catchment area and the cultivated area. In winter, measurements were taken after each rain event or once weekly. In summer, measurements were taken regularly, at intervals of 3–4 weeks. Different data sets were collected from the site during the 2005/06, 2006/07, and 2007/08 seasons. Fodder production data covers the abovementioned time period; however, data on natural vegetation was taken for the three seasons. Surface land cover percentage was only taken during the 2005/06 season, biomass production for some plots was taken during 2006/07, and biomass production for all plots was taken during 2007/08. In addition, soil moisture as well as runoff and soil erosion data covered only 2005/06 and 2006/07.

Therefore, the reported water productivity results represent only one season and are limited to the biomass produced by *Atriplex.*

Runoff and Soil Erosion

Splash erosion was measured in the field for one season only (2005/06) using Morgan splash cups. The splashed soil material was collected after every heavy storm and weighed. Four splash cups were installed covering the catchment area at the two main slopes, the side of an earth ridge, and a control untilled area. This represented the maximum possible soil erosion caused by detached soil particles due to rain drops, and assumes that all detached soil particles will move with runoff water.

Locations of the splash cups

SP 1: Replicate 2, CRVC-8 at the lower slope on catchment area.
SP 2: Bare soil (control) in the higher slope area.
SP 3: Replicate 2, CRVC-8 on ridge (to test ridge stability and lifetime) at the higher slope.
SP 4: Replicate 2, CRVC-4 at the higher slope on catchment area.

There were 18 runoff plots constructed at the experiment site for measuring both runoff water and eroded soil within implemented interventions. A set of runoff plots (Photo 2.2) replicated twice were used in each of the two slope classes recognized in the site with dimensions of 2 m × 4 m and 2 m × 8 m. An additional set of two runoff plots replicated twice within untreated land were used as controls with dimensions of 2 m × 16 m. Runoff plots representing the intermittent Vallerani ridges (both 4-m and 8-m spaced) were not closed from the upper side. Runoff from each plot was collected using 250-L metal barrels. Runoff volume was measured and a water sample taken after each runoff event from each barrel for measurements of eroded soil.

Photo 2.2. A pair of constructed runoff plots with collection tanks.

Statistical Analysis

The data of the Mharib experimental site were analyzed using the GLM procedures of SAS (2002) system for a split-block arrangement. All factors were included in the analysis, with their possible interactions, that may have affected the studied variables. The independent variables included in the model were slope gradient, WH intervention, and the spacing between rows, whereas, the dependent variables were water productivity of fresh, browse, and dry matter production (FYW, BYW, and DYW, respectively, expressed as kg/m^3).

Majidiyah site

Microcatchments for 17-ha experimental site in Majidiyah.
Thirteen treatments were implemented in the selected sites

- T1: (NV) – native vegetation, land resting with protection.
- T2: (NVCR) – native vegetation under contour ridges.
- T3: (BT50) – traditional cultivation of barley, with seed rate of 50 kg/ha.
- T4: (BT100) – traditional cultivation of barley, with seed rate of 100 kg/ha.
- T5: (BCR50) – barley in modified contour ridges, with seed rate of 50 kg/ha.
- T6: (BCR100) – barley in modified contour ridges, with seed rate of 100 kg/ha.
- T7: (BCS50) – barley (seed rate of 50 kg/ha) in contour strips of 2:1 catchment:cultivated area ratio with a line of Atriplex shrubs (1.5-m spacing) at the downstream end of the strip as a contour mark.
- T8: (BCS100) – barley (seed rate of 100 kg/ha) in contour strips of 2:1 catchment:cultivated area ratio with a line of Atriplex shrubs at the downstream end of the strip as a contour mark.
- T9: (D2L1FS) – fodder shrubs planted in Vallerani pits size 2 with five lines of pits followed by a contour ridge with 800 plants/ha.
- T10: (D2L2FS) – fodder shrubs planted in Vallerani pits size 2 with 10 lines of pits followed by a contour ridge with 800 plants/ha.
- T11: (D4L1FS) – fodder shrubs planted in Vallerani pits size 4 with five lines of pits followed by a contour ridge with 800 plants/ha.
- T12: (D4L2FS) – fodder shrubs planted in Vallerani pits size 4 with 10 lines of pits followed by a contour ridge with 800 plants/ha.
- T13: (FS800) – fodder shrubs under contour ridges with 800 plants/ha.

The spacing between contour lines was 6 m for all treatments, and a plant density of 800 plant/ha for the fodder shrub treatments. Each treatment was implemented on a plot of 120 m × 35 m. The plot configuration was such that the 120-m length was in the direction of the slope. The treatments were arranged to fit a randomized complete block design with three replications.

The experimental layout is described below for one replication as an example:

T2	T7	T4	T11	T9	T12	T6	T10	T8	T13	T1	T5	T3	↓ Slope

2.4 Results and discussion

2.4.1 Climate

There were 34 rainy days in the 2005/06 season, with a total rainfall of 117.82 mm. Although the total rainfall was close to the expected rainfall average, most rain was during December, February, and April (Figure 2.3). The highest rainfall was during April with around 37% of the seasonal rain.

The daily distribution of rainfall (Figure 2.4) clearly showed that the number of rainy days was high during December (24%), January (28%), and February (21%).

The highest rainfall intensities (22.86 and 18.3 mm/h) were recorded on 25 December, with 8.63 mm/h as the highest 60-min continuous intensity. The longest duration of continuous rain (140 min) was also on 25 December and on 2 April.

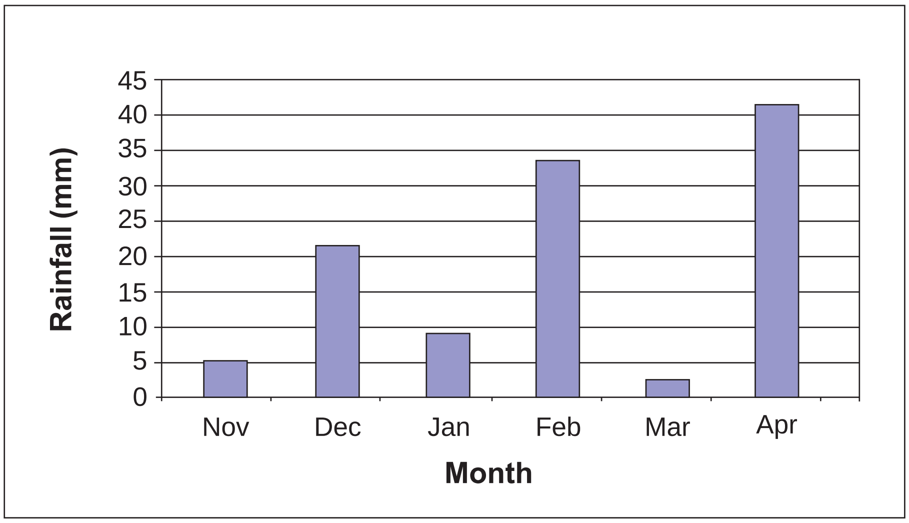

Figure 2.3. The monthly rainfall distribution at Mharib (2005/06 season).

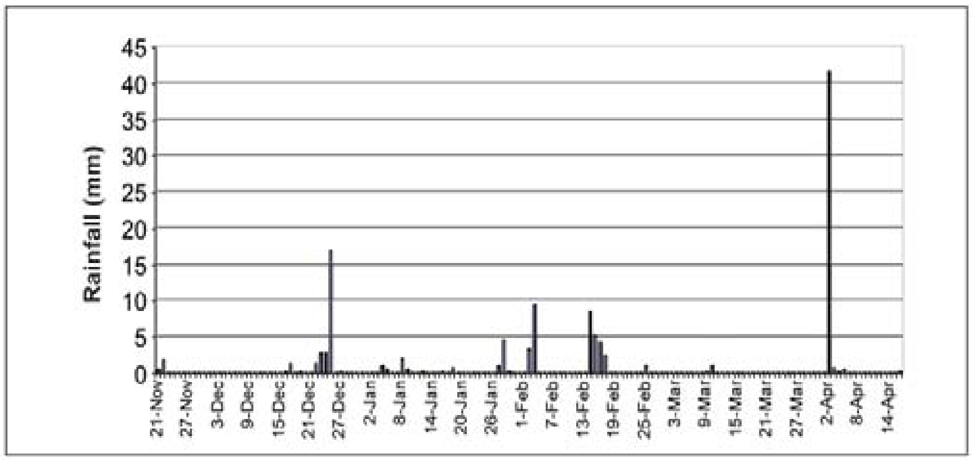

Figure 2.4. Daily rainfall pattern at Mharib (2005/06 season).

During the 2006/07 season, total rainfall was only 111.2 mm, and this was spread over a period of about 6.5 months. The rainfall was concentrated in only three months December, January, and February (Figure 2.5).

There were 38 rainy days, and rainfall distribution and amounts were poor during the season. The rainfall during the season was generally light and poorly distributed with most rainy days concentrated during the period from the end of December until the beginning of March (Figure 2.6). The first two rainy days (one each during October and November 2006) were followed by a very long dry period of 47 d. This long rainless period made the early rainy days ineffective, given that the early rainfall was very light. It is important to consider that the spring rainy days during May were preceded by another relatively long dry period of 25 d. This also decreased the effectiveness of the last four rainy days during May, in addition to the effect of higher air temperatures and low relative humidity during this month (Figure 2.6).

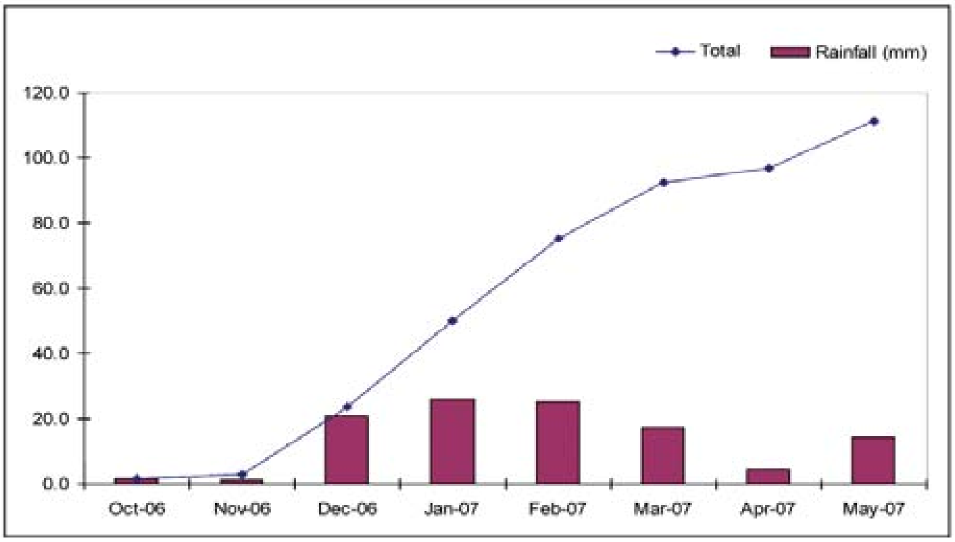

Figure 2.5. Monthly rainfall distribution (in mm) at Mharib (2006/07 season).

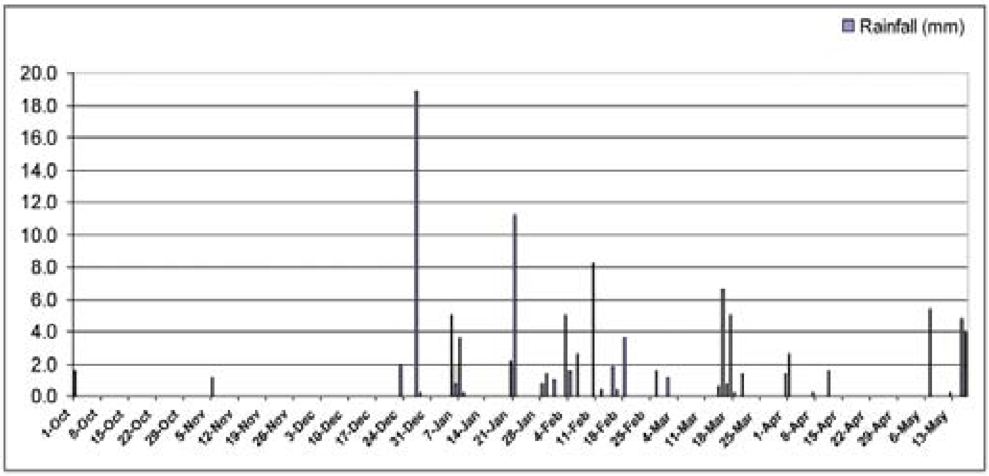

Figure 2.6. Daily rainfall distribution at Mharib (2006/07 season).

The highest daily rainfall amount was 18.8 mm on 27 December 2006 followed by 11.2 mm on 21 January 2007, then by 8.2 mm on 10 February 2007. However, when considering rain events (individual rain storms), there were 37 rain events (rainfall separated by ≥ 6 h). Average rainfall per rain event was only 3.0 mm (standard deviation = 3.8). The highest rain events were 18.8, 13.4, and 8.2 mm on 27 December, 20 January, and 2 February, respectively. The highest storm duration of continuous rain was 170 min on 27 December 2006 with an average rain intensity of 3.5 mm/h, a maximum 20-min rain intensity of 7.8 mm/h, and a maximum 10-min rain intensity of 8.4 mm/h. The following highest storm duration of continuous rain was 150 min on 21 January 2007 with an average intensity of 3.12 mm/h, a maximum 20-min rain intensity of 5.2 mm/h, and a maximum 10-min rain intensity of 6.0 mm/h.

The third-highest rain storm duration of continuous rain was 90 min on 7 May 2007 with an average rain intensity of 3.6 mm/h

and a maximum 10-min rain intensity of 15.6 mm/h. The following highest rainfall storm duration was 80 min on 1 April 2007 with an average rainfall intensity of 2.85 mm/h and a maximum 10-min rain intensity of 9.6 mm/h. Another interesting storm was on 15 May 2007 with continuous rain duration of 30 min and an average rain intensity of 9.6 mm/h, but with a maximum 10-min rain intensity of 16.8 mm/h.
The temperatures at Mharib on a monthly basis for the 2006/07 season are shown in (Figure 2.7).

2.4.2 Establishment and characterization of water-harvesting interventions

(Tables 2.2 and 2.3) show the lsit of implemented WHTs and the interventions conducted in 2005/06 and sites physical properties in Mharib region.

2.4.3 Mharib experimental site

Runoff

In general, during the 2005/06 season and its four runoff events, the slope clearly increased the runoff efficiency for the Vallerani continuous contour ridges compared to intermittent ridges. This was mainly due to: (1) the catchment area for intermittent ridges was higher by default (i.e. spacing between two pits along an intermittent ridge means that the length of the catchment area at that location extends beyond the distance between ridges, compared with continuous ridges where the catchment length is the distance between two ridges) on both the 4-m and 8-m spacing compared to the continuous ridges, and (2) the direction of furrows from the previous barley cultiva-

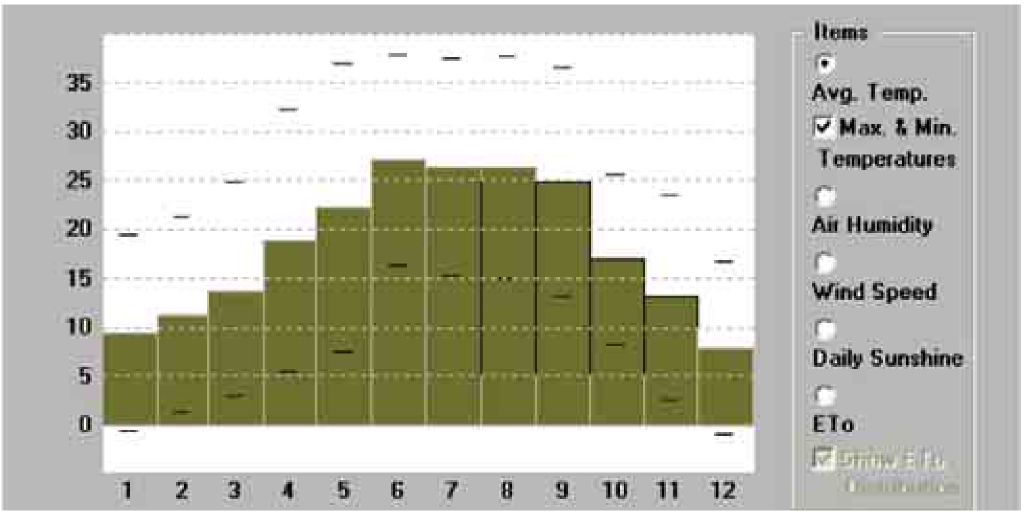

Figure 2.7. Temperature values (average, maximum, and minimum) on a monthly basis for Mharib (2006/07 season).

Table 2.2. List of implemented WHTs.

	Mharib		Al-Majidiyah	
	No. of sites	**ha**	**No. of sites**	**ha**
Contour ridges, shrubs	11 sites	14.0	5 sites	10.4
Contour furrows, barley	2 sites	1.1	5 sites	11.6
Runoff strips, barley	4 sites	4.2	2 sites	9.0
Vallerani bunds, shrubs	5 sites	15.5	1 site	15.6

Table 2.3. Mharib intervention sites conducted during 2005/06 and the sites' physical properties.

Site code	Area (ha)	Site Description	Shrub species	Planting date	slope (CLASS)	slope %	surface crust (CLASS)	soil depth (CLASS)	soil depth (cm)
MH1CRS	0.6	Mhareb, Plot 1,Contour Ridges, Shrubs	Atreplix	Nov, 05	C	7	2	m	47+
MH3CRSa	0.94	Mhareb, Plot 3,Contour Ridges, Shrubs, Sub Site	Atreplix	Nov, 05	C	7	1	d	60+
MH3CRSb	3.61	Mhareb, Plot 3,Contour Ridges, Shrubs, Sub Site	Atreplix	Nov, 05	D	9	2	m	50
MH3CRSc	1.96	Mhareb, Plot 3,Contour Ridges, Shrubs, Sub Site	Atreplix	Nov, 05	E	14	2	sm	45
MH4CRSa	0.49	Mhareb, Plot 4,Contour Ridges, Shrub, Sub Site	Atreplix	Nov, 05	D	12	2	sm	45
MH4CRSb	0.41	Mhareb, Plot 4,Contour Ridges, Shrub, Sub Site	Atreplix	Nov, 05	C	3	2	m	80+
MH6CRSa	0.23	Mhareb, Plot6,Contour Ridges, Shrubs,Sub Site	Atreplix	Nov, 05	C	6	2	m	60+
MH6CRSb	0.33	Mhareb, Plot6,Contour Ridges, Shrubs,Sub Site	Atreplix	Nov, 05	B	5	2	d	40+
MH7CRS	0.13	Mhareb, Plot 7,Contour Ridges, Shrub	Atreplix	Nov, 05	D	10	3	m	42+
MH8CRS	0.33	Mhareb, Plot 8,Contour Ridges, Shrub	Atreplix	Nov, 05	E	10	3	m	50+
MH9CRS	0.18	Mhareb, Plot 9,Contour Ridges, Shrub	Atreplix	Nov, 05	C	14	2	m	60+
MH10CRS	1.24	Mhareb, Plot 10,Contour Ridges, Shrub	Atreplix	Dec, 04	B	9	2	m	65+
MH12VSa	2.08	Mhareb, Plot 12,Vallerani, Shrub, Sub Site	Atreplix	Jan, 06	C	7	2	m	45
MH12VSb	0.61	Mhareb, Plot 12,Vallerani, Shrub, Sub Site	Atreplix	Jan, 06	A	3	2	d	60+

Table 2.3. (Continued).

Site code	Area (ha)	Site Description	Shrub species	Planting date	slope (CLASS)	slope %	surface crust (CLASS)	soil depth (CLASS)	soil depth (cm)
MH13VS	0.61	Mhareb, Plot 13,Vallerani, Shrub, Sub Site	Atreplix	Jan, 06	D	12	2	m	40+
MH14VS	1.73	Mhareb, Plot 14,Vallerani, Shrub, Sub Site	Atreplix	Jan, 06	D	6	2	m	35+
MH17VSa	1.72	Mhareb, Plot 17, Vallerani, Shrub, Sub Site	Salsola ver-miculata L.	Jan, 06	E	11	2	m	50
MH17VSb	1.65	Mhareb, Plot 17, Vallerani, Shrub, Sub Site	Salsola ver-miculata L.	Jan, 06	D	14	3	m	60+
MH17VSc	4.51	Mhareb, Plot 17, Vallerani, Shrub, Sub Site	Salsola ver-miculata L.	Jan, 06	B	5	3	d	55
MH17VSd	0.53	Mhareb, Plot 17, Vallerani, Shrub, Sub Site	Atreplix	Jan, 06	C	7	2	d	50
MH18CRS	1.07	Mhareb, Plot 18,Contour Ridges, Shrubs	Atreplix	Jan, 06	B	9	1	d	45
MH19VSa	0.84	Mhareb, Plot 19, Vallerani, Shrub, Sub Site	Atreplix	Jan, 06	A	5	1	d	50
MH19VSb	0.21	Mhareb, Plot 19, Vallerani, Shrub, Sub Site	Atreplix	Jan, 06	C	8	1	m	45
MH20CRS	0.29	Mhareb, Plot 20, Contour Ridges, Shrub	Salsola ver-miculata L.	Jan, 06	D	11	2	m	55+
MH21CRSa	0.49	Mhareb, Plot 21, Contour Ridges, Shrub,Sub Site	Salsola ver-miculata L.	Jan, 06	B	5	2	d	60+
MH21CRSb	1.17	Mhareb, Plot 21, Contour Ridges, Shrub,Sub Site	Salsola ver-miculata L.	Jan, 06	B	6	2	m	50
MH22VSa	1.01	Mhareb, Plot 22, Vallerani, Shrub,Sub Site	Salsola ver-miculata L.	Jan, 06	C	5	2	m	50
MH22VSb	1.03	Mhareb, Plot 21, Vallerani, Shrub,Sub Site	Salsola ver-miculata L.	Jan, 06	C	3	2	d	60+

Legend:

Slope class	Description
a	Almost flat 0–5%
b	Gently sloping 5–10%
c	Sloping 10–15%
d	Moderate sloping 15–25%
Depth	
d	Deep soil > 1 m
m	Medium soil depth 50–100 cm
sm	Shallow to medium soil depth 30–100 cm
s	Shallow soil depth < 30 cm
Crust	
1	Weak surface crust that is thin and easy to break
2	Moderate crust
3	Strong crust that is thick and hard to break
Stoniness	
0	0–10%
1	10–25%
2	25–50%
3	> 50%

tion which altered the length of the runoff path. Runoff efficiency (Figure 2.8) was higher for the 4-m compared to both the 8-m and the 16-m plots (control). In general runoff efficiency was higher with shorter run distances and higher slopes. However, other interfering factors (e.g. previous cultivation, uncultivated parts, and the direction of cultivation) affected the runoff efficiency in some plots.

The volume of runoff was higher for the low slope treatments, except in the continuous ridge treatments where the opposite occurred for both the 4-m and 8-m spacing (Figure 2.9). Runoff volume was expected to be higher under the higher slope, and higher under the higher spacing. The results for the continuous ridges matched the expectations; however, the intermittent and control plots on both slopes did not – this could be attributed to the conditions in the field regarding mainly the direction of tillage. There may also have been an effect of slope length, since length increases infiltration and so any interception by local depressions might reduce runoff.

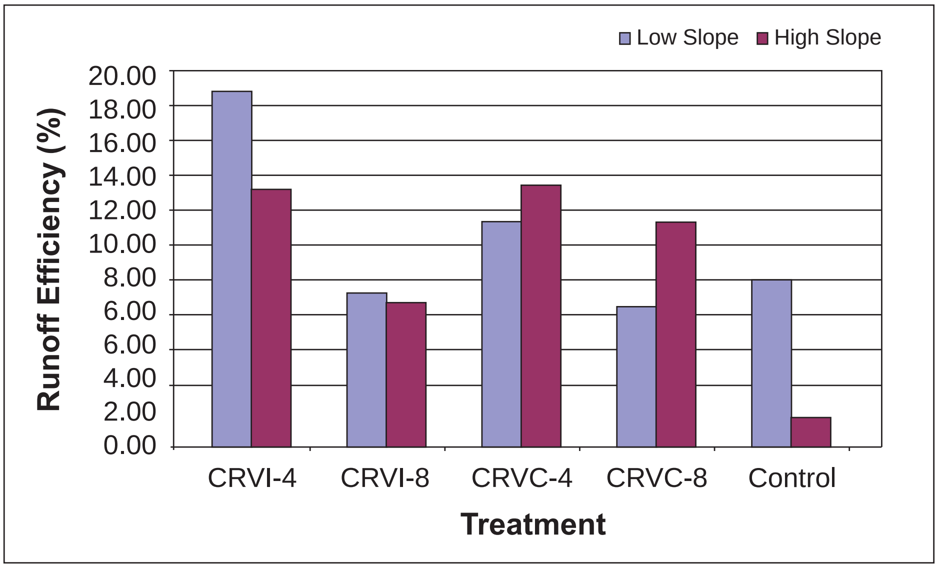

Figure 2.8. Runoff efficiency for the different treatments in the 2005/06 season (x-axis is treatment type: continuous and intermittent ridges with 4-m and 8-m spacing).

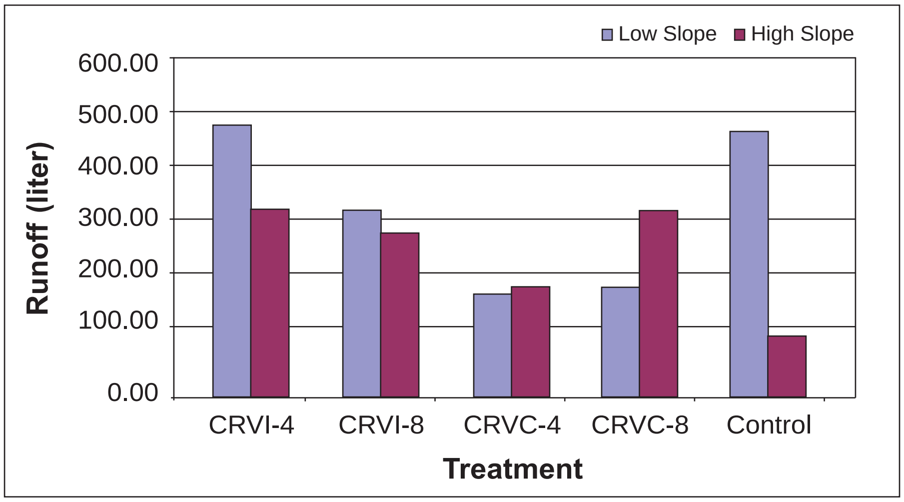

Figure 2.9. Runoff volume under the different treatments for the 2005/06 season.

There were also four runoff events during the 2006/07 season. The fourth runoff event was during May and the volume was so little that it could not be measured accurately and so was neglected. Thus, only three runoff events were considered. The highest event was relatively early in the season (27 December). The runoff events matched with the largest rain storms (in terms of rain amount); however, the highest runoff depth (depth per unit area) was under the 4-m followed by the 16-m spacing and the lowest was for the 8-m spacing. Soil erosion percent (percent of eroded soil material weight per volume of runoff collected), as well as infiltration depth was highest under the 8-m followed by the 4-m, while the lowest was the 16-m spacing (Figure 2.10).

Runoff initiated by the rain events generally traveled short run distances, depending on the rain intensity and duration, expressed as runoff depth (Figure 2.10). Under these conditions, 4-m was better than 8-m spacing. Runoff depth was higher at the higher slope (slope A) in all treatments. However, the highest runoff depth was for 4-m followed by 16-m, and the lowest for 8-m spacing (Figure 2.11).

Soil Erosion

During the 2005/06 season, there were four separate measurements from collecting the soil material for each splash cup and drying it in the oven. The highest amount of soil material that could be eroded at the end of the rainy season was 30.048 t/ha, reflecting the conditions of the catchment area for the CRVC-4 treatment in replicate 2, which has a history of being plowed and planted with barley. The measurement taken on the side slope of the ridge also showed a high potential for erosion (24.064 t/ha). This means that the ridge height would rapidly decrease due to the effect of rain drops until there was sufficient compaction of soil to resist the detachment of soil particles by rain drops.

The catchment area of CRVC-8 had measured soil erosion of 20.754 t/ha. This result again reflected the relatively better soil surface conditions in this treatment, which is located in the lower end of the slope from the hill even though it was planted with barley during 2005.

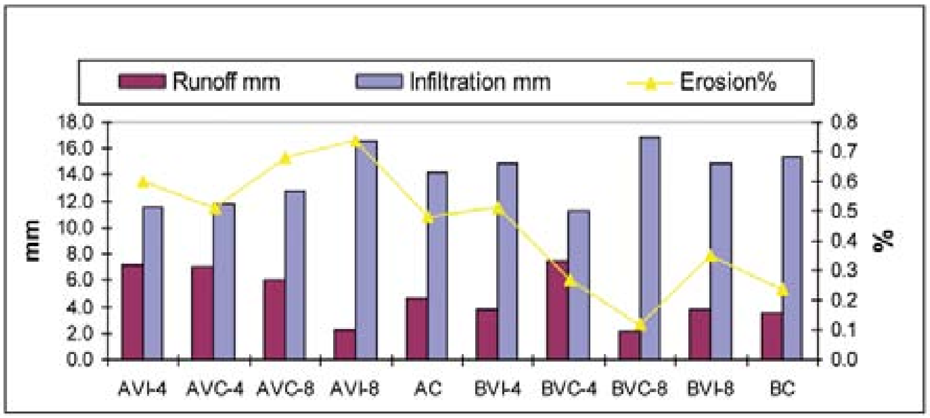

Figure 2.10. Runoff, infiltration, and soil erosion for the 2006/07 season.

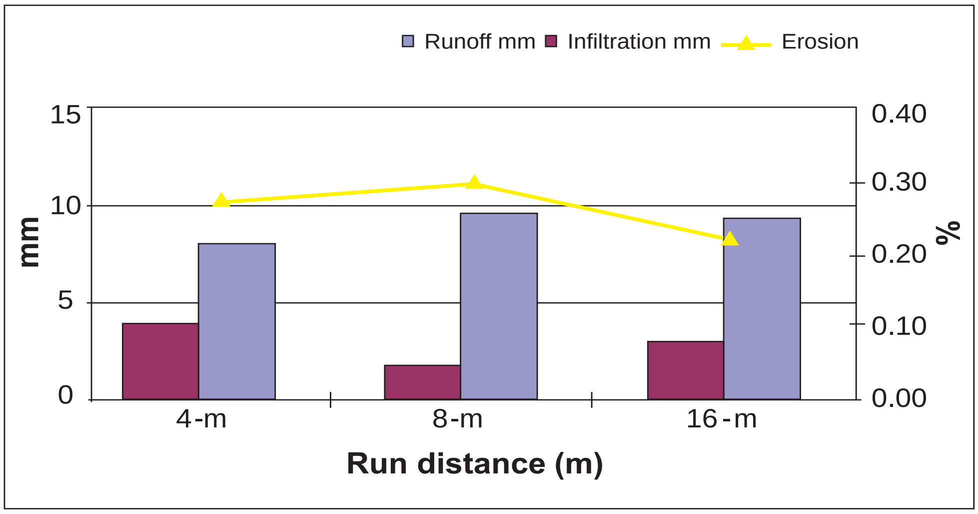

Figure 2.11. Runoff, infiltration, and soil erosion for the 2006/07 season.

The lowest amount of detached soil was for the unplanted control treatment of 13.750 t/ha, mainly due to the presence of a root mat in this untilled area to a depth of 7–10 cm (crust formation might also explain this). The highest amount of detached soil for all four splash cups was on 4 February and on 6 April; while the lowest was on 26 December, directly due to the drying of the soil surface and soil crust formation after the high intensity rainfall in December.

The runoff plot data showed a similar trend for soil erosion to that for runoff, whereby there was more eroded soil due to the effect of slope on the continuous ridge treatments, with the reverse on the intermittent ridge treatments (Figure 2.12). Generally, the catchment area for the intermittent ridge treatments was higher than for the continuous treatments, which partially explains the results. Eroded soil from the 4-m was higher than from the 8-m and 16-m plots, due to higher runoff efficiency and higher runoff depth in the smaller plots.

During the 2006/07 season, average and total soil erosion over the three runoff events was generally higher for the plots at the high slope (slope A) except for the plot with intermittent 4-m spaced Vallerani ridges (Figure 2.13). Soil erosion was higher

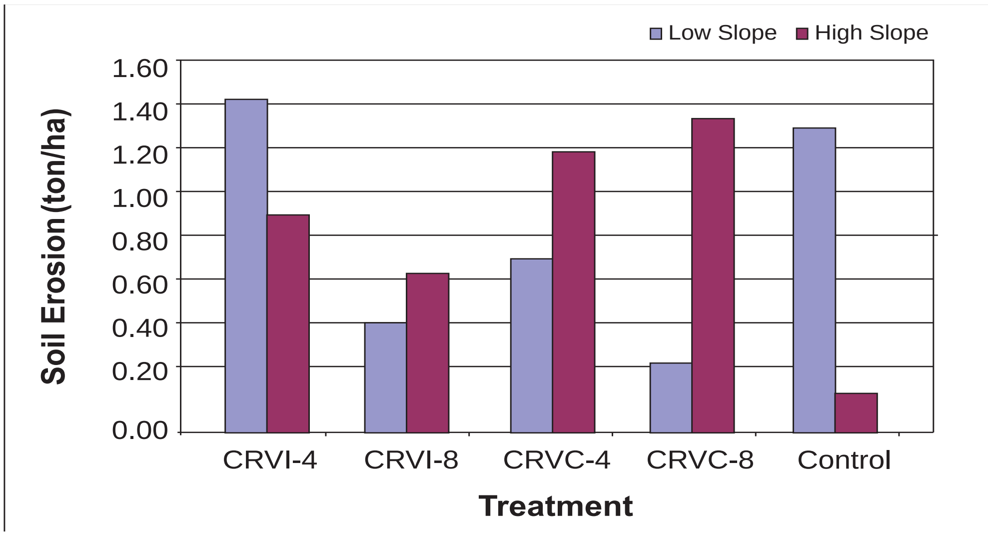

Figure 2.12. Total soil erosion under the different treatments (2005/06 season).

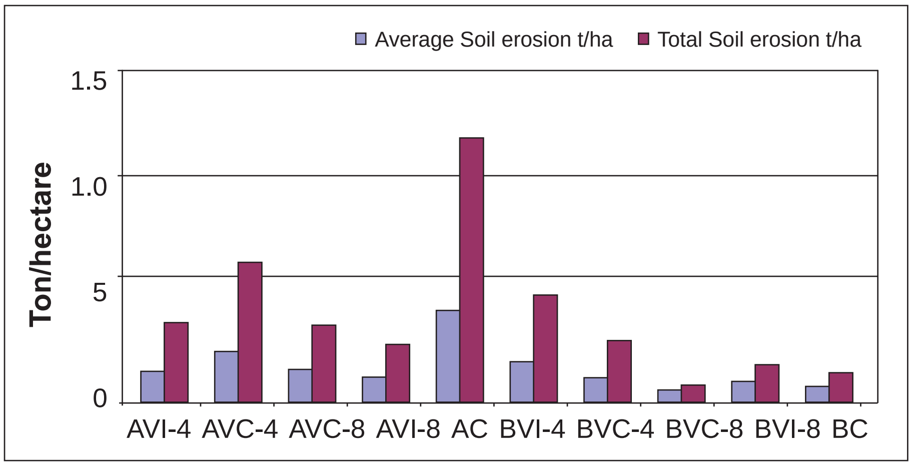

Figure 2.13. Soil erosion under the different treatments (2006/07 season).

for the 4-m compared to the 8-m spacing between ridges.

Soil erosion percentage as well as infiltration depth was highest under the 8-m followed by the 4-m, with 16-m spacing the lowest (Figure 2.11). Thus when considering soil erosion at the microcatchment scale (between contour lines) for both seasons, soil erosion was mostly sheet erosion and did not travel long distances (due to previous cultivation of barley) unless runoff volume was sufficiently high enough to move eroded particles to a further distance.. This pattern is interesting but requires more explanation, especially for the impact on selecting appropriate spacing for WHTs.

Water Productivity

Water productivity was significantly ($P < 0.05$) affected by the interaction between WHTs and land slope (regardless of spacing). The Atriplex water productivity under intermittent contour ridges and high slope was significantly higher than for the control (without contour ridges and regardless of spacing) under both low and high land slope in terms of production of fresh, browse, and dry weights (Figure 2.14).

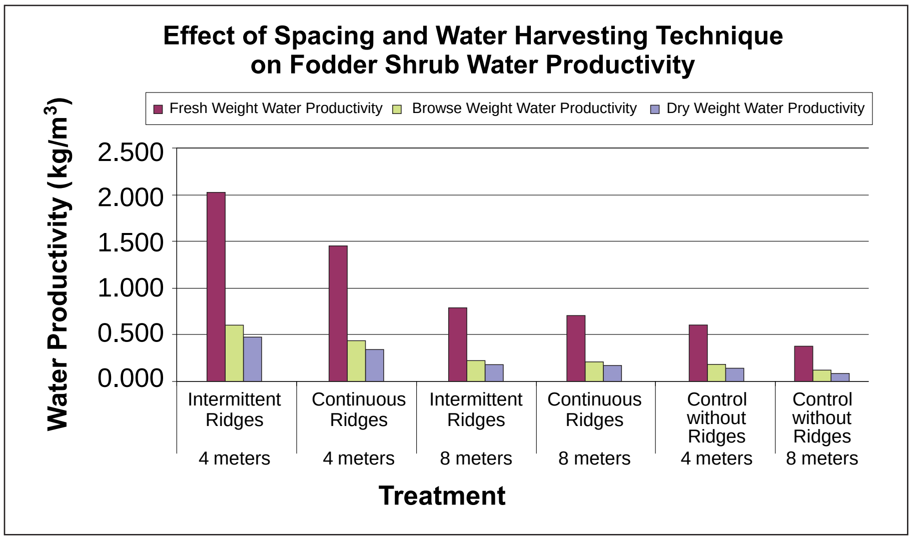

Figure 2.14. Water productivity of *Atriplex* shrubs as affected by WHT and land slope (2006/07 season).

Water productivity under intermittent contour ridges and high slope was more than double that of the control. Additionally, intermittent contour ridges resulted in higher water productivity (although non-significant) compared to the continuous ridges and controls. These results are mainly due to the fact that the catchment area under intermittent ridges is higher than the catchment area under continuous ridges. The higher slope generally resulted in better water productivity compared to the lower slope, again due to higher runoff volume under high slope.

The interaction between the spacing of contour ridges and land slope treatments was significant ($P < 0.05$) regardless of WHT. The water productivity under the 4-m spacing between rows under the high land slope was significantly higher than that under the 8-m spacing on both land slopes (Figure 2.15). This was mainly due to higher runoff efficiency under the shorter spacing, and that with 8-m spacing, the plant density was higher (three plants per 4-m length of row) compared to 4-m spacing (two plants per 4-m length of row). The competition between the planted shrubs, together with a limited water supply, reduced the water productivity of *Atriplex*. The 4-m spacing between contour ridges resulted in higher water productivity of Atriplex than 8-m spacing, regardless of WHT and land slope. Similarly, the 4-m spacing between contour ridges resulted in higher water productivity than the 8-m spacing, regardless of land slope or WHT used, including the control.

The water productivity for 4-m spacing with intermittent contour ridges was significantly ($P < 0.05$) higher than for 8-m spacing under both intermittent and continuous contour ridges, and was also

significantly ($P < 0.05$) higher than the two control treatments (Figure 2.16).

The interaction between the spacing of contour ridges, WHTs, and land slope treatments was significant ($P < 0.05$). The highest water productivity for Atriplex was obtained from the intermittent contour ridges, 4-m spacing, and high slope and was significantly greater ($P < 0.05$) than for all other treatments (Figure 2.17).

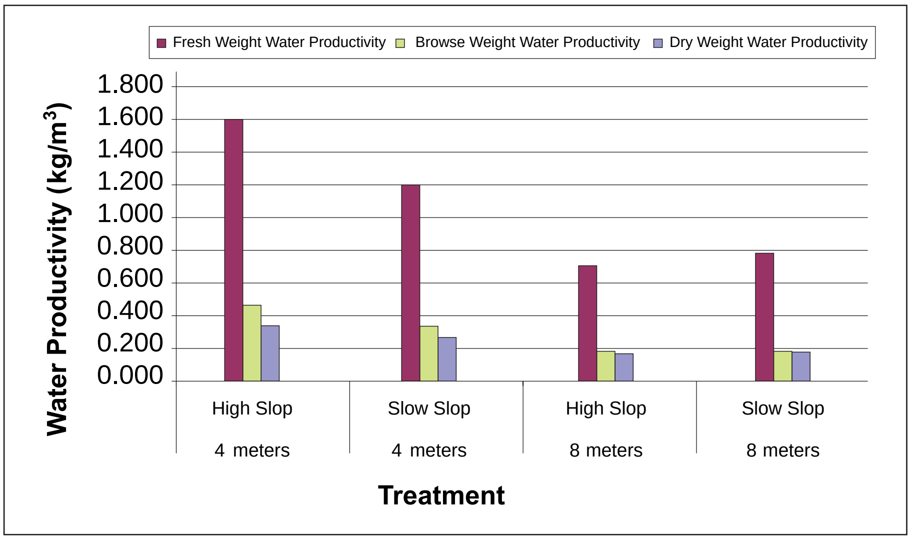

Figure 2.15. Water productivity of *Atriplex* shrubs as affected by spacing of contour ridges and land slope (2006/07 season).

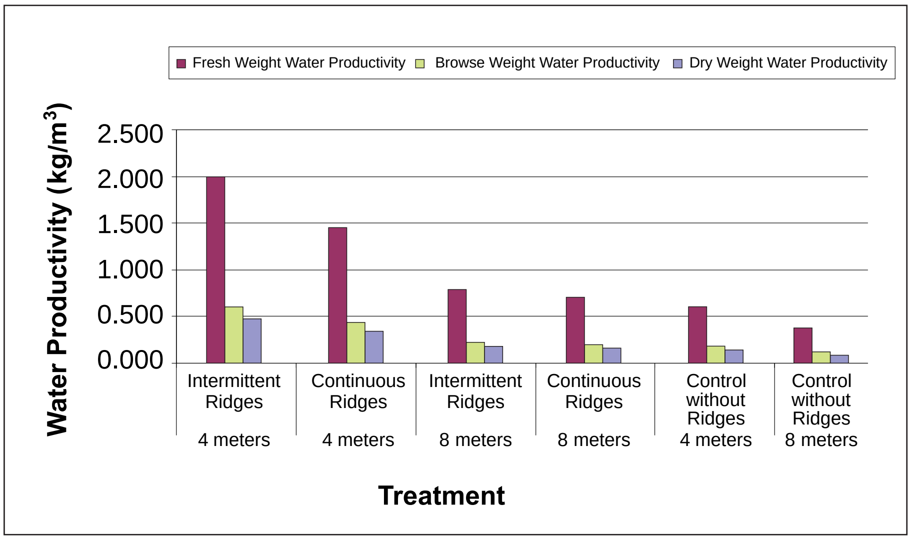

Figure 2.16. Water productivity of *Atriplex* shrubs as affected by WHT and spacing of contour ridges (2006/07 season).

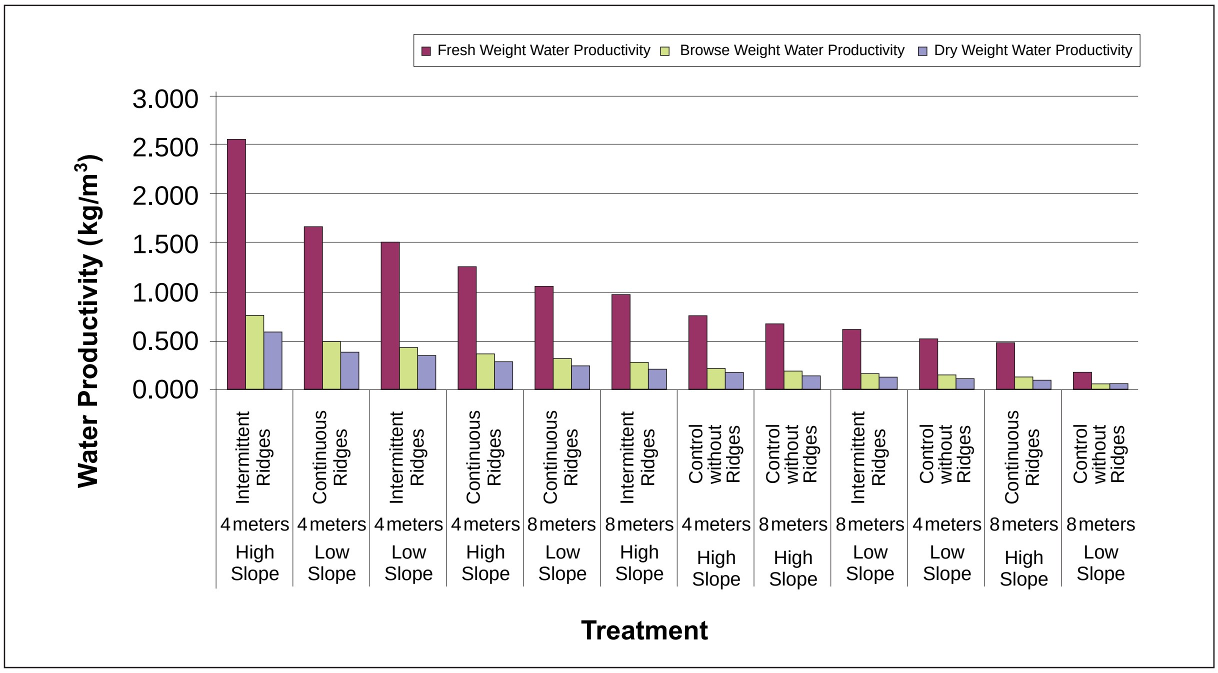

Figure 2.17. Water productivity of Atriplex shrubs as affected by WHT, spacing between contour ridges, and land slope (2006/07 season).

2.5 Conclusions and recommendations

The following conclusions and recommendations can be extracted from the results: The intermittent contour ridges with 4-m spacing and plant density of one shrub per 8 m^2 performed better than the other treatment combinations in terms of runoff, water productivity, and resulted in lower soil erosion of all the WHTs.

Continuous and intermittent contour ridges implemented with a 4-m spacing reduced soil erosion within the treated area, and resulted in high water productivity.

The higher land slope treatment resulted in higher runoff and higher water productivity regardless of the spacing between planted rows and WHTs used.
A suitable plant density for Atriplex shrubs is important to achieve high water productivity.

The 4-m spacing of intermittent Vallerani ridges is recommended for both tested slopes.

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