Water Benchmarks of CWANA project

9

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M. Karrou, T. Oweis, F. Ziadat and F. Awawdeh

ICARDA International Center for Agricultural Research in the Dry Areas

National Center for Agricultural Research and Extension, Jordan

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Community-Based Optimization of the Management of Scarce Water Resources in Agriculture in Central and West Asia and North Africa Project

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EXECUTIVE SUMMARY

The Central and West Asia and North Africa (CWANA) region encompasses large areas of arid and semi-arid zones. These zones may be defined as areas where rainfall, relative to the level of evapotranspiration, is inadequate to sustain reliable crop production. Most of the arid and semi-arid zones of the CWANA region are rangelands and are characterized by wide variability in rainfall and temperature. Droughts are common, resulting in low forage production and crop productivity as well as water scarcity.

In the CWANA region, the increase in human population has increased the demand for meat, in turn causing a major increase in livestock numbers, especially sheep. The escalating demand for forage by grazing animals exceeds the potential productivity of grazing resources. This has resulted in increasing barley cultivation by taking lands from steppe and desert rangelands. The increase in grazing pressure and cultivation of traditional and fragile grazing lands has led to severe degradation of these resources.

The main limiting factors to growth of plants in the desert rangelands are low precipitation, and poor soil quality. Maximizing the use of water runoff by making microcatchments and macrocatchments might be practical to increase forage production, which is essential to feed the sheep and goat flocks of pastoral societies in these areas. Since the Jordanian Badia is representative of the vast dry environments found in WANA, it was chosen as a benchmark site (with satellite sites in Saudi Arabia and Libya) to develop and disseminate water harvesting (WH) approaches and techniques to capture and efficiently utilize rainwater runoff in more productive and sustainable agricultural systems, which are to be integrated and adopted by people in the drier of the CWANA environments.

The project started in 2004 with the analysis of the existing and collected bio-physical and socioeconomic data, participative workshops, meetings, and field visits in the Jordanian Badia. Based on all this information and on agreed criteria, the benchmark site in Jordan was chosen and characterized. This site is represented by the two watersheds of Al-Majidyya and Mharib. In these sites, different research, dissemination, and capacity-building activities related to WH were conducted during 2004/05–2007/08.

The different activities conducted and the outputs of research work conducted in the Badia benchmark site are summarized below.

1. Effect of water harvesting (WH) on productivity and soil erosion

Badia soils have high silt and high calcium carbonate content. The water infiltration rate of such soils is low, with range 4–20 mm/h. The soil surface is often crusted, leading to high runoff flows. Soil erodibility is relatively high, associated with poor soil structure and high runoff flows over bare or plowed land (no vegetative cover). The objectives of this study were to assess the effect of different water harvesting techniques on runoff and soil erosion under field conditions and to evaluate the water productivity of the implemented WHTs. To reach this objective, a tri-factorial experiment with *Atriplex halimus* shrubs was conducted with two levels of land slope (2–8% and 10–20%), two spacings (4 m and 8 m) and three land management treatments (continuous contour ridges, intermittent contour ridges, and without any intervention). The continuous and intermittent contour ridges implemented with 4-m spacing reduced the soil erosion within the treated area, allowed for higher runoff efficiency, and resulted in higher water productivity. Moreover, the higher land slope (but up to certain limits, otherwise it increased erosion) resulted in higher runoff and water productivity, regardless of the spacing between rows and the WHTs used.

2. Use of microcatchments to improve fodder shrubs production

Fodder shrubs in low rainfall areas are subject to water shortages, overgrazing, and coppicing. Since micro-catchment water harvesting techniques are a means of collecting and concentrating rainfall runoff in the root zone area, hence increasing the amount of soil water available for shrubs, this activity aimed at determining and demonstrating the effect of the location, slope, and WH structure on shrub productivity. To reach this objective, an experiment was conducted during years 2007 and 2008 in two locations (Al-Majidyya and Mharib), two slope gradients (> 5% and < 5%), two WH structures (Vallerani intermittent and Vallerani continuous structures), and two shrub species (*A. halimus* and *Salsola vermiculata*). This experiment showed that (1) Al-Majidyya was more suitable for planting fodder shrubs and forage production; (2) *S. vermiculata* was more drought tolerant in terms of survival than *A. halimus*, although *A.halimus* showed more adaptation to prevailing conditions for forage production; (3) the Vallerani continuous structure technique allowed more rainwater collection and forage production; and (4) the low slope (< 5%) showed a high efficiency in forage production. Finally, it was recommended to plant *A. halimus* shrubs at Al-Majidyya using Vallerani continuous structure in the low slopes (< 5%) for higher forage production.

3. Microcatchment WH systems for fruit trees and shrubs

The experimental results for two seasons (2004/05 and 2005/06) led to the following recommendations:

For fruit trees: use the runoff system with a catchment area of 36 m^2 for growing pistachio and almond trees, and 64 m^2 for olive trees.

For shrubs: use the ridges constructed by the Vallerani implement at a spacing of 5 m (14 m^2 catchment area) since this is much cheaper and faster than conventionally constructed ridges.

4. Impact of WH on native plant reproduction and biodiversity

Many plant species are severely affected by the degradation of rangelands caused by overgrazing and the cultivation of barley. Microcatchment WH systems associated with suitable grazing management provide an opportunity for plants to regenerate and improve vegetation. However, there is no information and/or research on the potential and constraints associated with regenerating the native vegetation in the Badia, regarding the best way and the impact on diversity of plant species and vegetation cover. This study aimed at conducting the followings activities: (1) to survey and identify the flora of the Mharib watershed (the intervention area for the Badia Benchmark Project); (2) to study the effect of microcatchment WHTs on the soil seed bank compared with the current situation; (3) to evaluate the effect of microcatchment WH on the native vegetation regeneration and improvement; and (4) to multiply and reintroduce the annual native species collected from the rangelands. The survey and testing of different microcatchment WH systems showed that in dry areas the native vegetation was much diversified, with 23 families and 90 plant species recorded in the Mharib watershed area. This area is dominated by annual plant type with 19% of total plant species recorded during our study.

The microcatchment WH had a significant effect on increasing the native vegetation in terms of vegetation cover, species richness and species abundance, as well as the size of the soil seed bank. The Vallerani intermittent contours treatment was the most suited intervention, resulting in improvement of native vegetation and the size of the soil seed bank. Finally, the native vegetation rehabilitation was possible and direct seeding was a good practice due to its low cost and effort; but it cannot guarantee germination due to rainfall variability. Moreover, native plants can be multiplied under controlled conditions.

5. Mechanization of transplanting shrubs seedling using Vallerani implement

Many WHTs have been successfully tested over many years, including small-scale WH with contour furrows and microcatchments of different shapes and sizes.

Drought-tolerant forage shrubs (most commonly *Atriplex spp*) have been successfully established under these WH systems. Moreover, the mechanization of WH using the Vallerani machine was evaluated in the Badia ecosystem. Nevertheless, there were problems with the establishment of forage shrubs due to the cost and low rates of establishment of old transplants and the low mastery of the Vallerani machinery operation. The objectives of this study were: (1) to evaluate the feasibility of establishment of *Atriplex* plants from young (1–2-months old) seedlings instead of six-month and older plants, (2) to determine the best conditions under which the transplanting technique is expected to be most successful, and (3) to modify the traditional transplanting unit to cope with the specific WH structure of the furrow (planting on the incline of the furrow ridge) and to develop a laser-guided tractor furrowing system. To reach these objectives, an experiment was conducted to study the combined effect of the time of transplanting (before first rain, a few days after a good runoff event, and in spring), the length of the harvested area (4, 8, and 12 m), and the placement of seedlings in the furrow (transplanting in the bottom close to the ridge and above the bottom 1/3 of the ridge). The traditional transplanter was also modified to improve performance: changing the slot-opening device; adding protecting boards to the slot opener; changing the depth-wheel design, the pressing device design, and the hitching system of the transplanter; and adding a covering disc. The modified transplanting unit was attached to a WH furrow-opening plow (designed previously at the University of Jordan). In addition to the activities described above, a laser-guided tractor furrowing device was developed and tested. Transplanting young seedlings was a successful practice for the establishment of forage shrubs in marginal rangelands or steppe regions (Badia) under WH systems. Transplanting after the first good rainfall events reduced the risk of rainfall delay and increased the survival percentage of plants. Planting in the bottom 1/3 of the ridge showed better plant growth. The new integrated furrow opener and transplanting unit was able to open a continuous deep furrow and transplant seedlings inside the furrow in one pass of the tractor. This dramatically reduced the amount of work usually needed to open WH furrows and plant *Atriplex* in them. The laser-guided furrowing system was tested and proven to be time, effort, and cost saving, as well as more accurate.

6. Database management and Geographic Information Systems (GIS)

Among project activities was the establishment of a project database. The outputs were the establishment of a GIS database for the intervention sites, which defined each site in terms of its geographic location and extent and a nomenclature system and dynamic links, using an html-based application, to all available data and information; and the preparation of data-forms for data collection, entry and analysis, for different seasons.

7. Economic analysis and environmental impact of WH

The results of economic analysis of the technologies tested by the Badia Benchmark Project showed that the economic internal rate of return (EIRR) of planting barley with WH gave the highest value, compared with other WHTs, of 17% compared to an estimated 7.8% for planting barley the traditional way. The planting of shrubs with WH was more feasible than the traditional pit method, with EIRRs estimated at 13% and 7.4%, respectively. The contribution of environmental benefits in the calculations of return on investment for WHTs showed increased financial internal rate of return (FIRR) to 36% and EIRR to 17% compared to 13% and 17%, respectively, when calculated based on only economic benefits in the case of planting shrubs using WHTs. The valuation and assessment of environmental benefits associated with implementing WHTs is important to justify the public investment for these techniques in dry areas of Jordan. Since Environmental benefits were not taken into account when implementing this type of agricultural project, the direct economic benefits based on individual economic analysis did not justify investment in such projects in the arid areas of Jordan.

BACKGROUND

Water scarcity in West Asia and North Africa (WANA) is a well-known and alarming problem. Today the issue is of increasing concern to national governments and research institutions. Increasing water scarcity is threatening the economic development and the stability of many parts of the region. At present, agriculture accounts for over 75% of the total consumption of water. However, with rapidly growing demand it seems certain that water will increasingly be reallocated away from agriculture to other sectors. Moreover, opportunities for the significant capture of new water are now limited. Most river systems suitable for large-scale irrigation have already been developed. Few major resources of renewable groundwater remain untapped and current resources are subject to over-exploitation, with extraction exceeding recharge rate in many cases.

While gains in efficiency are potentially available from improved distribution and use of water in fully irrigated agriculture, a great proportion of the region's agricultural livelihoods are based on dryland farming systems where production is dependent on low and extremely variable rainfall. The challenge in rainfed areas is to enhance productivity through improving on-farm water use efficiency and supplementing rainfall either through water harvesting or the strategic use of sources of renewable water to augment essentially rainfed production. However, conventional practices, which have been developed for managing water under normal water supply conditions, are not suitable under conditions of water scarcity. The need for special management of water under conditions of scarcity, based on maximizing the return from each unit of water available for agriculture, now applies to almost all the countries of WANA.

Technologies for improved management of scarce water resources are available. However, many of these technologies are not widely implemented or are not seen as feasible by farmers. This can be attributed to a number of constraints, including technical, socioeconomic and policy factors, but most importantly the lack of community participation in the development and implementation of improved technologies. This project is based on community participation in research and the development, testing and adaptation of improved water management options at the farm level.

The project consisted of three main components: the Badia Benchmark site in Jordan, with two satellite sites in Saudi Arabia and Libya; the Rainfed Benchmark site in Morocco, with three satellite sites in Tunisia, Algeria and Syria, and the *Irrigated* Benchmark site in Egypt, with two satellite sites in Sudan and Iraq.

Objectives and outputs

The main long-term development goal of the project is to achieve sustainable and profitable agricultural production in the dry areas of WANA based upon the efficient and sustainable management of the scarce water resources.

To reach this goal the project developed and tested, with *community participation;* water management options that increase water productivity, optimize water use and which are economically viable, socially acceptable and environmentally sound.

The research concentrated its activities in the three benchmark sites. Each benchmark site was linked to satellite sites as indicated earlier. These satellite sites were designated to complement the research of the benchmark.
The four main outputs planned are:

- Strategies and tested technologies for the optimal conjunctive use of rainwater and scarce water resources in supple-

mental irrigation systems adopted by farming communities for improved and sustainable water productivity in the rainfed areas on WANA
- Suitable water harvesting techniques to capture and efficiently utilize rainwater runoff in more productive and sustainable agricultural systems integrated and adopted, by people in the WANA drier environments.
- Techniques and systems that optimize water productivity in irrigated systems, including water management, alternative crops, use of different water sources, and policy and institutional options.
- Enhanced capabilities of national programs and the integration of researchers, extension personnel, farmers and decision-makers in a regional program for sustainable management of water resources.

The project approach

The research approach is based on five principles: the participation, the integration, the complementarities, the multi-disciplinary and multi-institutions and socio-economic analysis.

a) Community participatory based approach
The research uses an integrated approach, based on community participation. At each site, the local community is a full partner in planning, implementation, monitoring, and evaluation. Farmers work with scientists and extension staff to test a range of "best-bet' technologies and select those that best meet their needs-often adopting the technologies to suit local conditions. This created a sense of 'ownership', leading to rapid adoption of technologies that were found to be effective and relevant.

b) Integrating technologies with policy and institutions
The project addressed problems from a technical, socioeconomic, cultural, institutional, and policy perspectives, with the full participation of the intended beneficiaries and other stakeholders.

c) Benchmark and satellites sites (complementarities)
Benchmark sites were established in the three agro-ecologies (rainfed areas, the steppe and irrigated areas) to study these issues. At these benchmark sites, water use was addressed at different levels: household, community, watershed and policy level.

Each of these benchmark sites are linked to several *satellite* sites as indicated in the previous section.

The benchmark sites represent the majority of the conditions in the above three agro-ecologies. However, some conditions and issues in the region related to the natural resources, the environment and/or the socioeconomics may not be apparent in the benchmark site and thus are addressed in the *satellite* sites. Examples include water quality, special soil conditions and local water related policies and institutions.

d) Multidisciplinary, multi-institutions
The project approach requires a multidisciplinary and inter-institutions teams, involving many different research disciplines, to understanding the current situation and to developing and testing water-use efficient technologies under farm conditions.

e) Socioeconomic analysis and community participation
Socioeconomic surveys that characterize the communities involved in the project sites have been conducted in order to identify the main technical, social, economic and environmental problems that constraint the community livelihood improvement. The surveys also focused on the water resources available at the community level and how they deal with this resource. The surveys' results established the base line information for the project target areas and communities. Following

that, the community participated in the development of the work plan and the intended interventions that the project would introduce. A community action plan was developed and implemented by the project with full participation of the community.

A community-based participatory monitoring and evaluation (PME) system was developed in the first phase. The PME involves local people in deciding how progress should be measured, in defining criteria for success and in determining how results should be acted upon. It will strive to be an internal learning process that enables local people to reflect on past experience, examine present realities, revisit objectives and define future strategies by recognizing differential stakeholders' priorities and negotiating their diverse claims and interests.

Technical and socioeconomic indicators of progress and impact were developed during the commencement workshop and were implemented by the project teams. Major indicators include the level of adoption by communities of the introduced technologies.

Badia benchmark and satellite sites

A large proportion of WANA's agriculture is based on dryland farming systems, wherein production depends on low and extremely variable rainfall. Almost all countries in WANA now need to manage water in special ways, under conditions of scarcity, to maximize the agricultural returns from each unit of water.

The Jordanian Badia is representative of the vast dry environments found in WANA. The underlying aim of the project conducted at the Badia benchmark site in Jordan (and satellite sites in Saudi Arabia and Libya) was to ensure the widespread adoption of suitable WHTs by people in the Badia. This will allow them to capture and efficiently use rainwater runoff in more productive and sustainable systems. This component of the project was expected to result in the following outputs:

a. Selection and characterization of Badia watershed research sites;
b. Techniques for providing sustainable supplies of water from rainfall runoff for economic production from rangeland, field crops, and fruit trees, and methodologies for designing and implementing such techniques at the field and watershed levels;
c. Analysis of potential economic and institutional constraints, and recommend policies to support the integration of WH in agricultural systems;
d. Enhanced capabilities of national programs and the integration of researchers, extension specialists, farmers, and decision-makers in a regional program for sustainable management of water resources in CWANA.

Chapter 1

Selection and Characterization Of the *Badia* Benchmark research site

Chapter 1: Selection and Characterization Of the *Badia* Benchmark site

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How suitable an area is for WH depends on local society, farming practices, and whether the area meets the basic technical requirements of the WH system in question. When planning such systems, appropriate data must be available on the climate, soil, crops, topography, and socioeconomics of the project area. The available tools and methods of data acquisition for planning, designing, and implementing WH systems, include field visits, site inspections, topographic and thematic maps, aerial photos, satellite images, and geographic information systems (GIS) must also be considered.

1.1 Selection of the watersheds

1.1.1 Watershed selection process

During the early stages of the project, emphasis was placed on the fact that the approach used was multi-disciplinary and integrated technology, management, institutions, and research. It was also agreed that the final selection of the potential watershed sites should match certain criteria. These were divided into three major groups: (i) target area criteria, (ii) watershed criteria, and (iii) community criteria. These criteria are listed below under the relevant group.

Group 1. target area criteria:

- The area must have an annual rainfall of 100–250 mm
- The area must consist of rangeland where the barley–livestock-based land-use system predominates other land use systems
- Livestock production must be the main farming enterprise
- The land must be degraded (displaying low vegetative cover, soil erosion, and low levels of soil organic matter)
- There must be a shortage of feed
- The adoption rates for improved technologies must be low
- Levels of public and private investment must be low

Group 2. watershed criteria:

- The area must be representative of the major physical and social characteristics of the *Badia*
- There must be communities in the upper, mid, and lower part of the watershed
- The potential for WH must exist
- A rangeland-based land-use system must dominate
- The potential must exist for halting/reducing land degradation at a relatively low cost
- The area must display multiple rangeland uses
- The area must be 30–150 km^2
- The area must encompass both private and communal natural resources
- Land ownership in the area must include both private and government land
- Rangeland use must involve open access
- The area must have been exposed to other projects
- The potential must exist for the project to have a noticeable impact in the area
- The area must be easily accessible
- Basic data and previous studies must be available for the area

Group 3. community criteria:
- The community chosen must be poor
- The community must be committed to participating in the project
- Institutions (informal and/or formal) must exist
- A range of livestock-production systems must exist, from transhumant to sedentary systems
- Agriculture must play a significant role in household income-earning
- There must be access to government/ development projects

These criteria were suggested by an inter-disciplinary team of specialists. However, while they are obviously very important for the success of the project, it must be recognized that selecting a watershed (or watersheds), which satisfies all these criteria would not be an easy task. Importantly, it was also recognized that the selection process should be simple, so that it could be easily reproduced in other similar areas.

Accordingly, the watershed-selection process was divided into the following sub-components:
- Scoring and weighting of the selection criteria
- Selection of potential watersheds (three stages)
- Rapid rural, hydrological, and environmental appraisals of the most promising watershed(s)
- Data management and manipulation
- Integration of sub-components 2–5 for the purposes of final selection

An integral part of the above sub-components were continuous field visits and verification by the inter-disciplinary team. The field visits were meant to verify GIS and remote-sensing information (maps, images, and other information) and to conduct ground-truthing. Most importantly, these field visits were also meant to provide greater insight into local communities at the project sites. The technical approach applied in the site-selection process is outlined in Chart 1.1.

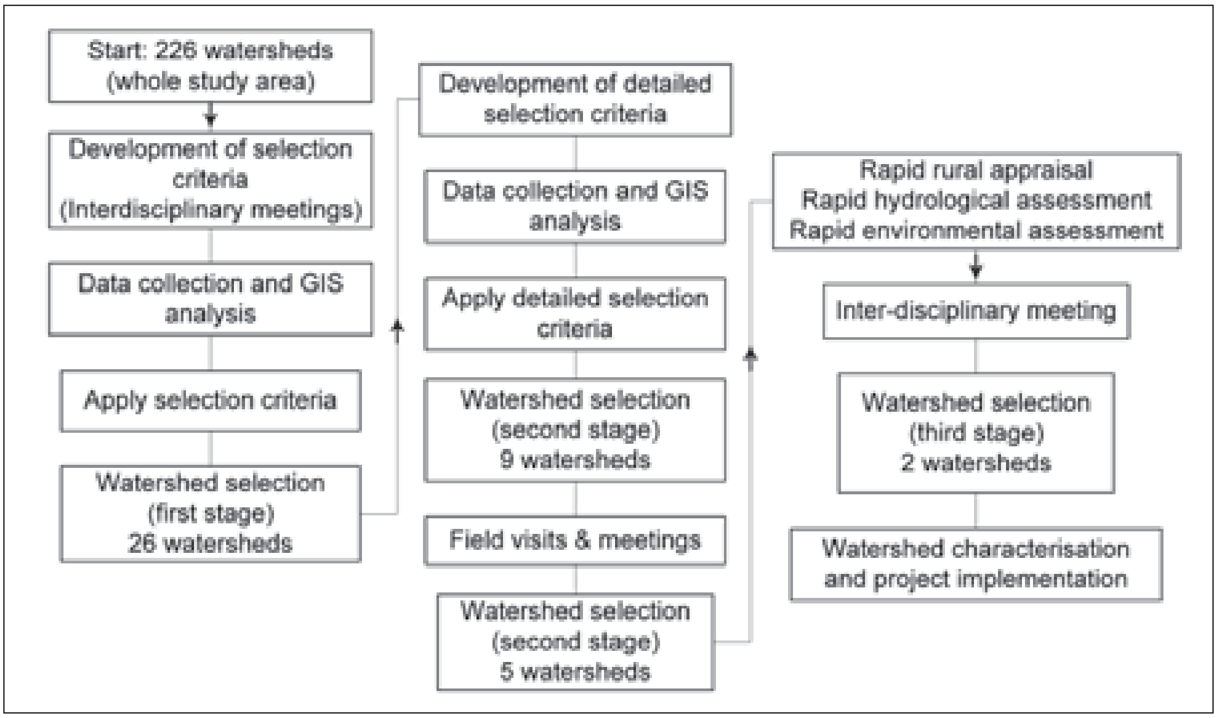

Chart 1.1 Flowchart of the watershed-selection process.

1.1.2 Development of selection criteria

The criteria and its application for the first stage of selection

The watershed selection criteria agreed upon at an early stage of the project were chosen and revised by a multi-disciplinary team of experts in several meetings. To be selected, watersheds had to satisfy a scoring of five main criteria (Table 1.1).

Rainfall was considered the most important factor at this stage, as it is integral to the definition of the study area. It was, therefore, agreed that areas receiving either < 100 mm or > 250 mm of annual rainfall should be excluded, and hence were given a score of zero (Table 1.1).

The basic map used in various analyses showed the subdivisions of each watershed. This map was developed from the hardcopies of topographic maps (scale 1:50 000) produced during a previous project (Jordan Arid Zone Productivity Project) conducted by the University of Jordan.

Contour lines and streams were used to define the boundaries of each main watershed and the sub-watersheds found throughout the transitional Badia (100–200 mm rainfall).

The output indicated that the Badia was covered by 226 main watersheds with range in area of 0.3–266 km^2. It would be very difficult to work with such a large number of watersheds; therefore, the criteria assigned for the first stage (Table 1.1), which were very general in nature, were applied to exclude unsuitable watersheds.

A large number of watersheds received a final score of zero (Figure 1.1). However, these watersheds should not necessarily be considered unsuitable for other research activities in the Badia, despite being unsuited to this project. Of the 226 watersheds, 158 were excluded, thus leaving 68 for further consideration (Table 1.2). Forty of the watersheds had scores of 60, 65, or 70, the three highest scores obtained. These were considered for further investigation. Some, however, were then excluded because their boundaries extended into Syria, something which could complicate project activities (Figure 1.2). Other watersheds were excluded because much of their area fell outside the Badia, leaving 26 watersheds (Figure 1.3).

The criteria and its application for the second stage of site selection

The second stage of site selection required the researchers to apply more rigorous

Table 1.1. Scoring criteria used in the first stage of site selection.

Criterion	Score*			
	0	5	10	15
Rainfall (mm/y), obtained from isohyets	< 100 or > 250	100–149	200–250	150–199
Presence of communities (no. of villages)	None	One	Two	> Two
Soil type (dominant soil)	Lithic, Calcic, Psamment	Lithic and/or Psamment	Calcic	Other
Watershed area (km^2)	< 30	110–150	30–70	70–110
Topography (relative relief, m)	> 200	100–200	50–100	< 50

Note: * If assigned a score of zero, the watershed was excluded.

Table 1.2. Final scoring (first stage) after excluding watersheds with scores of zero.

Watershed number	Area score	Rainfall score	Community score	Soil score	Topography score	Final score	Watershed number	Area score	Rainfall score	Community score	Soil score	Topography score	Final Score	Watershed number	Area score	Rainfall score	Community score	Soil score	Topography score	Final score
18	15	15	15	15	10	**70**	16	15	10	5	15	15	**60**	189	5	15	15	10	10	**55**
19	15	15	15	15	10	**70**	17	10	15	10	15	10	**60**	200	10	15	15	10	5	**55**
35	10	15	15	15	15	**70**	29	15	15	5	15	10	**60**	38	10	15	5	5	15	**50**
36	15	15	15	10	15	**70**	33	10	10	15	10	15	**60**	90	5	15	5	10	15	**50**
37	15	15	15	10	15	**70**	51	5	15	15	10	15	**60**	129	15	10	5	15	5	**50**
50	15	15	15	10	15	**70**	55	10	10	15	10	15	**60**	132	15	5	5	15	10	**50**
54	15	10	15	15	15	**70**	57	10	10	15	10	15	**60**	136	15	5	5	15	10	**50**
61	15	15	15	10	15	**70**	58	10	10	15	15	10	**60**	148	5	15	5	15	10	**50**
62	15	15	15	10	15	**70**	79	15	15	10	10	10	**60**	152	10	5	5	15	15	**50**
190	15	15	15	15	10	**70**	108	10	10	15	15	10	**60**	167	10	5	10	15	10	**50**
27	15	10	15	15	10	**65**	120	15	15	5	15	10	**60**	169	10	5	5	15	15	**50**
28	15	10	15	15	10	**65**	125	10	15	5	15	15	**60**	184	5	10	15	10	10	**50**
30	5	15	15	15	15	**65**	173	15	15	5	15	10	**60**	186	10	15	5	10	10	**50**
31	10	10	15	15	15	**65**	174	15	15	5	15	10	**60**	187	5	10	15	10	10	**50**
34	15	10	15	10	15	**65**	182	15	15	5	15	10	**60**	192	10	15	5	15	5	**50**
59	15	10	15	15	10	**65**	197	10	15	15	15	5	**60**	161	10	10	5	15	5	**45**
103	15	10	10	15	15	**65**	199	10	15	15	15	5	**60**	164	10	5	5	15	10	**45**
121	15	10	15	15	10	**65**	15	5	10	15	15	10	**55**	191	15	5	5	10	10	**45**
122	10	10	15	15	15	**65**	65	5	15	15	5	15	**55**	195	10	15	5	10	5	**45**
123	10	10	15	15	15	**65**	78	5	15	15	10	10	**55**	215	10	15	10	5	5	**45**
128	15	10	15	15	10	**65**	117	10	10	10	15	10	**55**	77	10	5	5	10	10	**40**
193	15	15	15	15	5	**65**	118	15	10	5	15	10	**55**	196	15	5	5	10	5	**40**
13	10	10	15	15	10	**60**	179	10	15	5	15	10	**55**							

Note: Bold text for each individual score per watershed signifies watersheds in Figure 1.1 whose boundaries did not fall outside the Badia, or outside the country.

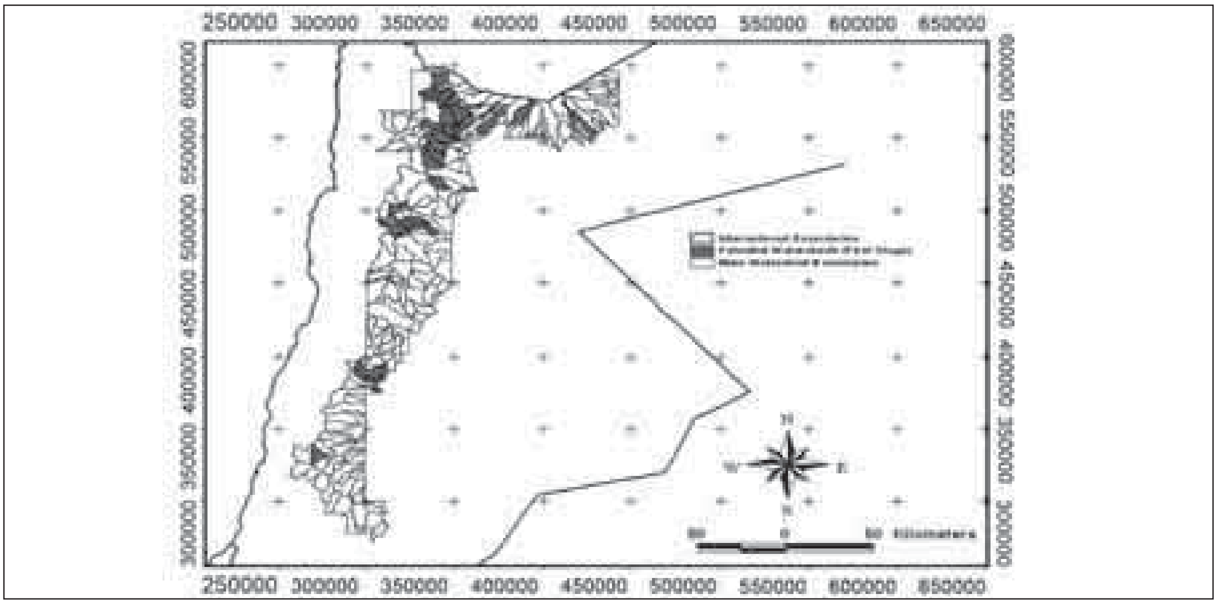

Figure1.1. Final selection of potential watersheds (first stage).

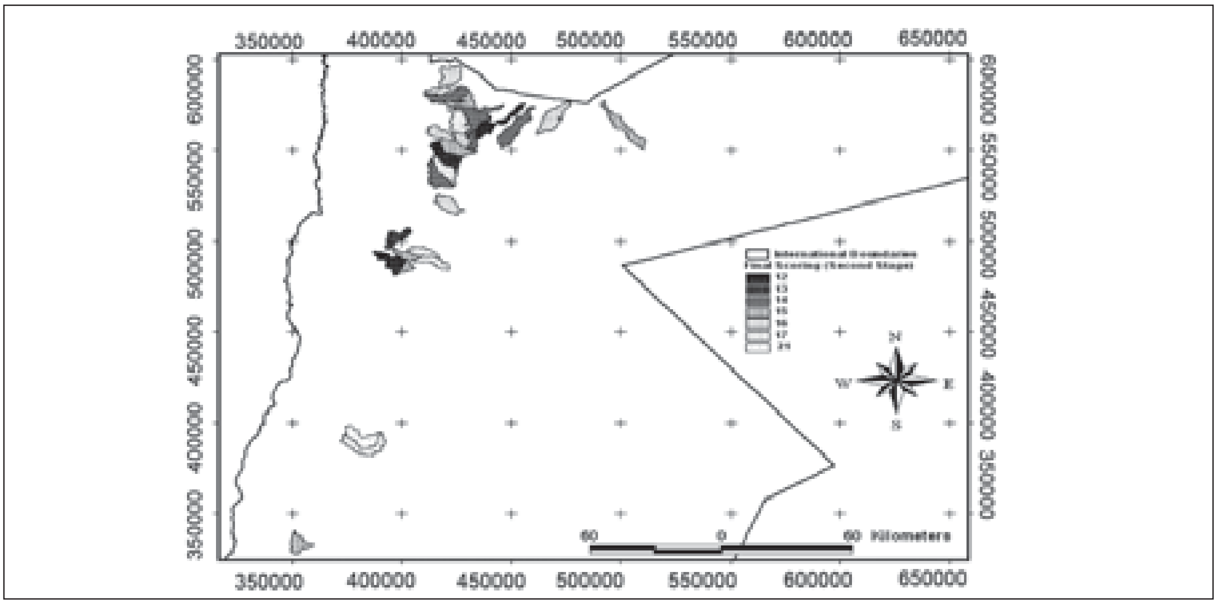

Figure1.2. Distribution of watersheds with different final scores (second stage).

criteria to the watersheds selected in the first stage. Those watersheds given a score of zero for any of the five selection criteria in the first stage were excluded. The rankings assigned to the revised selection criteria used in the second stage are given in (Table 1.3) and are discussed below.

The final scores were calculated for each of the 26 watersheds (Table 1.4) based on the eight selection criteria considered in the second stage.

The best possible score for a watershed was 8 (i.e. all criteria scored 1) and the worst was 32 (i.e. all criteria scored 4). The 26 water-

Table 1.3. Scoring of criteria for the second stage of the site selection process.

Potential for WH	4th (lowest score)	3rd	2nd	1st (highest score)
Soil depth (cm)	< 50	50–100	100–200	> 200
Slope steepness	< 1% or > 10%	8–10%	5–8%	1–5%
Community (location in watershed)	Upper and/or middle	Lower and/or middle	Upper and lower	Upper, middle and lower
Rangeland-based system	Irrigated agriculture dominates	Lack of native vegetation and barley	Native vegetation and barley dominates	Native vegetation dominates
Land use	Field crops	Bare	Range–barley–livestock-based system	Range–livestock-based system
Watershed area (km^2)		110–150	30–70	70–110
Accessibility and visibility	Not connected to roads	Connected only on one part	One road passing through watershed	Road network inside and main road passing through
Land tenure		Government	Private	Private and government
Basic data	Not available and no previous studies	Insufficient and previous studies	Available and previous studies	Available

sheds tended to have high scores (Table 1.4): the highest score for suitability was 12 and the lowest was 21, indicating that all watersheds selected in the first stage had the potential to satisfy the project's purposes.

The distribution of watersheds and their final scores is illustrated in (Figure 1.2).

Nine watersheds (those with scores of 12–14) were selected, with their spatial distribution providing a reasonably comprehensive coverage of the Badia (Figure 1.2).

Table 1.4. Final scores for the second-stage selection.

Watershed Number	Soil depth	Slope steepness	Community	Accessibility and visibility	Watershed area	Rangeland system	Land use	Land tenure	Final* score
19	3	2	1	1	1	1	1	2	12
36	3	1	1	1	1	1	2	2	12
128	3	1	1	1	1	2	2	1	12
108	3	2	1	1	2	1	2	1	13
28	3	2	1	1	1	2	2	2	14
30	3	1	1	1	3	1	2	2	14
35	3	1	2	1	2	1	2	2	14
51	3	1	2	1	3	1	1	2	14
59	3	1	1	1	1	1	4	2	14
18	3	2	4	1	1	1	1	2	15
31	3	1	1	1	2	1	4	2	15
79	4	1	4	1	1	1	1	2	15
123	3	2	1	1	2	2	2	2	15
199	3	3	1	1	2	1	2	2	15
13	4	3	1	1	2	1	2	2	16
17	3	2	3	1	2	1	2	2	16
54	3	2	1	1	1	2	4	2	16
58	4	2	1	1	2	2	2	2	16
62	4	1	1	1	1	2	4	2	16
103	4	1	4	1	1	1	2	2	16
16	3	2	4	2	1	1	2	2	17
29	3	2	3	3	1	2	1	2	17
122	3	2	2	2	2	2	2	2	17
125	3	1	4	1	2	2	2	2	17
174	4	2	4	1	1	1	2	2	17
173	4	4	4	3	1	1	2	2	21

Note: * Low scores indicate higher potential for WH.

1.1.3 Field visits and outcomes

For the purposes of organizing the study, a detailed map was prepared for each of the nine watersheds and distributed to the whole project team. The maps show both the boundaries of each watershed as well as the network of roads. They also show villages and provide a coordinate grid. They helped investigators to navigate in the field and also to gather useful information about the watersheds, such as the actual distribution of communities.

The final decision regarding the selection or rejection of a watershed was made once all field visits for all the watersheds had been completed and the information gathered had been reviewed. Certain issues were highlighted by the team members during the field visits, some of which are listed below.

The large number of urban areas found within most of the watersheds visited was considered a disadvantage for some project activities.
The high concentration of irrigated farms within some watersheds was considered a disadvantage as WH would be less popular than intensive irrigated agriculture and so could not compete with it.

It has been also argued that most of the watersheds visited represent transitional Badia and are not typical of 'rangeland'. As a result of the issues discussed above, the team revised the scoring system for the community criterion and identified additional watersheds to be added to the nine watersheds already selected. The final scores obtained for the first stage of selection were recalculated to exclude the community score (i.e. the watershed scores without taking into account the community criterion). The distribution of the retained watersheds is presented in (Figure 1.3).

1.1.4 Final selection

The team held a final meeting after the field visits. During this, the results of the field visits were thoroughly discussed in order to determine which watersheds should be advanced to the third stage of the selection process.

The team started the discussion (i) by considering all the watersheds and then eliminating those they felt had any disadvantages, and (ii) by arranging the rest of the watersheds according to an agreed scaling methodology.

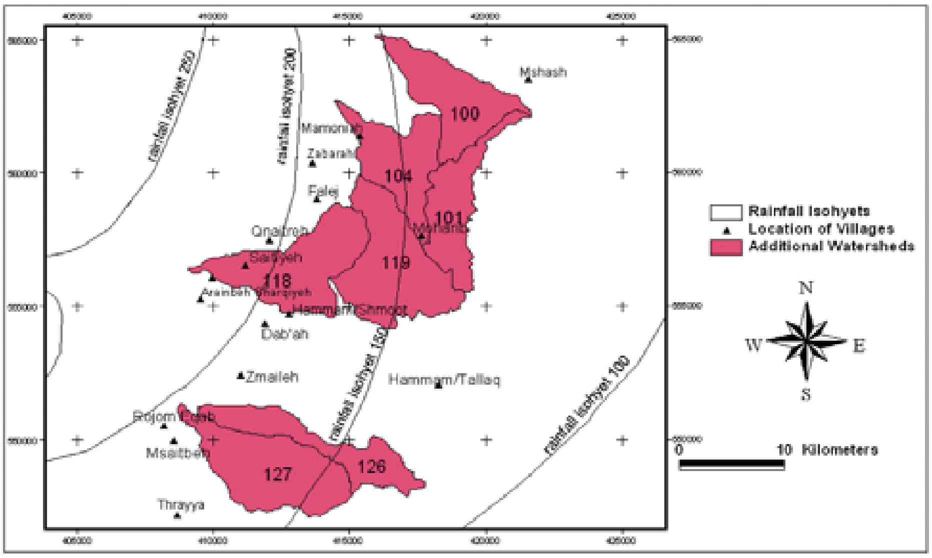

Figure1.3. Watersheds selected after revising the community criterion.

The aim of this process was to summarize the observations made in the field into rational items relevant to the project. These items fall under three major headings: biophysical factors, WH-related factors, and socioeconomic aspects.

Watershed number 128 was excluded for further consideration (in the third stage) due to its very low scores compared with the other watersheds considered (Table 1.5). In addition, watersheds 30 and 31 were combined, as they were adjacent and complemented each other in many respects. Ultimately, this stage of selection yielded a total of five watersheds (30 and 31, 59, 108, 104, and 119) which were further evaluated in the third stage.

1.1.5 Third stage – selection of the final stage

The third stage of the site-selection process included the detailed investigation of (i) socioeconomic issues (through Rapid Rural Appriasal), (ii) hydrological issues, and (iii) environmental issues (through impact assessments). All available information concerning the five watersheds was provided to the socioeconomic specialists responsible for undertaking each type of assessment.

1.1.6 Final decision

The results of the above three investigations were synthesized to allow the multidisciplinary project team to reach a final decision. The team then met and discussed the whole site-selection process, paying particular attention to the following:

- The project's evaluation of the communities in each watershed
- The biophysical conditions within each watershed
- The degree to which each area was representative of the Badia
- Any obvious hydrological and environmental impacts

Ultimately, it was decided that two watersheds would be necessary to undertake project activities and that these should be representative of the wide range of conditions (biophysical and socioeconomic) found in the Badia. Consequently, watershed 104 was selected as the main watershed for the project, and watershed 59 as a supplementary watershed (Figure 1.4).

Table 1.5. Ranking of the potential watersheds.

	Watershed number					
Criterion	**128**	**30 and 31**	**59**	**108**	**104**	**119**
Production system	1	2	2	2	3	3
Community	3	3	3	3	1	0
Urbanization	–3	–2	–2	–3	0	–1
Institutions	?	?	?	?	?	?
Development projects	?	?	?	?	?	?
Scaling-out potential	1	2	2	3	3	3
Competitiveness of WH	1	2	2	2	3	2
Total score	3	7	7	7	10	7

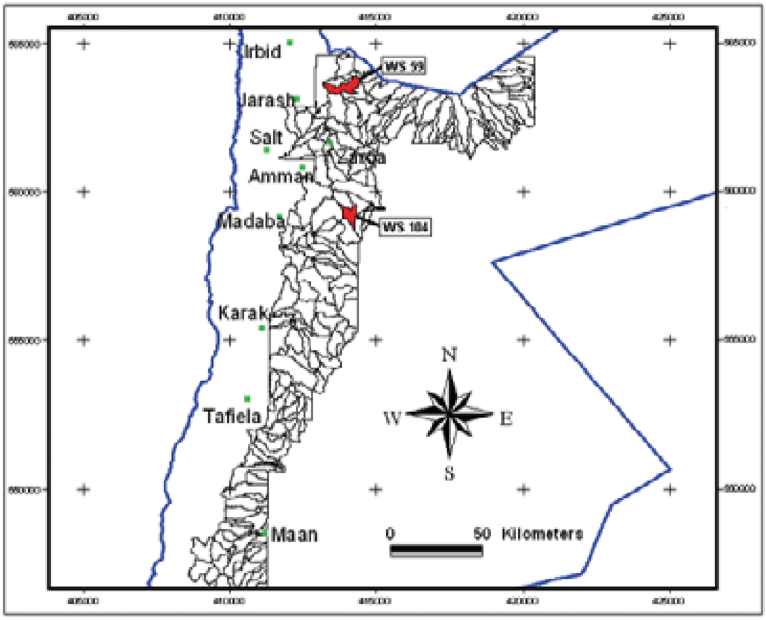

Figure1.4. The location of watersheds 104 and 59.

1.2 Characterization of the selected watersheds

1.2.1 Development of the suitability maps for water harvesting (WH) interventions

Watershed characterization aimed to provide data for the selection of sites suited to various WH interventions. To this end, data were collected from two watersheds (i.e. 59 and 104).

The main purpose of the characterization was to provide a suitability map showing the distribution of areas suited, from a biophysical point of view, to the various WHTs the project would implement within the watershed. The process emphasized the need for each unit to be suited to more than one type of intervention, in order to leave room to include socioeconomic issues in the selection process. In each case the intervention selected for an area must be acceptable biophysically, socially, and economically.

The sources of data used for the characterization of the selected watersheds were the Royal Jordanian Geographic Center for topographic and slope maps, and the Department of Land and Surveying for cadastral maps and data collection in the field. Suitability maps for WH interventions were then developed. The procedures and outcomes are detailed in a separate published report on Ziadat et al. (2006).

1.2.2 Watershed biophysical characterization (details described in Ziadat et al., 2006)

The dry rangelands of West Asia and North Africa are fragile and severely degraded due to low rainfall, drought, and mismanagement of natural resources. WHTs are used to improve soil moisture and hence vegetation cover and productivity in this environment. However, adoption of WHTs by the communities in the area is slow. To understand the constraints to adoption and to develop options for rapid and sustainable integration of WHTs within existing agro-pastoral systems, a benchmark watershed was established in the dry rangelands of Jordan. A methodology for identifying the suitability of different WHTs to various conditions at the watershed level was developed. The main biophysical parameters used to assess the suitability for WH in this environment were rainfall, slope, soil depth, soil texture, and stoniness. Criteria for each parameter were integrated and a suitability map was produced in a GIS environment. The suitability map was superimposed with land tenure and other ancillary maps. These maps were used to identify options for implementation of different WHTs with the local communities. Field investigations revealed that the applied approach helped in selection of the most promising fields. Within two years, four types of WH interventions were implemented in the fields of 41 farmers with a total area of 62.9 ha and in close collaboration with the local community. This approach showed that GIS may be used to integrate biophysical and socio-economic criteria to facilitate the selection of land that is suitable for implementing new land use alternatives. This ensures sustainable integration of WH interventions in the dry rangeland systems.

1.2.3 Study site and approach

The research site, named Mharib, is located in the eastern part of Amman district in Jordan within 31°39'–31°43' N and 36°12'–36° 18' E (Figure 1.5). The watershed has an area of approximately 60 km^2, within the xeric–aridic transitional moisture regime where annual rainfall range is 100–150 mm (Jordan transitional Badia). The major geologic formation is very finely dissected limestone, chert, and marl. The soils are highly calcareous and weakly saline, and have high silt contents, hard crusts, and weak aggregation on the surface layer. They are classified as Xerocherptic

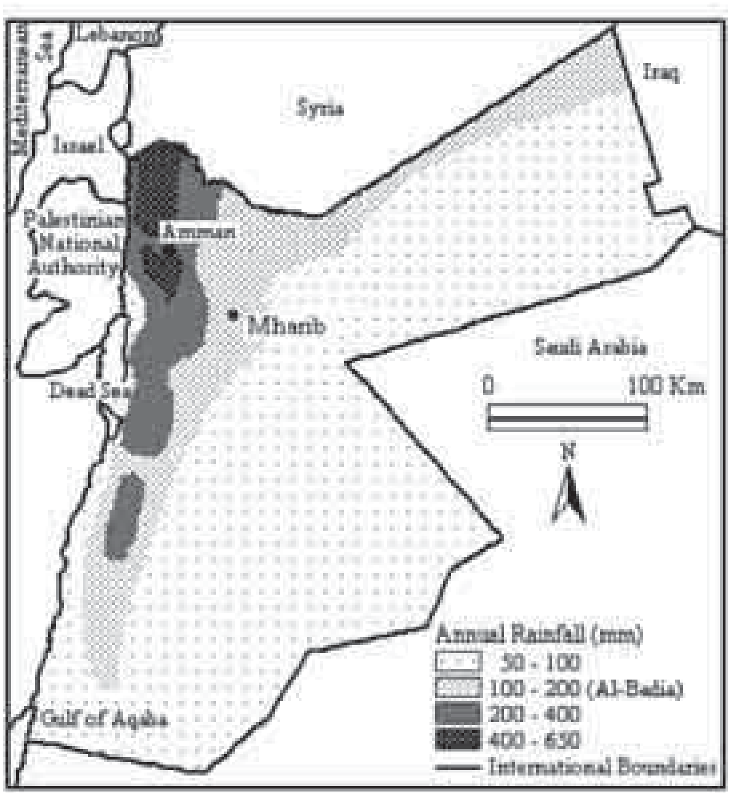

Figure1.5. Location of the study site (Mharib watershed) within the Jordanian transitional Badia.

Haplocambids and Haplocalcids (MoA, 1995). About 75% of the study area has shallow soils (< 50 cm) and slope gradients < 12%. The remaining part of study area has medium deep and deep soils with depth range of 50–140 cm. Rock outcrops cover 10% of the study area (MoA, 1995).

The elevation is 676–925 m above sea level. The watershed has rounded hills and crests, with steep upper slopes. Alluvial and colluvial fans merge downslope to fill the valleys. The watershed is characterized by highly degraded steppe vegetation, and barley is grown in the valley bottom and along the slopes where the moisture from the limited rainfall is augmented by runoff from the hill slopes. Barley and uncultivated land are the main land cover/land use types in the area. The dominant natural vegetation species are *Anabasis syriaca* and *Poa bulbosa*. The natural vegetation cover is degraded due to cultivation, overgrazing, and wood cutting.

A suitability analysis was undertaken to identify areas biophysically suitable for different WHTs. The process consists of three steps: (1) determining the bio-physical requirements of different WHTs, (2) biophysical characterization of land units, and (3) identification of areas suitable for WH interventions by matching steps (1) and (2).

a) Requirements for WH: The criteria used to determine the requirements of different WH interventions were: slope, soil depth, soil texture, vegetation cover, stoniness of the soil surface, and farm-size (Oweis et al., 2001) – discussions among an inter-disciplinary team of researchers led to some modifications of these criteria. For each criterion there were two ratings ('best' and 'second best' options), intended to provide more flexibility when determining the suitability of an intervention, and allowing for the incorporation of socioeconomic factors at a later stage. For example, if the land was suitable for three different interventions, the land user could select one of them based on his/her own preferences and needs. The final criteria agreed upon by the inter-disciplinary team of researchers are summarized in (Table 1.6).

b) Characterization of land units: The data required for the bio-physical characterization of the watershed were partly obtained from available data and from a dedicated field survey. Contour lines, stream lines, and spot heights were extracted from topographic maps (scale 1:50 000). A digital elevation model (DEM) with a 20-m resolution was generated from the contour lines and spot heights.

A slope map was derived from the DEM. The Arc/Info standard command 'SLOPE' was used to derive the slope grid. A 5 × 5 average (smoothing) filter was applied to clean the layer of small (suspicious) units.

The grid was then converted into polygons for subsequent analyses. Slope units (slope 1–18%) derived from this step were used as basic land-mapping units for the suitability analysis. Theoretically, soil mapping units should be used; however, this was not possible as the soil map available for the area (scale 1:250 000) provided insufficient detail. Fortunately, in the study area there was a strong relationship between slope steepness and the distribution of soils (Taimeh, 1989; Ziadat et al., 2003). In addition, slope steepness is one of the most important criteria for the selection and implementation of WH interventions.

The absence of detailed soil data is a common problem in arid areas. A field survey was designed to provide information on the relevant biophysical factors in the watershed. Samples were collected using a combination of two methods of sampling: free sampling and grid sampling. Grids composed of uniformly-sized cells were used (500 m × 500 m). One field observation was taken from each grid cell. To avoid an un-representative site being sampled, the surveyor was free to select the best site within each cell. This also ensured that the various conditions within

Table 1.6. Guidelines for selecting WHTs (modified from Oweis et al. 2001).

Technique	Crop	Soil						Land cover				Socio-economics	
		Depth (1)		Texture		Land slope (2)		Vegetation (3)		Stoniness (4)		Farm size (5)	
		P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Contour ridges	Range	shl	med	med	var	med	steep	poor	med	med	low	var	var
	Field	med	deep	med	var	low	med	poor	poor	low	low	sml	med
	Trees	deep	deep	heavy	med	med	low	poor	poor	low	med	sml	med
Semi-circular and triangular bunds	Range	shl	med	var	var	med	low	poor	med	med	low	var	var
	Field	med	deep	med	heavy	low	med	poor	poor	low	low	sml	med
Small basins	Trees	deep	deep	heavy	med	low	low	poor	med	low	med	sml	sml
Runoff strips	Range	med	var	med	var	med	low	poor	med	med	var	med	var
	Field	deep	med	med	med	low	med	poor	poor	low	med	sml	med
Inter-row system	Trees	deep	deep	heavy	med	low	low	poor	med	low	med	sml	med
Contour bench terraces	Trees	deep	med	heavy	heavy	steep	med	poor	med	low	med	sml	med
	Field	deep	med	heavy	var	steep	med	poor	poor	low	med	sml	med
Narrow-base contour terreces (Gradon)	Trees	deep	deep	med	heavy	steep	med	poor	med	low	low	sml	med
	Range	deep	med	med	var	med	steep	med	dense	low	med	med	var

Notes: P1= best conditions for this intervention (first priority), P2 =second-best conditions for this intervention (second priority)
(1) shl <50 cm, med: 50-100 cm, deep > 100 cm: (2) low < 4%, med: 4-12%, steep > 12%; (3) poor < 15%, med: 15-30%, dense > 30%; (4) low < 10%, med: 10-25%, high > 25%; (5) sml < 5 ha, med: 5-25 ha, large > 25 ha

the watershed were sampled by distributing the sampling evenly across the grids. The location of the sampling points was recorded with a GPS. The total number of sampling sites was 160. The following parameters were recorded for each field observation:

- Surface cover of stones (percentage stoniness)
- Vegetation type and coverage (visual estimation)
- Texture of the soil surface horizon (estimated by touch)
- Soil depth (cm): boreholes involved the digging of small 'chisel pits' to 40–50-cm depth, followed by augering to the auger's maximum depth or to an impeding layer (rock or large stones).

The Inverse Distance Weighted (IDW) interpolator of ArcView Spatial Analyst 3.2 was used to produce a continuous surface (grid file) of soil depth, stone percentage, soil texture, and vegetation cover. The interpolated grids were intersected with each other and with the slope-unit map. For each slope-unit the value of each variable was defined accordingly to provide a biophysical characterization of each unit.

c) Biophysical suitability for WH interventions: The criteria listed in (Table 1.6) were applied to each characterized slope-unit. The results in a row (Table 1.6) for each mapping unit and number of columns represent combinations of different WH interventions, each with different crop types (trees, field crops, and rangeland vegetation). For some cases two options were considered: best and second-best. In each column, the mapping units suited to the relevant intervention were marked with the symbol S1 (suitable), while those not suited to a particular intervention were assigned NS (not suitable). These data were compiled together to produce a biophysical suitability map of the watershed.

The biophysical suitability map (figure 1.7) was overlaid with the cadastral map to incorporate the area of the parcel as a final criterion for selection, resulting in a final WH suitability map. This is crucial for interventions that require a minimum area for successful implementation. The cadastral map was also used to identify the owner(s) of land suited for particular WH intervention(s). The socioeconomic team used this information to approach the relevant owner(s) and inquire about their interest in applying the recommended WH interventions in their land.

1.2.4 Findings and discussion

Interpolations for soil depth, stone percentage, soil texture, and vegetation cover were made for Mharib watershed (Figure 1.6), with the classes representing the values of each attribute as shown in (Table 1.6). The intersection of these grids with the slope-unit grid provides a biophysical characterization of each slope unit. Matching the requirements for various WHTs with

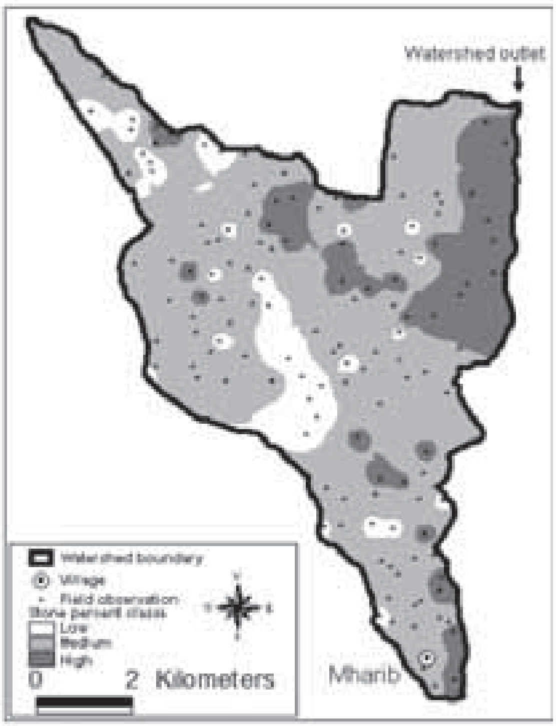

Figure 1.6. Surface stone cover classes (low < 10%, medium 10–25%, and high > 25%) in Mharib watershed, interpolated from field observations with the IDW method.

the characteristics of each slope-unit thus generated the biophysical suitability map of the watershed (Figure 1.7) – the abbreviations used in the legend are explained in (Table 1.7).

The team undertook several field visits to randomly selected sites to match the land suitability results with field suitability for various WH interventions. These visits indicated an acceptable agreement between land suitability from maps and those judged in the field.

A multi-disciplinary team visited the study area. The following data were used during the visits: (i) the land suitability map for different WH interventions (Figure 1.7); (ii) information on the locations of potential earth dams and hafair (small ponds), from separate hydrological analysis; (iii) satellite images and GPS (used for navigation); and (iv) cadastral maps. The team visited several sites and took notes and made observations (preliminary sites, Figure 1.8). The information was then summarized and used to decide on sites that should be selected, the interventions that should be applied at each site, and the priority of the selected sites for implementation.

The data collected was discussed during a meeting between the project team and the community. The results of this discussion are summarized in two points. First, the chance of successful implementation of interventions like earth dams and hafairs

Legend example, rs–r–p2: runoff strips – range crops – second best.

Figure 1.7. Potential land suitability for various WH options in Mharib watershed, see (Table 1.7) for legend abbreviations.

at sites which do not have communities nearby is limited. Such sites should be eliminated from further consideration. This decision excluded sites 1–5 (Figure 1.8), despite being rated as highly suitable from a biophysical point of view, the absence of community nearby would limit their use

Table 1.7. Index for WHTs.

Code	Wates-harvesting technique	Code	Crop/priority
CR	Contour ridges	R	Range crops
SCB	Semi circular bund	F	Field crops
SB	Small basins	T	Trees
RS	Runoff strips		
IRS	Inter row system		
CBT	Contour bench terraces	P1	Best
G	Gradoni	P2	Second Best

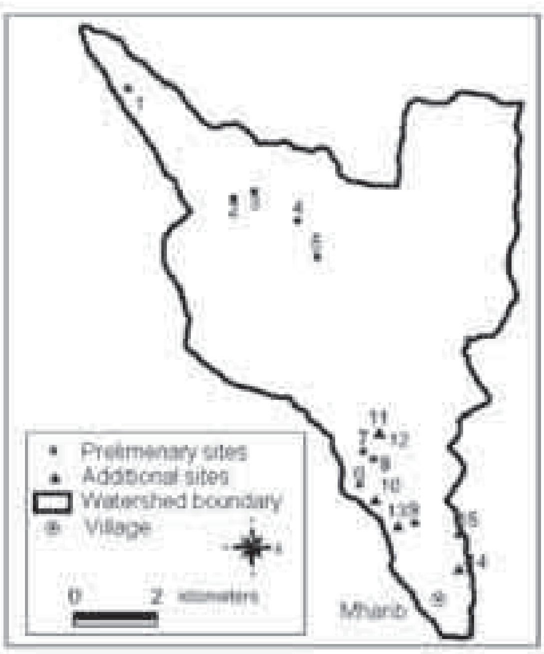

Figure 1.8. Locations of the sites considered for WH implementation.

and maintenance and therefore threaten their sustainability. Second, the project needed to collect information about the owners of sites deemed to have potential as a first step in the actual implementation of WH interventions. For potentially suitable sites, the owners were approached and the implementation of techniques discussed.

Some of the sites selected as potentially suitable were excluded from the study because their owners did not wish to participate in the project. Other sites were excluded because their owners did not live in the area (absentee owners) – a large number of land parcels were owned by people who have never lived in the area, since it is considered now suitable for investment, thus complicating the development of the area. A different approach was then followed by visiting the land of people who had indicated willingness to participate in the project. The biophysical suitability of their fields for their proposed interventions was assessed and consequently more sites were added to those previously considered and were marked as additional sites (Figure 1.8). This approach gave the farmers the opportunity to express their needs and at the same time incorporate the biophysical suitability of their land, which is an effective way to gain more involvement and participation of the local community.

Ultimately, all sites selected by this process were judged to be both biophysically and socioeconomically suitable to implement WH intervention(s) and to have a high chance of success. The project's technical team undertook data collection and detailed surveys at these sites, in order to design and implement various interventions. Within two years, four types of WH interventions were implemented in 41 farmers' fields (total area 62.9 ha) in close collaboration with the local community.

The Vallerani WHT (mechanized semi-circular bunds) was implemented in 17 fields (43.4 ha), contour ridges in 18 fields (14.5 ha), contour strips in four fields (3.9 ha), and narrow strips in two fields (1.1 ha).

Evaluation during field investigations showed that the applied approach for assessing WH suitability was very promising. Water harvesting is site-specific, and assessing the suitability of the land requires quantitative data and involves interaction between specific criteria. Therefore, the capacity of GIS to integrate different types of information facilitates and speeds up the process. Given that basic information is available, the approach could be applied for other suitability analyses for introducing WHTs in arid and semi-arid areas. GIS facilitated the integration of bio-physical and socio-economic aspects to undertake the selection process.
The findings of the field visits agreed with those of the suitability analyses. This emphasizes that these methods are reliable and could be used to choose sites suited to different types of WH interventions. The analyses undertaken using GIS information narrowed down the number of sites visited

by the team, guiding them to sites with a high potential for the intended WHTs.

Two methods of selection were adopted and used successfully to pick the most promising sites. The first utilized the suitability maps and then, using information from cadastral maps, the owners were approached and their willingness to cooperate was assessed. The other method was by allowing the local inhabitants to express their need for implementing of WHTs and then, by referring to the land suitability maps, the possibilities of implementing WH based on biophysical conditions was assessed. This iterative process proved to be efficient and practical in planning a successful WH scheme. The approach integrated biophysical and socioeconomic aspects in a dynamic way that benefited the whole process (Ziadat et al., 2006)[1].

1.3 References

Ziadat,F., Oweis, T., Mazahreh, S., Brugge man, A., Haddad, N., Karablieh, E., Benli, B., Abu Zanat, M., Al-Bakri, J., Ali, A. 2006. Selection and characterization of badia watershed research sites. International Center for Agricultural Research in the Dry Areas, Aleppo, Syria.

Chapter 2

Effect of water harvesting techniques on water productivity and soil erosion

Chapter 2: Effect of water harvesting techniques on water productivity and soil erosion

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

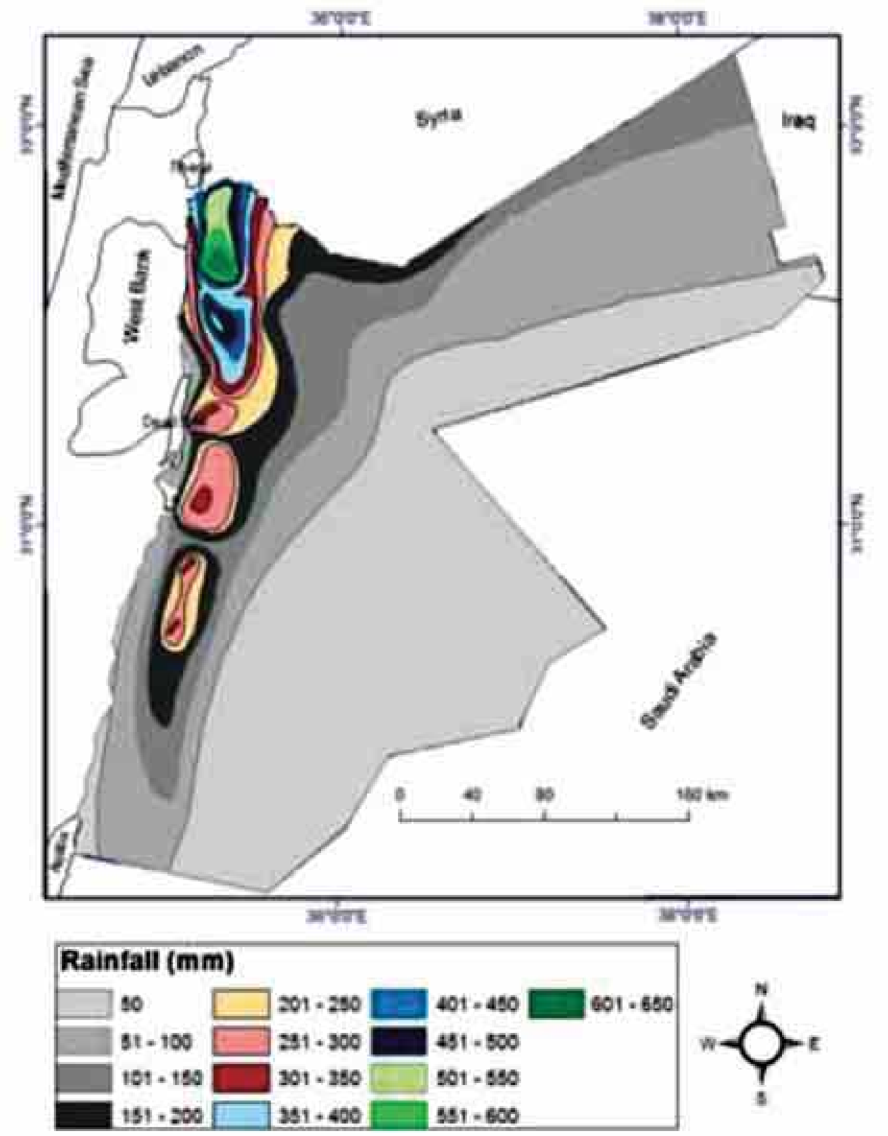

Figure 2.1. Annual rainfall of the Badia.

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 seminomadic, 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.

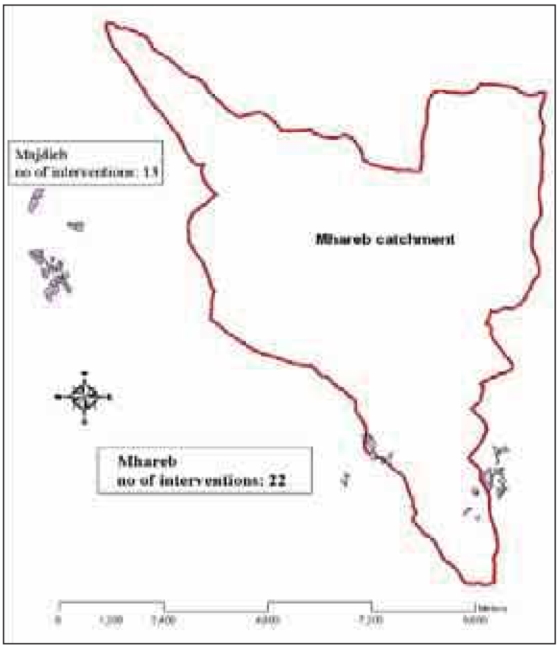

Figure 2.2. Selected watershed with intervention sites at both Mharib and Majidiyah.

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 (31° 40’ 27.1’’ North; 36° 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

<u>Fodder Shrub Production</u>

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.

<u>Soil Moisture</u>

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.

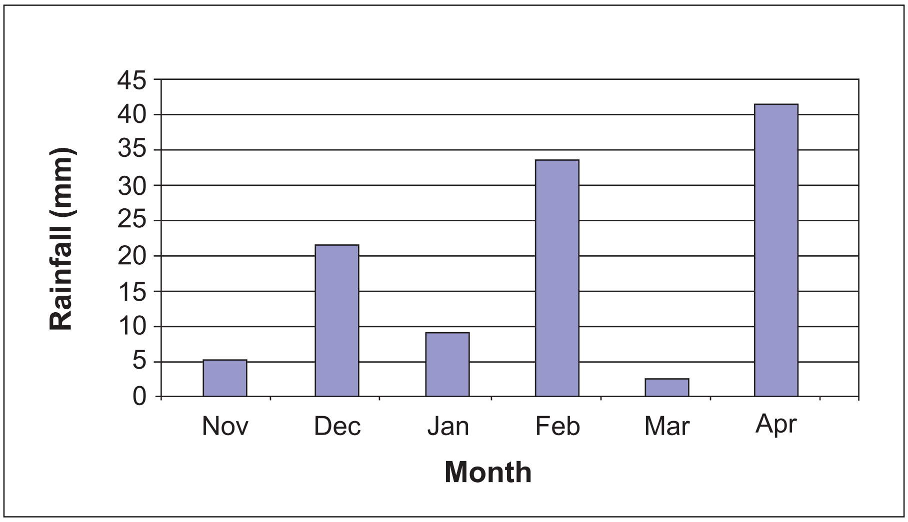

Figure 2.3. The monthly rainfall distribution at Mharib (2005/06 season).

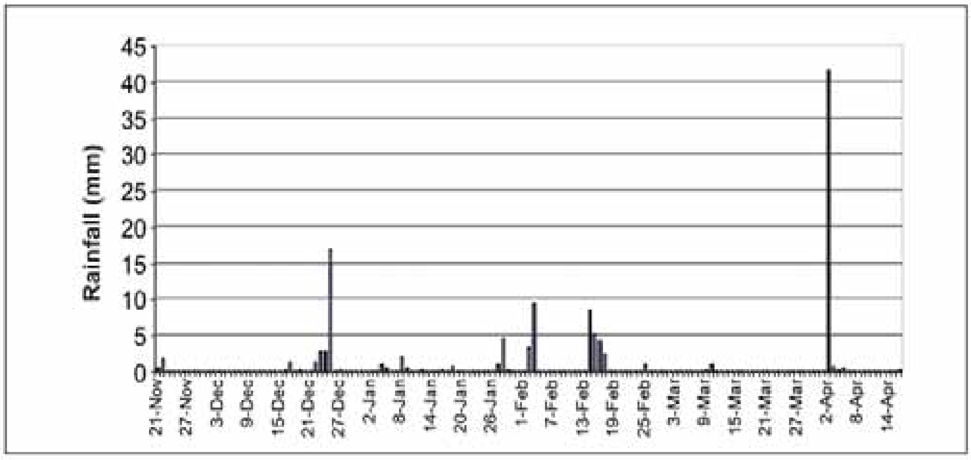

Figure 2.4. Daily rainfall pattern at Mharib (2005/06 season).

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).

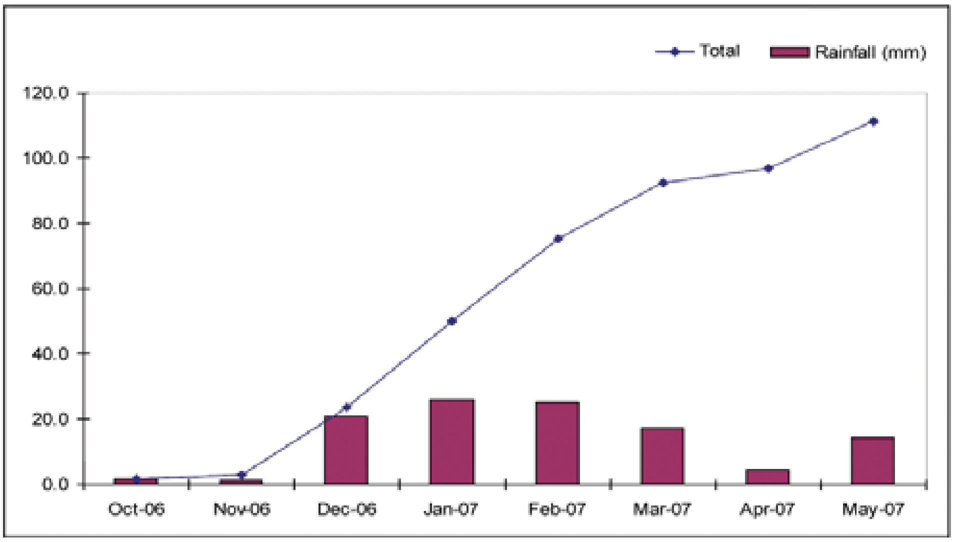

Figure 2.5. Monthly rainfall distribution (in mm) at Mharib (2006/07 season).

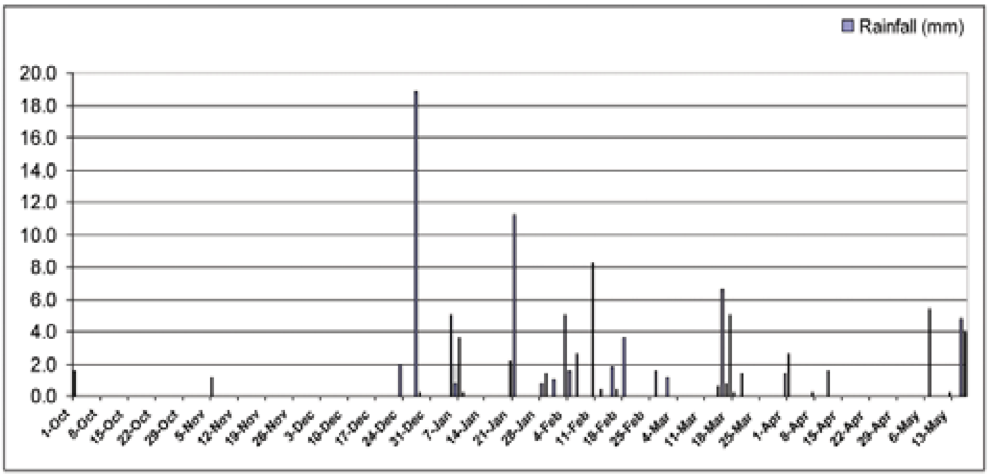

Figure 2.6. Daily rainfall distribution at Mharib (2006/07 season).

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-

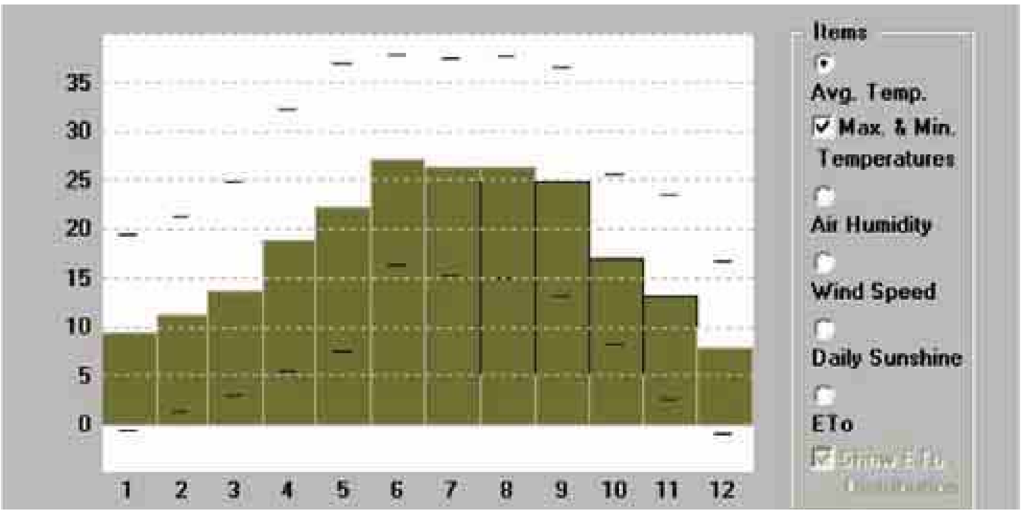

Figure 2.7. Temperature values (average, maximum, and minimum) on a monthly basis for Mharib (2006/07 season).

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.

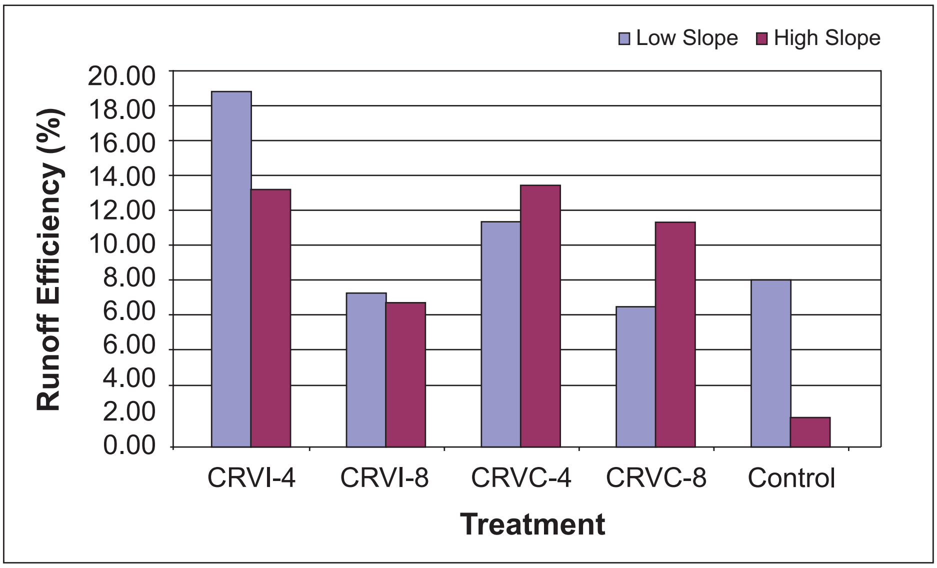

Figure 2.8. Runoff efficiency for the different treatments in the 2005/06 season (x-axis is treatment type: continuous and intermittent ridges with 4-m and 8-m spacing).

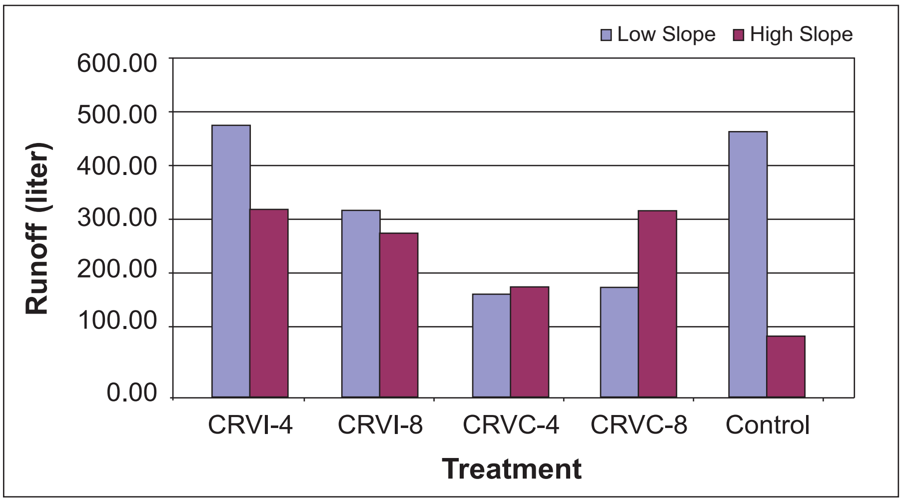

Figure 2.9. Runoff volume under the different treatments for the 2005/06 season.

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.

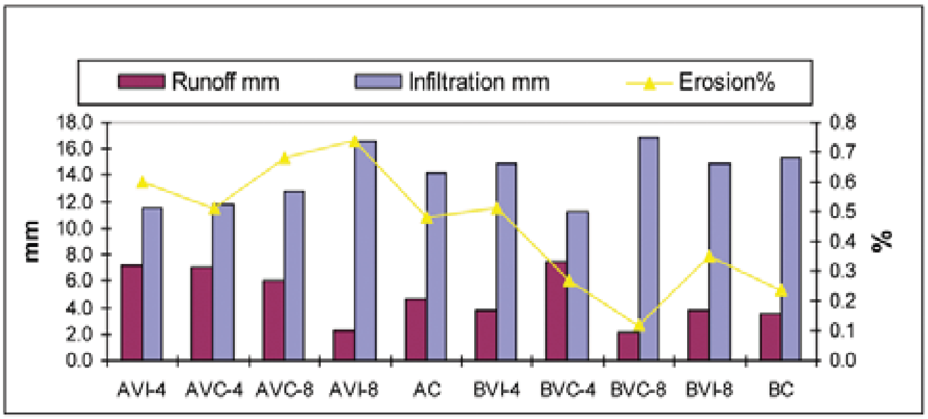

Figure 2.10. Runoff, infiltration, and soil erosion for the 2006/07 season.

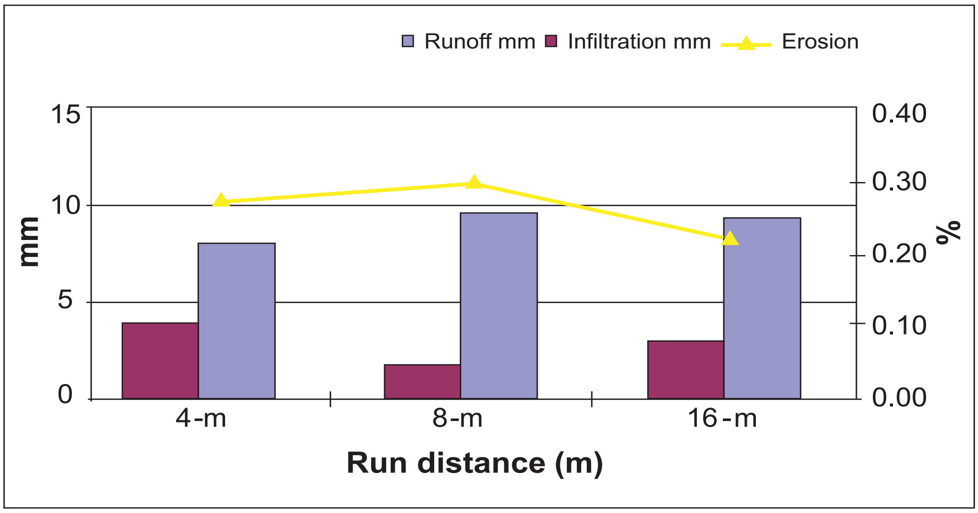

Figure 2.11. Runoff, infiltration, and soil erosion for the 2006/07 season.

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

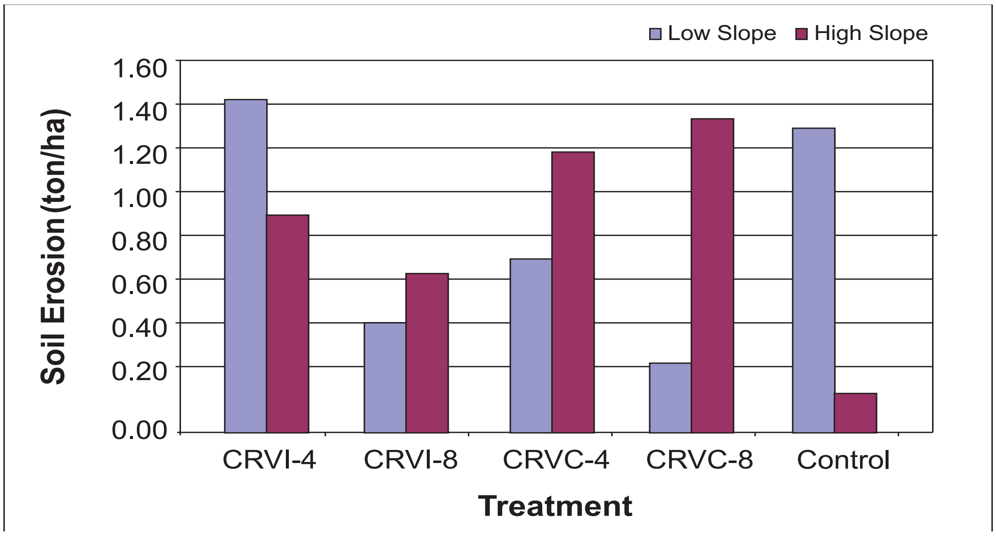

Figure 2.12. Total soil erosion under the different treatments (2005/06 season).

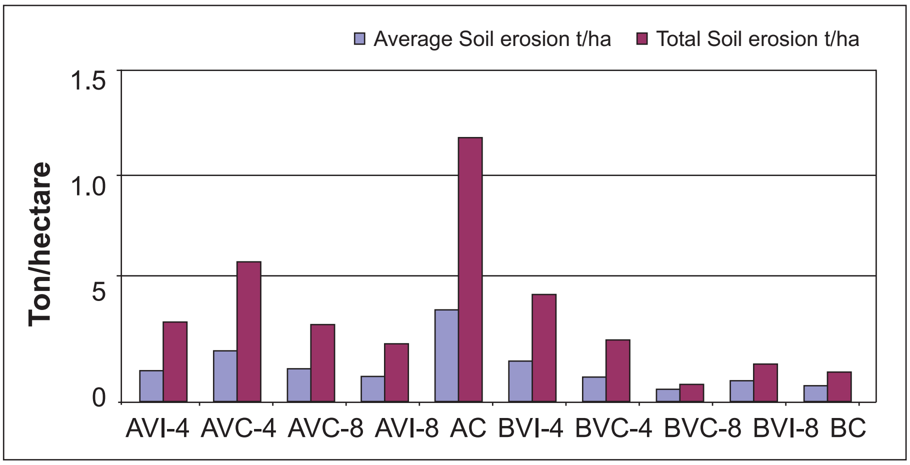

Figure 2.13. Soil erosion under the different treatments (2006/07 season).

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).

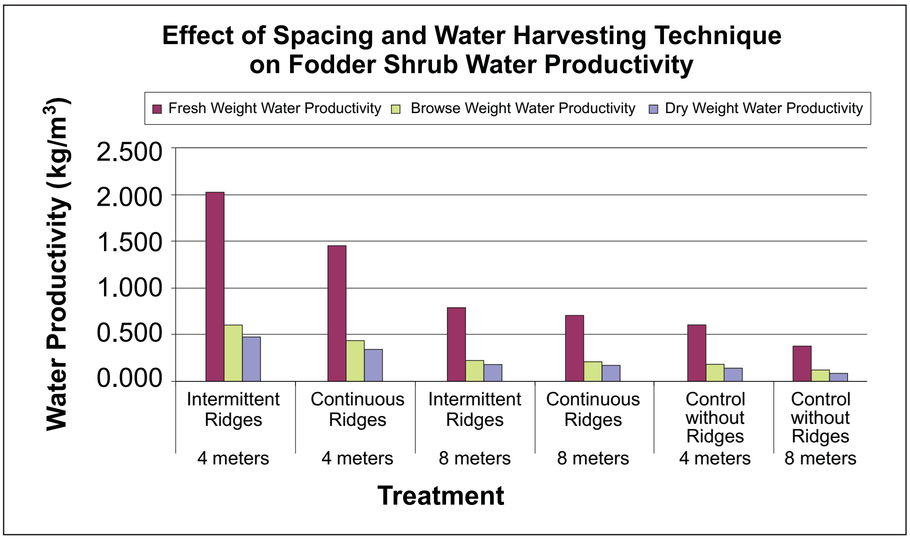

Figure 2.14. Water productivity of *Atriplex* shrubs as affected by WHT and land slope (2006/07 season).

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).

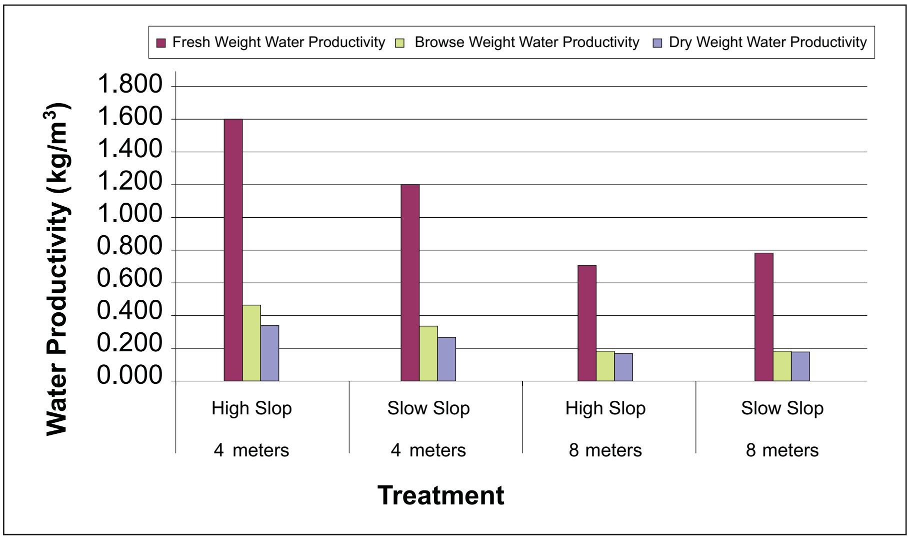

Figure 2.15. Water productivity of *Atriplex* shrubs as affected by spacing of contour ridges and land slope (2006/07 season).

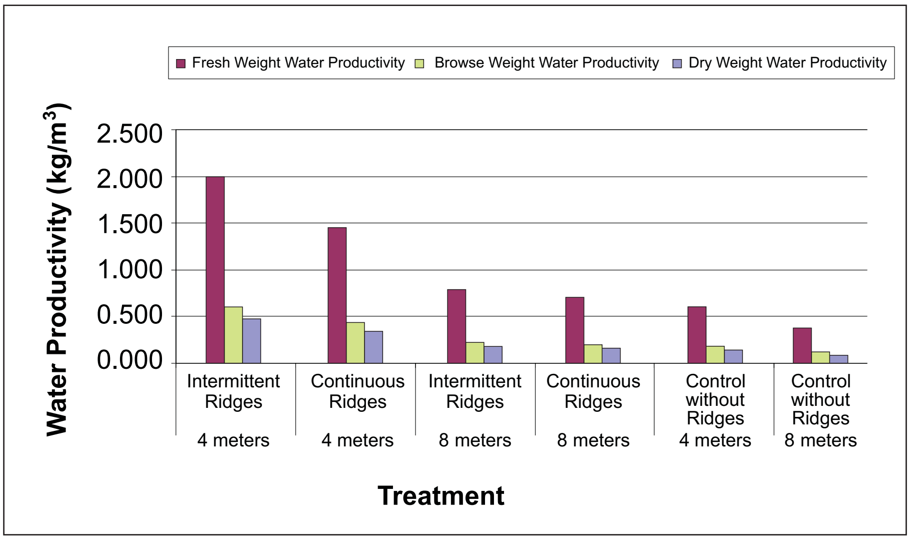

Figure 2.16. Water productivity of *Atriplex* shrubs as affected by WHT and spacing of contour ridges (2006/07 season).

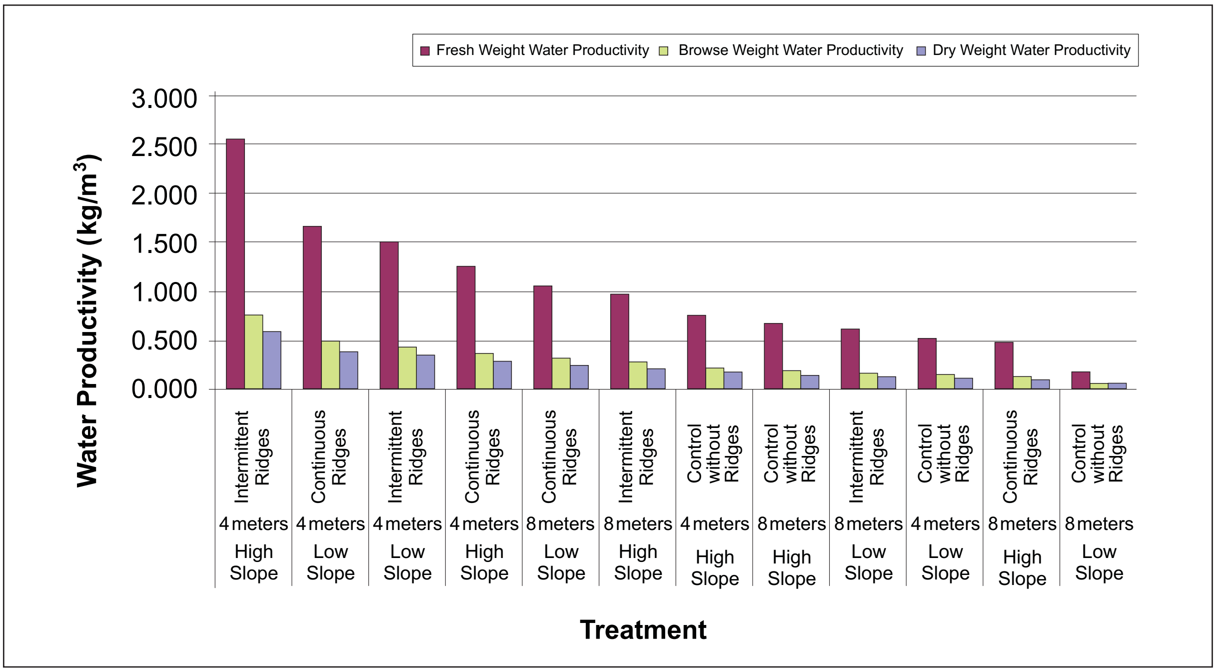

Figure 2.17. Water productivity of Atriplex shrubs as affected by WHT, spacing between contour ridges, and land slope (2006/07 season).

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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Chapter 3

Microcatchment water harvesting systems for fruit trees and shrubs

Chapter 3: Microcatchment water harvesting systems for different fruit trees and shrubs

B. A. Snobar, T. Oweis and H. Nofal

3.1 Introduction

Jordan depends on annual rainfall, estimated at 8500 million m³, for water for its domestic and irrigation needs since there are no rivers or lakes in Jordan, and the River Jordan is almost dry. Therefore, the utilization of surface water has been the focus of the Jordanian government for decades. Many dams have been built in the Jordan Valley and other places in Jordan to secure water for irrigation; however, a large percentage of this water has been shifted from irrigation to domestic use.

The water reserved behind dams (i.e. macrocatchment water harvesting) is used to irrigate land downstream through complicated and expensive irrigation systems, and so there was an urgent need to find a way to supplement the rainfed irrigated area located in the highlands, particularly those in the eastern desert of Jordan (called the Badia) by using microcatchment water harvesting (WH) systems.

Microcatchment WH is recognized as useful technique in improving vegetation and reducing land degradation. In the last ten years, increasing attention has been given by the Jordanian Government and farmers to microcatchment WH systems in the low rainfall zones (< 250 mm) to enable production of crops which require 300–400 mm of rainfall.

Experiments were conducted for four years (2002/03–2005/06) using the following microcatchment WH systems:

- Small runoff basins and semicircular bunds for fruit trees
- Ridges for shrubs
- Runoff strips for field crops (only 2002/03 and 2003/04 seasons)

The results obtained from the 2002/03 and 2003/04 seasons were encouraging for the small runoff basins, semicircular bunds, and ridges. However, the use of runoff strips to produce field crops did not significantly increase yields compared to not using the WH system. Thus the runoff strips were not used in the experiments of 2004/05 and 2005/06.

Since manually constructing the ridges is costly and time consuming, the Vallerani implement (Photo 3.1) was used to construct the ridges, up to 5 m long, 0.5 m wide, and up to 0.5 m deep, at an average rate of 400 bits/h at estimated cost

Photo 3.1. (a) The Vallerani implement, (b) the field after implementing the microcatchments, (c) target basins full of runoff water after a rainstorm and (d) small ruminants grazing shrubs after two seasons

of US$0.15/bit; compared to US$1.50/bit at a rate of 8 bits/d if done manually. The Vallerani implement can also make continuous contour ridges at a rate of 1 ha/h with 5-m spacing between ridges.

The Vallerani implement is a mounted reversible single-furrow plow, fitted with a subsoiler with a mechanism for gathering the surface fertile layer of soil and depositing it at regular and selected pre-set programmable intervals in the furrow in order to create ridges.

This report will focus on results of 2004/05 and 2005/06 seasons in which the conventional handmade microcatchment was compared to the mechanized one through research done at the Jordan University of Science and Technology site.

3.2 Materials and methods

3.2.1 Site specification

The experiment site, on the Jordan University of Science and Technology (JUST) campus at Ramtha City, is located at 32° 33' N, 35° 51' E and 520 m altitude. It is located in the semiarid zone in which the average annual rainfall is < 250 mm with an erratic distribution over the rainy season, which starts in October and ends in May (Tables 3.1a and 3.1b, and Figure 3.1).

An area of 12 ha of land located on the north east of JUST campus was selected (Figure 3.2). This piece of land was surveyed and the topographical map drawn. Soil profile description and analysis of the study area is shown in (Table 3.2).

3.2.2 Methodology

Four microcatchment WH systems were tested:
- Runoff basins
- Semicircular bunds
- Conventional ridges
- Mechanized ridges using Vallerani implement (Photo 3.1).

Runoff basins and semicircular bunds

The experiment was conducted on a 4-ha area. The experiment was a Completely

Table 3.1a. Monthly and seasonal rainfall distribution (mm) at Ramtha station for 1994/95–2005/06 seasons.

Season/ Month	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
1994/95	0.0	4.0	146.2	73.5	3.4	27.2	18.5	6.3	6.8	285.9
1995/96	0.0	0.0	0.0	31.1	52.6	7.0	58.2	3.9	0.0	152.8
1996/97	0.0	15.4	27.3	20.3	54.8	69.1	48.8	11.5	0.8	248.0
1997/98	2.9	26.7	27.5	60.3	64.9	31.9	76.5	4.4	5.6	300.7
1998/99	0.0	0.0	0.5	13.8	30.7	29.2	15.7	10.8	0.0	100.7
1999/00	0.0	0.0	0.0	7.6	94.1	20.2	19.0	0.0	0.0	140.9
2000/01	0.0	37.0	0.0	23.4	15.4	41.8	18.3	3.6	6.6	146.1
2001/02	0.0	3.7	23.2	55.0	73.8	19.1	66.0	32.0	0.6	273.4
2002/03	0.0	0.0	17.2	111.1	31.5	141.0	71.4	10.1	0.6	382.9
2003/04	0.0	14.8	5.3	65.0	58.1	44.4	17.7	2.8	3.1	211.2
2004/05	0.0	22.8	48.8	19.6	32.2	86.9	20.0	7.1	3.0	240.4
2005/06	0.0	5.3	14.6	30.0	50.8	49.5	8.8	29.7	0.0	188.7
Average	0.2	10.8	25.9	42.6	46.9	47.3	36.6	10.2	2.3	222.6

Table 3.1b. Monthly and seasonal rainfall distribution (mm) at the newly established weather station on JUST campus close to the experimental site for 2002/03–2005/06 seasons.

Season/ Month	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total
2002/03	0.0	0.0	5.0	113.8	26.4	162.3	77.6	9.5	0.0	394.6
2003/04	0.0	6.2	15.2	63.5	47.4	63.5	18.0	3.5	7.8	225.1
2004/05	0.0	16.0	52.5	19.5	30.7	91.0	8.0	2.4	3.5	223.6
2005/06	0.0	0.0	18.3	24.3	46.6	76.1	9.2	33.0	0.0	207.5
Average	0.0	5.6	22.8	55.3	37.8	98.2	28.2	12.1	2.8	281.1

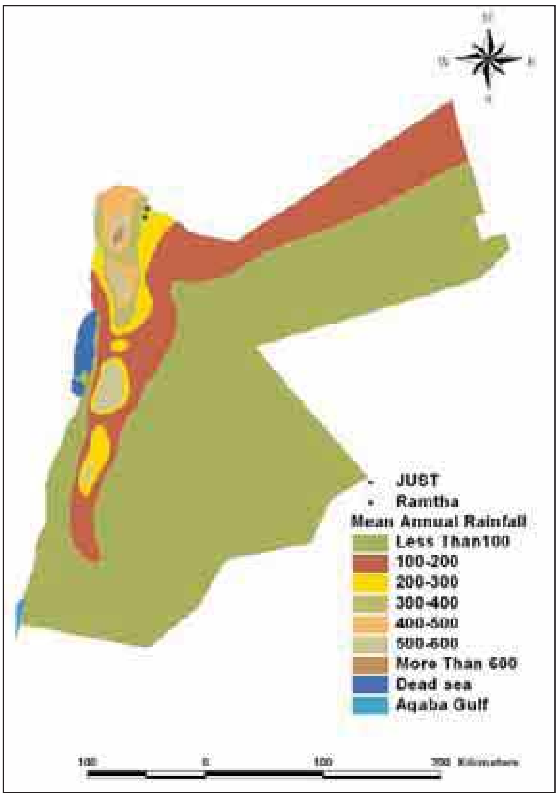

Figure 3.1. Mean annual rainfall in Jordan and location of the experimental site.

Table 3.2. Soil analyses of the experimental site.

Soil depth (cm)	0–20	20–40
pH	8.08	8.18
EC (ds/m)	1.006	0.445
Nitrogen (%)	0.083	0.107
Phosphorus (µg P/g soil)	58.3	41.1
Soil particle size distribution		
Clay (%)	59.25	48.40
Silt (%)	23.75	26.40
Sand (%)	16.95	25.20
Texture	Clay silty loam	Clay silty loam
Infiltration rate		
planted area	8.4 cm/h	
Infiltration rate		
Catchment area		
(compacted)	6.0 cm/h	
Infiltration rate	7.2 cm/h	
Catchment area		
(control)		

Randomized Design (CRD) in a split-plot arrangement, microcatchment types in the main plots, and microcatchment size in the subplots (Figures 3.3 and 3.4, and Photos 3.2 and 3.3). Fruit trees species selected for the experiment were pistachio (*Pistachio vera*), wild almond (*Prunus dulcis*), and olive (*Oleas europea*). Weeds grown on the plots were removed manually.

The applied treatments differed according to species:
Pistachio trees received two microcatchment type treatments: runoff basins and semicircular bunds with three catchment area treatments: 36, 64, and 100 m^2 with 12 replicates.

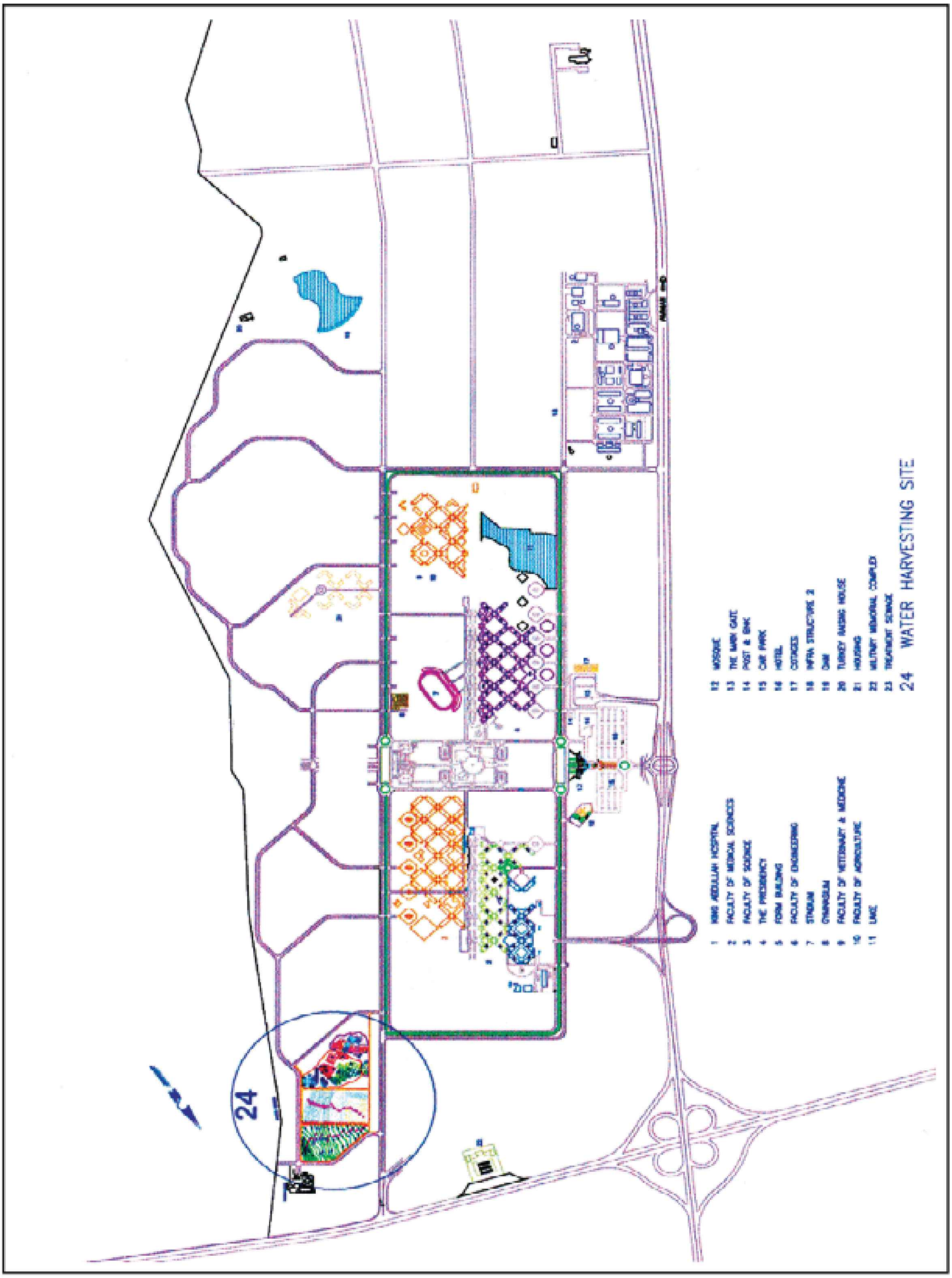

Figure 3.2. Location and layout of the water harvesting experimental site on the JUST campus.

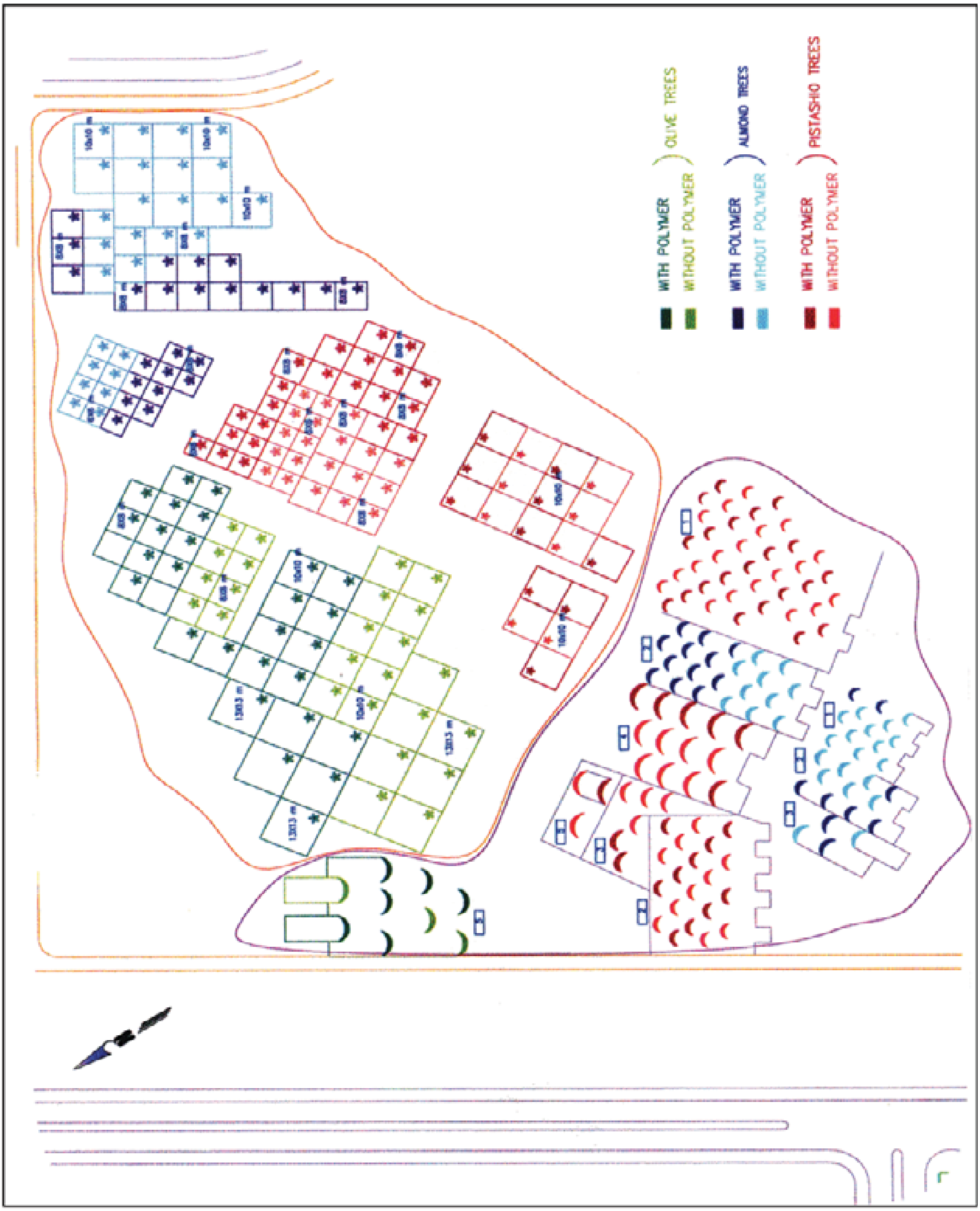

Figure 3.3. Layout of the runoff basin and semicircular bund experiment.

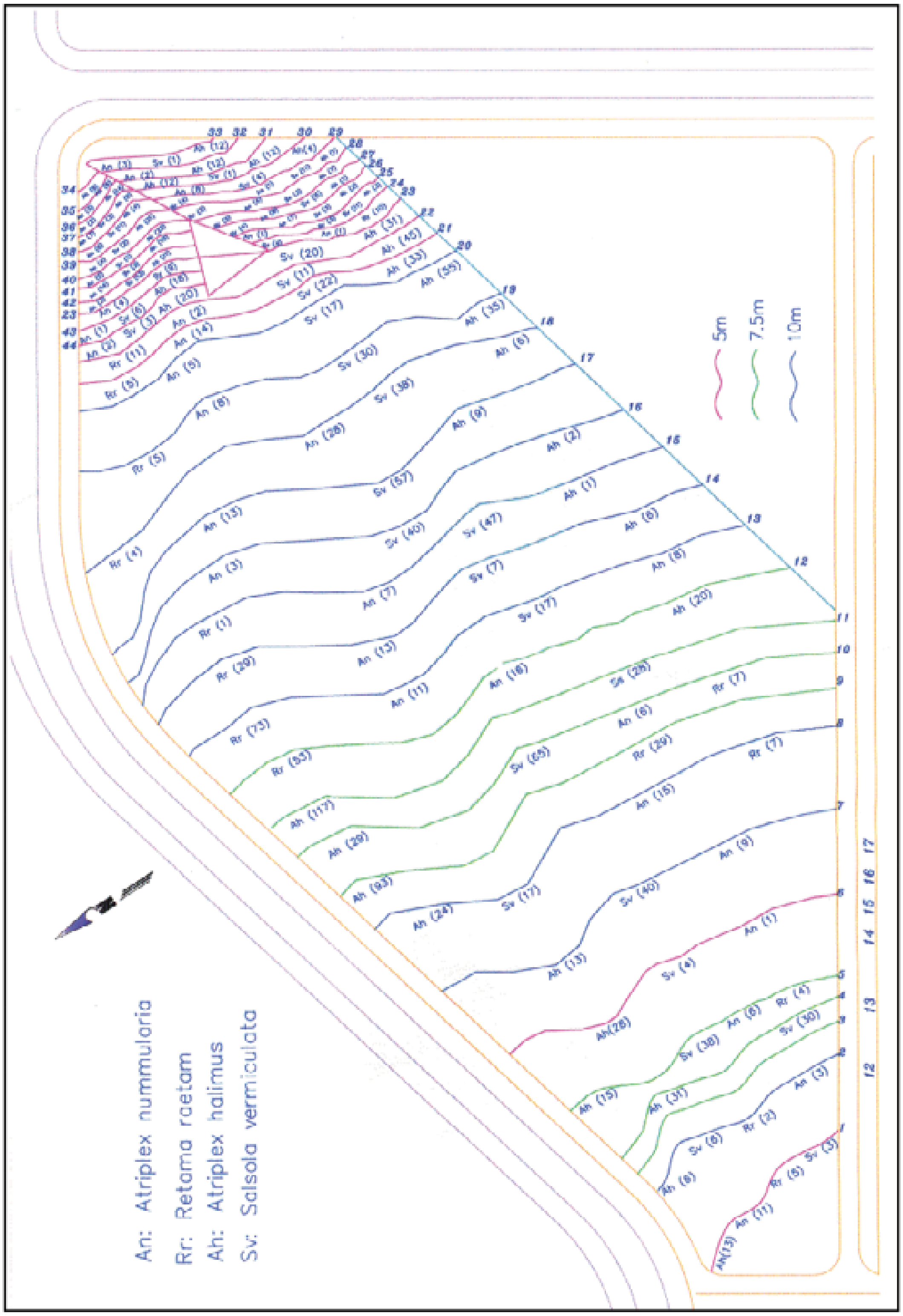

Figure 3.4. The dimensions and sizes of catchment areas of the semicircular bunds (1–5) in the Vallerani ImplementVallerani implement experiment (6 and 7).

Photo 3.2. The runoff basins for fruit trees after the 2nd seasons.

Photo 3.3. The semi-circular bunds for fruit trees.

Almond trees received three catchment area treatments: 36, 64, and 100 m^2. Each of the 36-m^2 and 64-m^2 treatments was assigned to four semicircular plots and six runoff basins; the 100-m^2 was applied to two semicircular plots and three runoff basins.

Olive trees received three catchment area treatments: 64, 100, and 169 m^2. The 64-m^2 treatment was applied to 12 runoff basins, the 100-m^2 to 6 runoff basins, and the 169-m^2 to six semicircular bunds and 12 runoff basins.

A control treatment was included in which no catchments were prepared.

Trees were planted on 15 and 16 March 2003 and some were replanted on 1 January 2004. Parameters measured included:

- Amount of water harvested
- Survival rate
- Vegetation cover

Conventional ridges

The experiment was conducted on 6 ha of land using conventional methods – a combination of using a disc plow and manual labor. Ridges were planted with shrub species at 2 m apart during January 2004 and some shrubs were replanted during December 2004. The planted shrubs were two Atriplex spp. (*A. halimus and A. nummularia*), retem (*Retama raetam*), and Mediterranean saltwort (*Salsola vermiculata*). A control treatment was included in which no catchments were prepared.

The experiment was a CRD with treatments of three spacings between ridges with unequal numbers of replicates. Treatments were 5, 7.5, and 10-m spacing between ridges forming 10, 15, and 20 m^2 catchment areas, respectively. The 7.5-m spacing treatment was replicated seven times, the 10-m spacing was replicated 11 times, and the 5-m treatment was replicated 26 times (Photo 3.4 and Figure 3.5). Parameters measured were amount of harvested water, survival rate, vegetation cover, and plant height.

Mechanized ridges

The experiment was conducted on 2 ha of land. The Vallerani implement was used to form the ridges, which were approximately 2.8 m long, 0.5 m wide, 0.4 m deep, and 1.2 m apart (Figure 3.6 and Photo 5). Treatments of two microcatchment spacings

Photo 3.4. The conventional ridges site for shrubs.

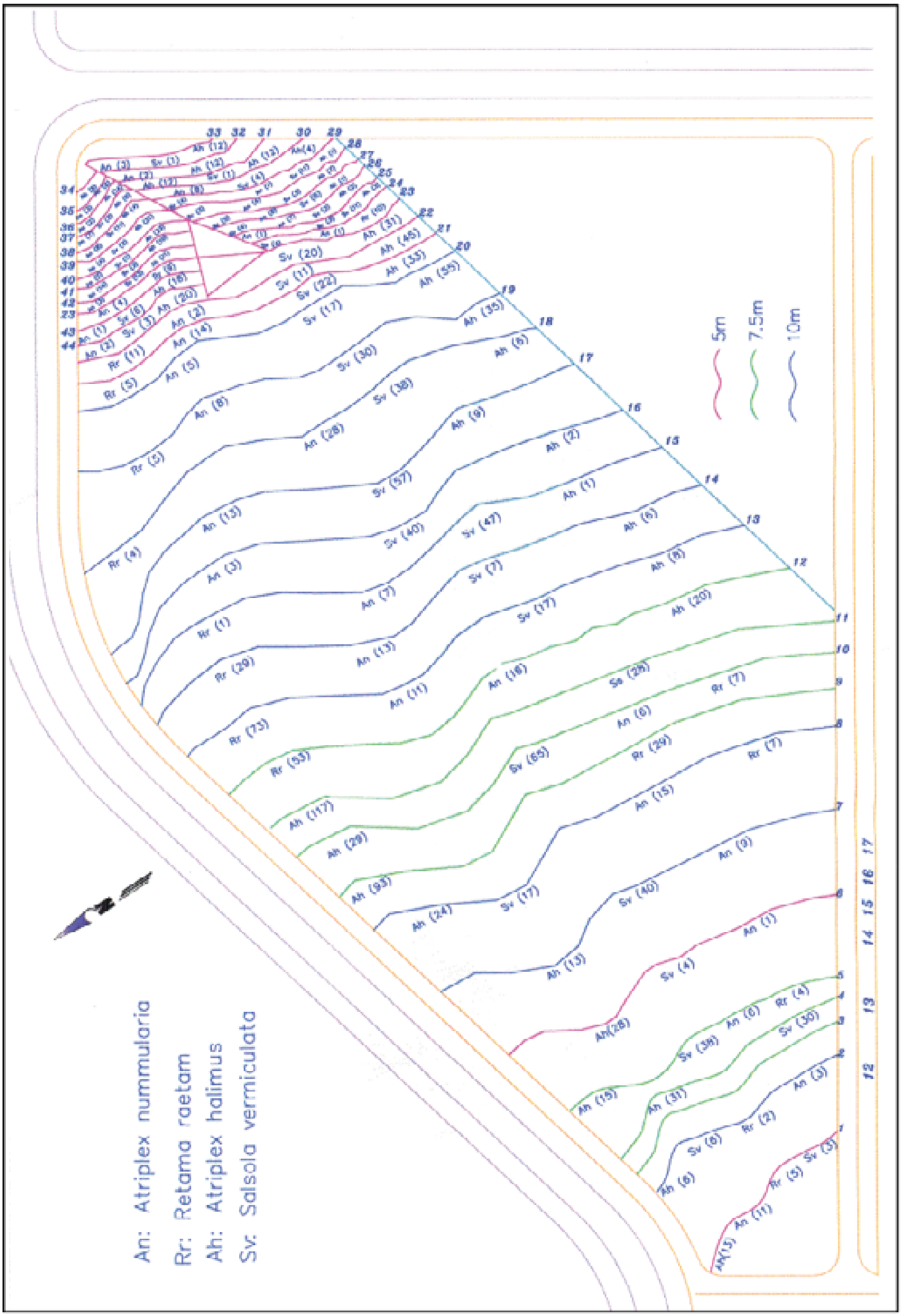

Figure 3.5. Layout of contour ridge experiment.

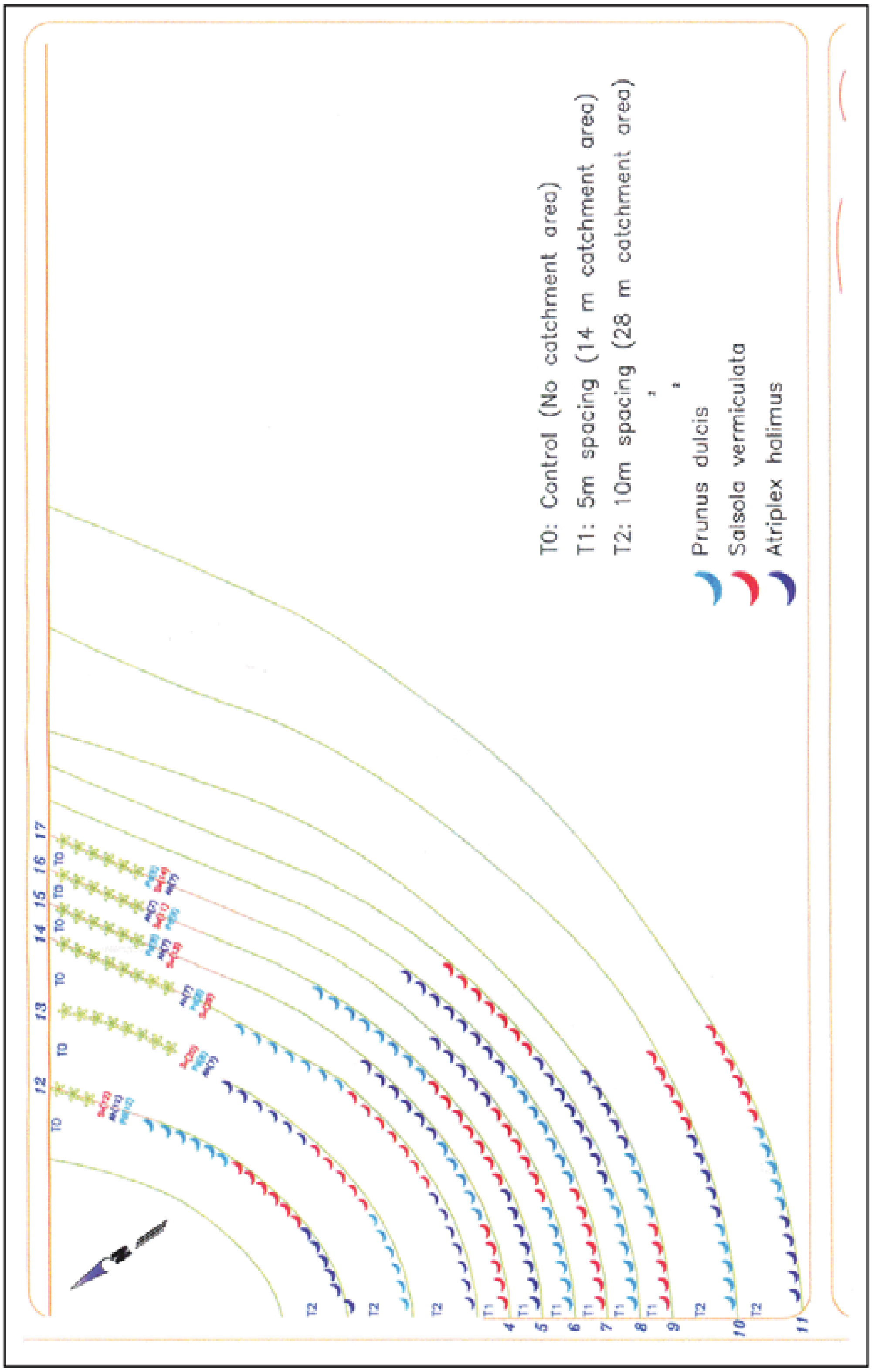

Figure 3.6. Layout of the Vallerani implement experiment.

Photo 3.5. The (Vallerani) ridges for forage shrubs after 3 seasons.

between ridges were used: one at 5 m, forming 14-m^2 catchments; and the other at 10-m spacing, forming 28-m^2 catchments. Wild almond, *A. halimus*, and *Mediterranean* saltwort were used in the experiment. A control treatment was included in which no catchments were prepared.

All selected species were planted on 9 January 2005. Two seedlings, 1 m apart per each species were planted in each ridge.

A CRD with unequal replicates was used. Control and 5-m spacing treatments had six replicates each, and the 10-m spacing treatments had five replicates.

Parameters measured were amount of harvested water, survival rate, vegetation cover, and plant height.

3.3 Results and discussion

In this report, the emphasis is on results for the ridges; however, for the sake of completing the picture on the microcatchment WH systems, the results of the runoff basins and semicircular bunds will also be discussed.

3.3.1 Runoff basins and semicircular bunds

Amount of water harvested: The amount of water harvested was higher in the runoff basins followed by semicircular bunds and least in controls for all fruit trees (Tables 3.3 and 3.4). The catchment size had no effect on the volume of water harvested. The percentage of evapotranspiration was highest in the runoff basins followed by semicircular bunds and lowest in controls (Tables 3.5 and 3.6).

Survival rate: The survival rate was 100% for all catchment sizes.

Vegetation cover: Vegetation cover was measured in terms of canopy diameter. The canopy diameter was not influenced by the type of catchment or by their size (Tables 3.7 and 3.8).

3.3.2 Conventional ridges

Amount of water harvested: The amount of water harvested and the percentage of evapotranspiration were highest for a catchment area of 20 m^2 (10-m spacing) and 15 m^2 (7.5-m spacing), and lowest for controls (Table 3.9).

Table 3.3. Amount of water harvested (cm) for fruit trees for two catchment types during the 2005/06 rainy season.

Catchment type	Pistachio	Almond	0–20
Control*	69 c**	69 c	69 c
Runoff basins	96 a	98 a	101 a
Semicircular bunds	86 b	87 b	95 b

Note: * Without catchment

** Means followed by the same letters are not significantly different (*P* < 0.05).

Table 3.4. Amount of water harvested (cm) for fruit trees for two catchment types during the 2005/06 rainy season.

Catchment area	Pistachio	Almond	Olive
36 m^2	90 a	90 a	– *
64 m^2	92 a	94 a	102 a
100 m^2	91 a	95 a	101 a
169 m^2	–	–	99 a

Note: * Not applicable catchment area.

Table 3.5. Evapotranspiration percentage for fruit trees for different catchment types during the 2005/06 growing season.

Catchment type	Pistachio	Almond	Olive
Control*	75 c	69 c	66 c
Runoff basins	104 a	324 a	97 a
Semicircular bunds	93 b	289 b	90 b

Note: * Without catchment.

Table 3.6. Evapotranspiration percentage for fruit trees for different catchment areas during the 2005/06 growing season.

Catchment area	Pistachio	Almond	Olive
36 m^2	98 a	297 a	–*
64 m^2	100 a	311 a	97 a
100 m^2	99 a	316 a	96 a
169 m^2	–*	–*	95 a

Note: * No applicable catchment area.

Table 3.7. Canopy diameter for fruit trees for different catchment types during the 2005/06 growing season.

Catchment type	Pistachio	Almond	Olive
Runoff basins	50 a	43 a	46 a
Semicircular bunds	52 a	37 b	35 a

Table 3.8. Canopy diameter for fruit trees for different catchment areas during the 2005/06 growing season.

Catchment area	Pistachio	Almond	Olive
36 m^2	53 a	35 a	–*
64 m^2	50 a	42 a	41 a
100 m^2	51 a	43 a	58 a
169 m^2	–*	–*	42 a

Note: * Not applicable catchment area.

Table 3.9. Amount of water harvested and evapotranspiration (ET) percentage for conventional ridges at different spacing treatments (catchment areas) during the 2005/06 rainy season.

Spacing (Catchment area)	Amount of water harvested (cm)	ET (%)
Control	66.5 c	120 c
5 m (10 m^2)	74.4 b	134 b
7.5 m (15 m^2)	77.5 ab	139 ab
10 m (20 m^2)	80.6 a	145 a

Survival rate: The survival rate was 100% for all species in all treatments.
Vegetation cover: The vegetation cover was greatest at 10-m spacing (20 m^2 area) and lowest in controls, i.e. no catchments (Table 3.10).

Plant height: The increase in plant height was not affected by catchment size for all shrub species (Table 3.11). However, the increase in plant height for controls (no catchments) was significantly lower than for catchment treatments.

3.3.3 Mechanized ridges

Amount of water harvested: The amount of harvested water was significantly higher for catchment areas of 14 and 28 m^2 than for the control (Table 3.12). However, the evapotranspiration percentage was significantly ($P < 0.05$) higher for 10-m spacing (28 m^2 catchment) than in 5-m spacing (14 m^2 catchment), and both were significantly higher than for controls (no catchment). When comparing conventional ridges with mechanized ridges at spacings of 5 and 10 m, although the catchment area was different, in the two systems for the same spacing, we find that amount of harvested water was not significantly different between them (Table 3.13).

Survival rate: The survival rate was 100% for *Atriplex* spp. and Mediterranean saltwort in all catchment treatments including controls; however, it was very low (16%) for controls and 40% for the 10-m spaced

Table 3.10. Vegetation cover for conventional ridges at different spacing treatments (catchment areas) during the 2005/06 growing season.

Spacing (Catchment area)	Vegetation cover (%)
Control	15 b
5 m (10 m^2)	59 a
7.5 m (15 m^2)	56 a
10 m (20 m^2)	64 a

Table 3.11. Plant height increase for conventional ridges at different spacing treatments (catchment areas) during the 2005/06 growing season.

	Plant height increase (cm)			
Spacing (Catchment area)	Atriplex halimus	Atriplex nummularia	Salsola vermiculata	Retama raetam
Control	5.25 b	1.25 b	1.25 b	–*
5 m (10 m^2)	38.25 a	19.5 a	5.75 a	1.25 b
7.5 m (15 m^2)	31.25 a	18.8 a	25.00 a	14.75 a
10 m (20 m^2)	10.75 a	17.25 a	16.25 a	11.25 a

Note: * No control treatment.

Table 3.12. Amount of water harvested (cm) and evapotranspiration (ET) percentage for Vallerani experiment for different spacing treatments (catchment areas) during the 2005/06 rainy season.

Spacing (Catchment area)	Water harvested (cm)	ET (%)
Control	60.7 b	109 c
5 m (14 m^2)	71.1 a	128 b
10 m (28 m^2)	75.8 a	136 a

Table 3.13. Amount of water harvested (cm) for Vallerani experiment with different spacing treatments (catchment areas) during the 2005/06 rainy season.

	Water harvested (cm)		
Catchment area	5-m spacing	10-m spacing	Overall
Conventional ridges	74.4a	80.6a	77.5a
Vallerani implement	71.1a	75.8a	73.4a

wild almonds. The only explanation for the low survival of 10-m spaced almond trees is that survival was low for reasons other than lack of water, e.g. shallow soil or disease (Table 3.14).

Vegetation cover: The vegetation cover was highest for 5-m and 10-m spaced *Atriplex* spp. and 5-m spaced Mediterranean Salsola(Table 3.15). The lowest vegetation cover was for controls.

Plant height: The plant height was highest for 10-m spacing and lowest in controls for *Atriplex* spp.; and was highest for 5-m and 10-m spacing and lowest for controls of Mediterranean saltwort (Table 3.15).

Table 3.14. Survival rate (%) for shrubs planted in ridges made using the Vallerani implement during 2005/06 growing season.

Spacing (Catchment area)	Atriplex halimus	Salsola vermiculata	Prunus dulcis
Control	100 a	100a	16 b
5 m (14 m^2)	100 a	100 a	100 a
10 m (28 m^2)	100 a	100 a	40 b

Table 3.15. Vegeation cover and plant height increase for *Atriplex* and *Salsola* species in the Vallerani experiment at different spacing treatments (catchment areas) during the 2005/06 growing season (until June).

Catchment area	*Atriplex* spp.		*Salsola* spp.	
	Cover (%)	Height (cm)	Cover (%)	Height (cm)
Control	17 b	13 b	17 c	7 b
5 m (14 m^2)	85 a	25 b	78 a	33 a
10 m (28 m^2)	82 a	42 a	62 b	35 a

3.4 Conclusions

The results of the experiments of 2004/05 and 2005/06 led to the following conclusions:

3.4.1 Runoff basins and semicircular bunds for fruit trees

The amount of water harvested in the runoff basin system was significantly higher than that harvested in the semicircular bund system.

The amount of water harvested was not influenced by catchment size, i.e. the amount of water harvested from a catchment of 36 m^2 was as much as that harvested from 64 or 100 m^2 for pistachio and almond. Similarly, the amount harvested from a catchment of 64 m^2 was the same as that harvested from a catchment of 100 m^2 for olive.

The canopy size of almond and olive trees was not influenced by the type of WH system. However, the canopy size of almond trees was significantly higher for the runoff basin system than the semicircular system.

The catchment size did not influence tree canopy size. A catchment 36 m^2 yielded the same canopy size as 64 or 100 m^2 for pistachio and almond; and a catchment of 64 m^2 yielded the same canopy size as a catchment of 100 or 169 m^2 for olive.

3.4.2 Conventional ridges for shrubs

Spacing of 10 m (20 m^2 area) gave a significantly higher amount of harvested water than the control and the 5-m (10 m^2 area) but not significantly higher than the 7.5-m spacing (15 m^2 area).

The vegetation cover was significantly higher in ridges of any catchment size than in controls (no ridges). However, catchment size did not influence the percentage of vegetation cover.

Plant height was significantly higher in ridges of any catchment size than in controls (no catchment). However, catchment size did not influence plant height.

3.4.3 Mechanized ridges for shrubs

The amount of water harvested was significantly higher in ridges constructed by the Vallerani implement than the control. However, there was no significant difference between spacings of 5 m (14 m^2 catchment) and 10 m (28 m^2 catchment).

Vegetation cover was significantly higher in ridges constructed by the Vallerani implement than the control. However, there was no significant difference in the percentage of vegetation cover between spacings of 5 m (14 m^2 catchment) and 10 m (28 m^2 catchment) for *Atriplex* spp. However, for Mediterranean Salsola, the percentage of vegetation cover was significantly higher at spacing of 5 m (14 m^2 catchment) than at 10 m (28 m^2 catchment).

Plant height was significantly higher in ridges for spacing of 10 m (28 m^2 catchment) than for 5 m and controls for *Atriplex* spp. However, plant height was significantly higher in ridges of spacings of 5 and 10 m than for controls for Mediterranean saltwort.

3.4.4 Comparison between conventional ridges and mechanized ridges

Within any one overall spacing the amount of water harvested did not significantly differ between conventional and mechanized ridges. However, a slight difference was due to the catchment size.

3.5 Recommendations

The experiment results for the 2004/05 and 2005/06 seasons led to the following recommendations:

For fruit trees: use the runoff system with a catchment of 36 m^2 for growing pistachio and almond trees, and 64 m^2 for olives.

For shrubs: use ridges constructed by the Vallerani implement at a spacing of 5 m (14 m^2 catchment) as it is much cheaper and faster than for ridges constructed conventionally.

Chapter 4

The use of the microcatchment water harvesting for fodder shrub production

Chapter 4: The use of the microcatchment water harvesting for fodder shrub production

Y. Al-Satari, M. Ali Mudabber, T. Oweis, A. Al-Kabneh, A. Al-Rossan, Y. Naser and M. Karrou

4.1 Introduction

The Badia constitutes about 90% of the total land area of Jordan, which is 89 342 km^2. Its average annual rainfall is < 200 mm. The area with annual rainfall of 100–200 mm is considered the promising rangeland for rehabilitation. The Badia (part of the rangeland) supplies the livestock sector with about 20% of forage needs, while all the other sources provide the sector with only about 5% of forage.

Fodder shrubs in the low rainfall areas are subject to water shortage, overgrazing, and coppicing. Within the rangeland, 1 ha of shrubs produces about 0.5 t of fresh forage and increases the feed productivityas compared to the pasture without shrubs. Fodder shrub plantations, in addition to their role in range protection, have increased productivity by 500% as compared to unprotected rangeland (Ministry of Agriculture, 2005).

Water harvesting techniques are a means of collecting rainfall from microcatchments and concentrating them in the root zone area and hence increasing the amount of soil water available for shrubs. These techniques allow the establishment of healthy shrubs that can withstand drought and grazing. They also improve soil characteristics, e.g. infiltration rate and organic matter contents, and play an important role in soil conservation and erosion control.

There are several kinds of fodder shrubs grown at the Jordanian Rangeland; but *Atriplex* spp. are the most important (Abu-Zanat, 1996) because of adaptation to the environment. These shrubs also tolerate high levels of soil salinity, and *A. halimus* is one species often planted as a feed resource. The relative success of fodder shrubs in the region is due to their drought tolerance, ability to accumulate green fodder over several seasons or years that can be used as livestock feed, their deep roots and high water use efficiencies, and the 3–5-fold increase in productivity. However, this plant must be integrated into various production systems (animal, croping, and mixed) that are economical and acceptable (Le Houerou, 1997).

Fodder shrubs are good sources of forage for livestock feed, and some are highly palatable. In addition, *Atriplex* spp. have a high crude protein content of about 10–15%. In addition to natural native vegetation, they are a good complementary source of feed in the rangeland.

The overall objective of the Badia Benchmark Project is to improve the livelihood of rural and pastoral communities in the Badia. The specific objectives of the rangeland activity are:

- To determine and demonstrate the effect of the location, slope, and water harvesting structure (WHS) on *A. halimus* and *Salsola vermiculata* productivity;
- To develop suitable rangeland and livestock grazing management in the *Badia* (requiring 5–7 y from the planting date).

4.2 Methodology

4.2.1 Description of the study area and treatments

Fodder shrubs (*A. halimus and S. vermiculata*) were planted in about 100 locations. The planted area was 162.7 ha. For this study, two main locations were selected: Mharib and Al-Majidyya villages, which receive an average of about 130 and 150 mm of annual rainfall, respectively. They are characterized by a deterioration of vegetation cover due to drought, introduction of mechanization, soil plowing for barley cultivation, early grazing, and overgrazing. The remaining vegetation consists of *Poa bulbosa, Anabasis syriaca, Hordeum glaucum, and Bromus* sp. The soils are silty clay loams with an effective rooting zone < 60 cm. The selected sites had slope gradients of 2–10%. The upper part of the location with slopes of > 5% was termed 'slope 1', and the lower part with < 5% slopes 'slope 2'. The selected locations were evaluated in terms of slope gradient, slope length, and soil depth to select the proper intervention in terms of water-harvesting structures for plantations of fodder shrubs and barley cultivation (Abu-Zanat et al., 2006).

The two main locations were planted with fodder shrubs to compare the suitability of microcatchments for plantations: 70 ha at Mharib and 25 ha at Al-Majidyya.

The spacing between microcatchments averaged 9 m. The seedlings were planted at 2-m spacings within the microcatchments. The spacings between the rows of microcatchments and shrubs resulted in 556 shrubs/ha. The microcatchments or WHSs, which included the Vallerani bund structure (VBS; Photo 4.1a) and the Vallerani contour ridges or Vallerani continuous structure (VCS; Photo 4.1b), were opened using a Vallerani implement (Photo 4.2).

Nine-month-old seedlings of *A. halimus* and *S. vermiculata* were planted in holes inside the microcatchments in January 2006. At the two sites there was a total of about 38 000 planted seedlings. The first location was planted with *A. halimus* on December 2004, covering 1.2 ha and using about 400 shrubs. Other seedlings were planted with *A. halimus* and *S. vermiculata* on December 2006 and January 2007.

Photo 4.1a. Vallerani bund contour ridges.

Photo 4.1b. Vallerani bund contour ridges.

Photo 4.2. Vallerani implement.

4.2.2 Experimental design and data analysis

The treatments were arranged in a split-split-block in randomized complete block design with sub-sampling. Data were recorded for two years (2007 and 2008) for the two main sites. The slope gradient (slope 1 and slope 2), WHSs (VBS and VCS), and shrub species (*A. halimus* and *S. vermiculata*) occupied the main plots, the sub-plots, and the sub-sub-plots, respectively.

Data were analyzed using the GLM procedures of (SAS 1995) system for a split-split-block arrangement. All factors were included in the analysis with their possible interactions. The independent variables included in the model were slope gradient, WHS, and shrub species. The dependent variables were survival percentage, and fresh, browse, and dry matter production. Duncan's multiple range test was used for mean separation.

4.2.3 Measurements

About 800 shrubs were selected randomly from Mharib and Al-Majidyya for monitoring survival and biomass production in 2007 and 2008. Within each treatment, 15 plants were used for recording the required data on the vegetation.

Survival rate: The percentage of shrubs alive (number of shrubs alive compared to the total number of shrubs) planted on March 2007 and June 2008.

Empirical equations: From each shrub species (*A. halimus and S. vermiculata*), 75 plants were selected randomly from the plantation grown at Al-Majedeyah study site. The height, excluding the inflorescence, and the largest and smallest canopy diameters were recorded for each shrub. The general shape for each shrub species was identified for estimating the plant volume. The 150 selected shrubs were cut at ground level and the fresh weight recorded for each individual shrub. Browses (leaves and small twigs < 5 mm in diameter) were separated for each shrub and weighed, then dried in an air-circulating oven at 70°C for 72 h for dry weight determination. Stepwise regression (SAS, 1995) was performed on the recorded variables to determine the empirical equations for predicting fresh, browse, and dry weights per shrub. They were used to determine the shrub volume (SVOL) of the elliptical-shaped shrubs using the following equation:

$$SVOL = (4/3)\times(3.14)\times(PH/2)\times(SD/2)\times(LD/2)$$

where PH = plant height, SD = shortest shrub diameter, and LD = longest shrub diameter (Howard, 1995).

Fresh yield (FY): The total shrub biomass (leaves and wood) production above ground level.

Browse yield (BY): The total shrub fresh biomass (including leaves and twigs < 5 mm in diameter) production above ground level.

Dry yield (DY): The total shrub dry matter (including leaves and twigs < 5 mm in diameter) production above ground level.

The productivity was determined using the empirical equations generated from destructive sampling in the 2007/08 growing season. Data of shrub dimensions (PH, SD, LD, and SVOL) and survival percentage were used for calculating FY, BY, and DY (kg/ha).

4.3 Results

4.3.1 Rainfall

The quantities of rainfall received in 2005/06, 2006/07, and 2007/08 seasons represented 90, 86, and 64% at Mharib and 87, 112, and 59% at Al-Majidyya of their respective long-term annual averages (Table 4.1).

Table 4.1. Rainfall amounts in the two locations and thre e seasons

Location	Mharib		Al-Majidyya	
	Rainfall (mm)	Proportion of average (%)	Rainfall (mm)	Proportion of average (%)
2005-06	117	90	131	87
2006-07	112	86	168	112
2007-08	83	64	89	59

4.3.2 Growth parameters

The equations for the best-fit models for shrub fresh, browse, and dry weights are shown in (Table 4.2). The PH, SD, LD, and SVOL variables were the best to predict fresh, browse, and dry weights of *A. halimus* and *S. vermiculata*. These equations are not suitable for short plants with heights or canopy diameters < 20 cm, but were applicable to shrub plantations in microcatchments in arid regions receiving 100–200 mm of annual rainfall.

The survival rate compared to the overall mean of fodder shrubs planted at Mharib and Al-Majidyya was 92%, a good result for three years after planting. The overall productivity means were 465.82, 200.55, and 73.29 kg/ha for fresh, browse, and dry yields, respectively (Table 4.3).

The interaction 'Location × Crop Type' had a highly significant effect on survival rate ($P < 0.0001$). The survival rates of *S. vermiculata* shrubs planted at Al-Majidyya and Mharib were 97 and 93%, respectively (Table 4.4). This shows a good establish-

Table 4.2. Empirical equations for predicting fresh, dry, and browse weights (g/shrub) for *A. halimus* and *S.vermiculata* plants grown at Mharib and Al-Majidyya sites during spring 2008.

Shrub Species	Response	Equation**	R^2
A. halimus*	Fresh weight (g)	508.93 – 1.41 SD – 0.72 LD + 0.004 SVOL	0.82
	Browse weight (g)	0.22 + 2.09 PH + 2.60 SD + 0.0008 VOL	0.60
	Browse dry weight (g)	–29.30 + 1.25 PH + 0.92 SD + 0.0002 VOL	0.64
S. vermiculata*	Fresh weight (g)	–191.95 + 3.85 SD + 5.36 LD + 0.001 VOL	0.80
	Browse weight (g)	53.27 – 3.40 PH + 4.25 SD + 0.001 VOL	0.58
	Browse dry weight (g)	–1.17 – 1.25 PH + 2.45 SD + 0.0003 VOL	0.51

Note: *38-month-old shrubs (10 months as seedlings in the nursery and 28 months after planting in the field)
**PH: plant height, SD: shortest shrub diameter, and LD: longest shrub diameter (cm).

Table 4.3. Overall means ± standard error (SE) of Fodder shrubs (*A.halimus* and S.*vermiculata*) planted on Dec, 2006 at Mharib watershed.

Variable	Mean ± SE
Survival rate (%)	92 ± 1
Fresh yield (kg/ha)	465.82 ±12.48
Browse yield (kg/ha)	200.55 ± 4.55
Dry yield (kg/ha)	73.29 ± 1.48

Table 4.4. Effect of the interaction of locations and crop type on fodder-shrub survival rate (%) planted at Mharib and Al-Majidyya.

Location	Crop Type	
	A.halimus	***S.vermiculata***
Al-Majidyya	92 b	97 a
Mharib	71 c	93 ab

Note: Means with the same letter are not significantly different.

ment of *S. vermiculata* at Al-Majidyya, probably due to the higher rainfall received at this location; additionally, soil and other factors were slightly better in Al-Majidyya. This is in agreement with (Abu-Zanat et al. 2004), who showed that water harvesting increased shrub survival rate and biomass.

The 'Location × WHS' interaction had a significant effect on FY ($P = 0.0142$), BY ($P = 0.0546$), and DY ($P = 0.0599$). The FY, BY, and DY for VCS at Al-Majidyya were 720.98, 292.48, and 100.86 kg/ha, respectively (Table 4.5). The VCS technique seemed suitable for fodder shrub establishment at Al-Majidyya, represents the low rainfall areas receiving annual rainfall of 100–200 mm. A suitable amount of water was collected to satisfy the requirements for growth and development of shrubs that usually develop in an arid zone of annual average rainfall of 200–400 mm (Le Houerou, 1984).

The 'Location × WHS × Crop Type' interaction had a highly significant ($P = 0.0164$) effect on DY. The *A. halimus* DYs under VBS and VCS treatments at Al-Majidyya were 106 and 119 kg/ha, respectively. This is probably due to the higher amount of rainfall collection and the deeper soil at Al-Majidyya compared to Mharib. It may also indicate a benefit of growing *A. halimus* compared to *S. vermiculata* (Table 4.6).

Table 4.5. Fresh, browse, and dry yields (kg/ha) for fodder shrubs planted at two locations (Mharib and Al-Majidyya) under two WHS (VBS and VCS).

Location	WHS	FY	BY	DY
Al-Majidyya	VBS	602.50 b	255.06 b	90.2 b
	VCS	720.98 a	292.48 a	100.9 a
Mharib	VBS	267.02 c	125.55 c	51.4 c
	VCS	217.64 c	108.65 c	44.4 c

Note: Means followed by the same letter within the same column are not significantly different.

Table 4.6. Dry yield (kg/ha) for *A. halimus* and *S. vermiculata* planted at two locations (Mharib and Al-Majidyya) under two WHS (VBS and VCS).

Location	WHS			
	VBS		VCS	
	A. halimus	***S. vermiculata***	***A. halimus***	***S. vermiculata***
Al-Majidyya	106 a	72 b	119 a	77 b
Mharib	54 c	51 c	41 c	45 c

Note: Means followed by the same letter are not significantly different.

The 'Location × Slope × Crop Type' interaction had a significant (*P* = 0.0466) effect on DY. The *A. halimus* DY in slope 1 at Al-Majidyya was 156.54 kg/ha, probably due to good rainfall collection in the WHS in slope 1 compared to slope 2 for *A. halimus* (Table 4.7). This indicated that slope 1 (which had low slopes of < 5%) had greater soil depth, water collection, and infiltration rate. This is in addition to the benefits of higher average annual rainfall at Al-Majidyya.

The 'Location × Slope × WHS × Crop Type' interaction had a significant effect on FY (*P* = 0.0379) and BY (*P* = 0.0204). The *A. halimus* FY and BY using VCS for slope 1 at Al-Majidyya were 1387.36 and 533.84 kg/ha, respectively (Table 4.8). The higher FY and BY at Al-Majidyya was due to higher rainfall received and deeper soil: 150 mm and 100 cm at Al-Majidyya, respectively, compared to 130 mm and 50 cm at Mharib. Thus the soil stored more water from the WHSs (microcatchments) which increased

Table 4.7. Dry yield (kg/ha) for A. halimus and S. vermiculata planted at two locations (Mharib and Al-Majidyya) in two slopes (>5% and < 5%).

Location	Slope			
	Slope 1		Slope 2	
	A. halimus	*S. vermiculata*	*A. halimus*	*S. vermiculata*
Al-Majidyya	156.54 a	90.36 b	86.87 b	59.87 c
Mharib	60.45 c	61.19 c	32.72 d	42.62

Note: Means followed by the same letter are not significantly different.

Table 4.8: Fresh and dry yield (kg/ha) for *A. halimus* and *S. vermiculata* planted at two locations (Mharib and Al-Majidyya) under two WHSs (VBS and VCS) in two slopes.

Location	Crop	WHS	Slope	Fresh yield	Browse yield
Al-Majidyya	*A. halimus*	VBS	Slope 1	1186.93 b	477.78 b
			Slope 2	668.17 c	262.16 cd
		VCS	Slope 1	1387.36 a	533.84 a
			Slope 2	787.32 c	301.66 c
	S. vermiculata	VBS	Slope 1	340.08 ef	182.09 fg
			Slope 2	287.98 fg	134.82 gh
		VCS	Slope 1	428.07 de	209.60 ef
			Slope 2	244.50 fg	121.95 hi
Mharib	*A. halimus*	VBS	Slope 1	682.81 c	248.13 de
			Slope 2	262.65 fg	092.96 i
		VCS	Slope 1	473.91 d	156.59 gh
			Slope 2	334.05 ef	132.05 gi
	S. vermiculata	VBS	Slope 1	290.23 fg	145.86 gi
			Slope 2	198.66 fg	102.74 i
		VCS	Slope 1	258.32 fg	131.49 gi
			Slope 2	164.45 g	92.57 i

Note: Means followed by the same letter are not significantly different.

the evapotranspiration by plants at Al-Majidyya and thus caused better shrub establishment and growth compared to Mharib. The *A. halimus* showed higher fresh, browse, and dry yields compared to *S. vermiculata* because it is a taller denser plant, of larger size, and with more wood.

4.4 Conclusions

Al-Majidyya was more suitable for planting fodder shrubs and forage production.
The *S. vermiculata* seemed to be more drought tolerant in terms of survival than *A. halimus*; however, *A. halimus* showed more adaptation in terms of total forage production.
The VCS technique showed high efficiency in rainfall collection and forage production.
The low slopes (< 5%) showed high efficiency in forage production.
For higher forage production, it is recommended that *A. halimus* shrubs be planted at Al-Majidyya using a Vallerani continuous structure in the low slopes (< 5%).

4.5 References

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Chapter 5

Impact of microcatchment water harvesting on the diversity of the Badia rangelands of Jordan

Chapter 5: Impact of microcatchment water harvesting on the diversity of the Badia rangelands of Jordan

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5.1 Introduction

The Badia of Jordan encompasses a wide and significant part of the Hashemite Kingdom of Jordan, covering an area of approximately 72 600 km^2, which constitutes 81% of the total area of the country (Allison at al., 1998). The region is subdivided into four major topographic features as follows. (1) The Jordan Rift Valley and Wadi Araba extend from Lake Tiberias in the north to the Gulf of Aqaba in the south. This is the Jordanian part of a continental shelf extending from Aqaba in the south to the Adasiyyah in the north. This zone is divided into three areas: the Jordan Valley, the Southern Ghor, and Wadi Araba. (2) The Highlands extend from the Yarmouk River in the north passing through the Ajloun Mountains, the hills of Ammon and Moab, and the Edom Mountains. Many creeks and wadis drain from the east to the Jordan River, the Dead Sea, and Wadi Araba. (3) The Arid zone (plains) comprises the plains between the Badia (a semi-desert) and the Highlands. (4) The Badia (eastern desert) covers about 8 090 000 ha or 90% of the Kingdom. The Badia is characterized by very sparse vegetation cover and an annual rainfall of < 200 mm. In the past it was only used for grazing. In the last two decades, however, 20 000 ha has been irrigated, using underground water, to grow vegetables (especially tomato, watermelon, and potato), fruit trees and cereals, particularly wheat.

The Mharib pilot site is located about 65 km south-east of Amman in Jordan (31.672358° N and 36.21763° E). It consists of a sub-watershed of 30 ha and 7 ha as the net site area. The Mharib community consists of 30 households with a population of 300 inhabitants. Land use is mainly rangeland and barley cultivation. Some of the population are nomads and travel with their flocks to distant areas in search of better feed. The average flock size is around 200 heads per holder. The grazing period for the community is 2–5 months, according to the rangeland situation. The average annual rainfall is 152 mm, and sporadic with most during short intense storms. Surface runoff is medium (ICARDA, 2007).

The area lies wholly within the xeric–aridic transitional moisture regime. The Mharib region lies within the grassland steppe vegetation zone. Barley is grown in the valley bottom alluvium, where the moisture from the limited rainfall is augmented by runoff from the hill slopes (ICARDA, 2007). The dominant plants are *Anabasis* and *Poa* spp. Some *Achillea*, *Colchicum*, and *Salsola* spp. can also be seen in the area. The steppe grassland produces a tough turf, which protects the soil surface from wind and water erosion. Frequent grazing keeps vegetation growth close to the soil surface (BBM Annual Report, 2005). Rangeland degradation has severely affected the biodiversity of plants and other organisms, and in many cases palatable plant species have been entirely eliminated from plant communities (Al-Jaloudy, 2001). Factors such as the climatic conditions (causing declining rainfall; Blench, 1995), droughts and depletion of soil nutrients, overgrazing, premature grazing, and overuse of natural resources by humans has resulted in the decline of native vegetation in the Badia region (Al-Jaloudy, 2001) and loss of indigenous plants. Other problems are related to the uprooting of bushes for firewood by pastoral communities, uncontrolled arbitrary movement of vehicles in grazing lands, and increasing livestock densities (Al-Jaloudy, 2001). Other environmental problems can be related to plowing of marginal lands to guarantee property rights over the land (Abu-Zanat 1997) and plastic waste in rangelands adjacent to agricultural areas (Blench, 1995).

Sound knowledge of the biodiversity status of the rangeland and its degradation levels will help scientists and planners to develop technical and socioeconomic solutions aimed at restoration of the vegetation and the sustainability of rangeland. In dry areas, water, not land availability, is the most limiting resource for improved agricultural production. Maximizing water productivity, and not yield per unit of land, is therefore a better strategy for dry farming systems (Oweis and Hachum, 2006). Shaping the ground to concentrate available rainfall has been very effective for establishment of vegetation in deserts. Microcatchment systems provide many advantages over alternative irrigation schemes. They are simple and inexpensive to construct and can be built rapidly using local materials and manpower and, once constructed, little maintenance is required (Bainbridge, 2003).

Many plant species are severely affected by rangeland degradation resulted from overgrazing and cultivation of barley. Microcatchment water harvesting (WH) systems associated with suitable grazing management provide an opportunity for plant regeneration and improving vegetation. However, there is no information and/or research work on the potential and constraints associated with regenerating the native vegetation in the Badia regarding the best way and the impact on diversity of plant species and vegetation cover. This study aimed at conducting the followings activities:

- To survey and identify the flora at the Mharib watershed (the intervention area of the Badia Benchmark Project),
- to study the effect of microcatchment WH techniques on the soil seed bank compared with the current situation,
- to evaluate the effect of microcatchment WH on the native vegetation regeneration and improvement, and
- to multiply and reintroduce the annual native plant species collected from the rangelands.

The study is presented in five main sections:

- Documentation of the flora of the Mharib watershed,
- Assessment of the soil seed bank under different microcatchments,
- Evaluation of the effect of microcatchment WH on native vegetation,
- Regenerating native vegetation cover using WH techniques, and
- Evaluation of the potential of seed of native plant species for multiplication/propagation.

5.2 Documentation of the flora of the Mharib watershed

5.2.1 Materials and methods

The Mharib pilot site exists within a sub-watershed of 30 ha, with 7 ha as the net site area for the intervention. The intervention sites (sites where WH microcatchments were implemented) were established between November 2005 and January 2006 on an area of 27.1 ha divided into 28 sites where different intervention techniques were implemented. The sites were identified by taking GPS points for their boundaries, and converted into maps using the GIS lab facilities at the National Center for Agricultural Research and Extension (NCARE). For each intervention site the following characteristics were recorded: area, site description, shrub species, slope class, slope (%), surface crust class, soil depth class, soil depth (cm), stone cover class, gravel (%), stone (%), boulders (%), rock outcrop class, infiltration rate, soil properties (pH and electrical conductivity), organic matter (%), P (ppm), K (ppm), and percentage of $CaCO_3$ (Annex 1.1).

A native vegetation field survey was conducted for each of the above sites using the Belt transects method (Schmutz et al., 1982). A 50-m-long transect line was laid out across the area to be surveyed and a 1-m^2 quadrat was placed on the first marked point on the line and at 10-m intervals on both sides, making a total of five quadrats per line (Figure 5.1). Two transects were taken: one between the contour ridges (catchment area), and the other within the WH contour ridges (planted area). This was done for each 0.6 ha, referred to as a sub-site (even if the site area was < 0.6 ha it was considered as one sub-site), making a total of 114 transects and 570 quadrats for each survey date (Table 5.1).

Vegetation cover percentage, stone cover percentage, and the individual plants inside the quadrat were then determined. Individual plants for each species were counted (Kutiel and Danin, 1987) and recorded. Species identification was performed in the field for known species (Zohary, 1966; Al-Eisawi, 1998).

ICARDA's passport data sheets (Annex 1.2) were filled for the study site. The documentation process was carried out twice during this study (December 2006 and April 2007) to determine whether there was any change in vegetation cover with time.

The following parameters were recorded and computed for each site:
Vegetation (shrubs and grasses) cover – the area of the quadrat occupied by the aboveground parts of a species when viewed from above.

Stone cover percentage – visually estimated and recorded for each quadrat.

Species richness (SR; Wilson and Shmida, 1984) – simply calculated by counting the number of species of a site.

Rank-abundance curves (Preston, 1948) – obtained by plotting abundance rank as the X-axis against species proportional abundance (log10 scale) as the Y-axis.
Shannon–Wiener Diversity Index (SDI) (Whittaker, 1972) – calculated using the formula:

$$H = -\sum_{i=1}^{s} P_i \ln P_i$$

H: Shannon's diversity index (SDI).
SR: total number of species in the community (richness)
P_i: proportion of S made up of the i^{th} species

Shannon's equitability (E_H) – calculated by dividing H by H_{max} (here H_{max} = lnS)

$$EH = H/H_{max} = H/\ln S$$

Annuals–perennials ratio (AP-ratio) – calculated using the formula

AP-ratio=A/(A+P)

A: number of individual annual plants
P: number of individual perennial plants
Plant families – the number of different plant families found in the area.
Forbs/Herbs species – the number of forbs/herbs plants recorded.

Flora map
The objective was to identify the variety of vegetation associated with the sub-watersheds and then establish the extent and distribution of the community. ICARDA's passport data sheet (Annex 1.2) was used here and only species recorded in the spring survey were entered onto the map. A legend was created to identify the species easily on the map. As a result, a flora map was obtained with a detailed description of vegetation.

Table 5.1. Area (ha), number of transects, and number of quadrats, between and within contour ridges, of the intervention sites in the Mharib area.

Site name	Area (ha)	Site description	No. of transects		No. of quadrats	
			Between rows	Within rows	Between rows	Within rows
MH1CRS	0.6	Mharib, Plot 1, Contour Ridges, Shrub	1	1	5	5
MH3CRSa	0.94	Mharib, Plot 3, Contour Ridges, Shrubs, Sub Site a	2	2	10	10
MH3CRSb	3.61	Mharib, Plot 3, Contour Ridges, Shrubs, Sub Site b	6	6	30	30
MH3CRSc	1.96	Mharib, Plot 3, Contour Ridges, Shrubs, Sub Site c	3	3	15	15
MH4CRSa	0.49	Mharib, Plot 4, Contour Ridges, Shrub, Sub Site a	1	1	5	5
MH4CRSb	0.41	Mharib, Plot 4, Contour Ridges, Shrub, Sub Site b	1	1	5	5
MH6CRSa	0.23	Mharib, Plot 6, Contour Ridges, Shrubs, Sub Site a	1	1	5	5
MH6CRSb	0.33	Mharib, Plot 6, Contour Ridges, Shrubs, Sub Site b	1	1	5	5
MH7CRS	0.13	Mharib, Plot 7, Contour Ridges, Shrub	1	1	5	5
MH8CRS	0.33	Mharib, Plot 8, Contour Ridges, Shrub	1	1	5	5
MH9CRS	0.18	Mharib, Plot 9, Contour Ridges, Shrub	1	1	5	5
MH10CRS	0.12	Mharib, Plot 10, Contour Ridges, Shrub	2	2	10	10
MH12VSa	0.21	Mharib, Plot 12, Vallerani, Shrub, Sub Site a	3	3	15	15
MH12VSb	0.61	Mharib, Plot 12,Vallerani, Shrub, Sub Site b	1	1	5	5
MH13VS	0.61	Mharib, Plot 13,Vallerani, Shrub	1	1	5	5
MH14VS	1.73	Mharib, Plot 14,Vallerani, Shrub	3	3	15	15
MH17VSa	1.72	Mharib, Plot 17, Vallerani, Shrub, Sub Site a	3	3	15	15
MH17VSb	1.65	Mharib, Plot 17, Vallerani, Shrub, Sub Site b	3	3	15	15
MH17VSc	4.51	Mharib, Plot 17, Vallerani, Shrub, Sub Site c	8	8	40	40
MH17VSd	0.53	Mharib, Plot 17, Vallerani, Shrub, Sub Site d	1	1	5	5

Table 5.1. (Continued).

Site name	Area (ha)	Site description	No. of transects		No. of quadrats	
			Between rows	**Within rows**	**Between rows**	**Within rows**
MH19VSa	0.84	Mharib, Plot 19, Vallerani, Shrub, Sub Site a	2	2	10	10
MH19VSb	0.21	Mharib, Plot 19, Vallerani, Shrub, Sub Site b	1	1	5	5
MH20CRS	0.29	Mharib, Plot 20, Contour Ridges, Shrub	1	1	5	5
MH21CRSa	0.49	Mharib, Plot 21, Contour Ridges, Shrub, Sub Site a	1	1	5	5
MH21CRSb	1.17	Mharib, Plot 21, Contour Ridges, Shrub, Sub Site b	2	2	10	10
MH22VSa	1.01	Mharib, Plot 22, Vallerani, Shrub, Sub Site a	2	2	10	10
MH22VSb	10.3	Mharib, Plot 22, Vallerani, Shrub, Sub Site b	2	2	10	10
Total	**27.01 ha**		**57**	**57**	**285**	**285**
Grand total	**27.01 ha**		**114**		**570**	

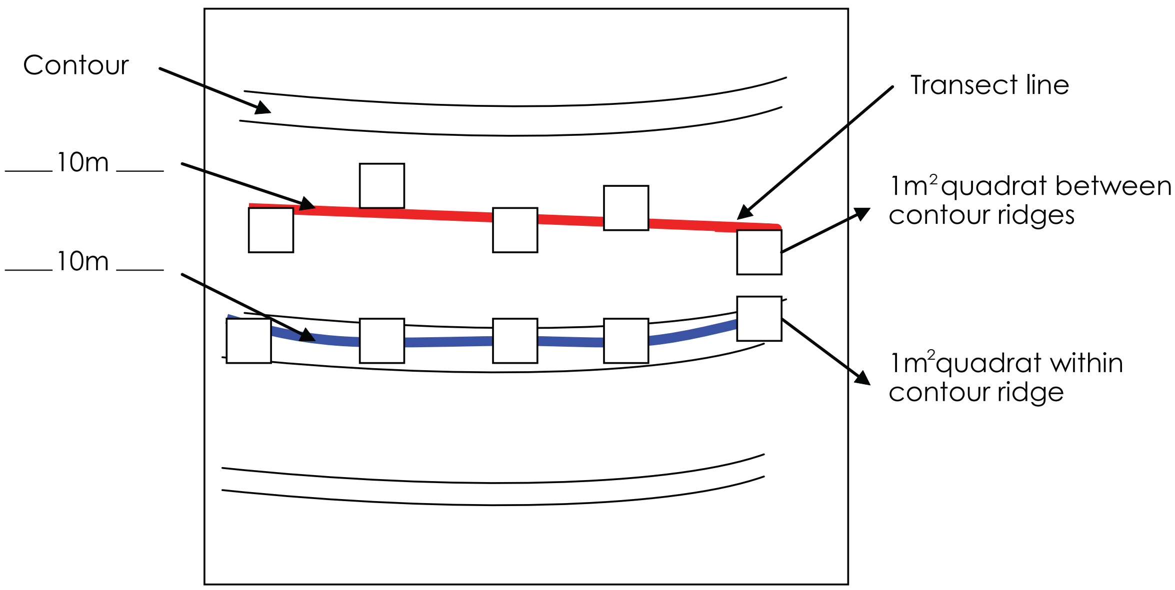

Figure 5.1. Layout of the sampling technique in the field.

5.2.2 Results and discussion

Vegetation cover

Vegetation cover percentages for the microcatchment watersheds were mapped in GIS format to easily distinguish between the vegetation situation in autumn (December 2006) and spring (April 2007) (Annexes 1.3–1.6). These maps clearly showed higher vegetation cover percentages in spring compared to autumn. The average vegetation cover for sites planted in November 2005 was higher (32%) than those planted in January 2006 (28%) in the autumn survey. Similar results were obtained in spring, where the average vegetation cover for sites planted in November 2005 were higher (53%) than those planted in January 2006 (46%). Vegetation cover percentages were almost double in most sites in spring compared to autumn.

The higher vegetation cover in April 2007 over December 2006 was expected since April is spring, when the plants flourish and increase vegetative growth and cover.

In December 2006, the vegetation cover percentages were highest (47%) for site 7CRS, and lowest (20%) for site 19VSb (Table 5.2). The average vegetation cover for all sub-watershed sites was 29.5%; with around 43% of sites with vegetation cover above the overall average. The average vegetation cover of the sub-watershed sites with the traditional plow contour ridges planted with shrubs (CRS) was higher (30.8%) than the sub-watershed sites with the intervention of Vallerani contours planted with shrubs (27.8%). The average vegetation cover of the sub-watershed sites established in November 2005 was higher (30.9%) than those established in January 2006 (27.9%), but lower than site 10CRS that was established in December 2004 (40%).

The increase in the number of the annual species that usually grow after the rainy season may be the main reason for increased vegetation cover. Rainfall is the major climatic factor influencing inter-annual variations of average vegetation cover. Such results are consistent with those of (Ayyad 1973) and (Kutiel et al. 2000), who found that the annual plant growth and number in dry areas were highly dependent on the climatic conditions, mainly rainfall.

In April 2007, the highest vegetation cover (69.7%) was at site 3CRSc and the lowest (28%) at site 18CRS (Table 5.2). The average vegetation cover for all sub-watershed sites was 49.3%, with around 53.6% of sites above the average. The average vegetation cover of CRS sites (50.2%) was higher than sites with the intervention of Vallerani planted with shrubs (17VSa, 17VSb, 17VSd and 13VS) (45.0%). The average vegetation cover of sub-watershed sites established in November 2005 was higher (53.5%) than for site 10CRS established in December 2004 (47.5%) or sites established in January 2006 (46.4%).

The increase in the number of the annual species that usually grow after the rainy season may be the main reason for increased vegetation cover. Rainfall is the major climatic factor influencing inter-annual variations of average vegetation cover. Such results are consistent with those of (Ayyad 1973) and Kutiel et al. (2000), who found that the annual plant growth and number in dry areas were highly dependent on the climatic conditions, mainly rainfall.

The highest vegetation cover in the first sampling was for MH7CRS (47%) with a south-facing slope, and the lowest for MH-19VSb (20%) with an east-facing slope. In south-facing slopes, the soils kept greater moisture content than those of other slopes; while east-facing slopes lost their moisture more rapidly before midday due to the earlier sun rise and the high day temperatures. This may be the main reason why MH7CRS (despite the small area of about 0.13 ha kept the highest vegeta-

Table 5.2. Vegetation cover percentages for the two survey dates (December 2006 and April 2007) in the sub-watersheds of the Mharib area.

Site	Vegetation cover (%) Dec. 2006	Vegetation cover (%) Apr. 2007	Site	Vegetation cover (%) Dec. 2006	Vegetation cover (%) Apr. 2007
7CRS	47	56	21CRSb	28.8	50.5
10CRS	40	47.5	14VS	28.5	55
17VSa	39.5	49. 7	17VSc	28.3	48
8CRS	39	54	9CRS	26	50
17VSb	37.9	58.3	4CRSa	25.5	45
13VS	35	46	6CRSa	23	40
3CRSc	34	69.7	12VSa	23	37.3
17VSd	33.8	44.17	22VSb	22.8	49.5
3CRSa	33.75	57.5	19VSa	22	56
6CRSb	32.5	52	12VSb	21.5	43
21CRSa	32.5	45	18CRS	21.5	28
20CRS	30.5	43	22VSa	21	47.9
4CRSb	29.5	58	1CRS	20.5	50
3CRSb	29.4	56.2	19VSb	20	44

tion cover after the hot summer season. MH7CRS refers to Mharib, Plot 7, and Contour Ridges, planted with *Atriplex halimus* on November 2005, and was the smallest area of the sub-watersheds. MH19VSb refers to Mharib, Plot 19, Vallerani, Sub Site planted with *Atriplex halimus* on January 2006 – a year after MH7CRS.

Total number of plants

The number of individual plants/m^2 was counted for the two survey dates. In December 2006 there was a clear difference among the sub-watershed sites, with the highest number of plants of 61 plants/m^2 at site 7CRS. This was 577% higher than the lowest number (9 plants/m^2) at sites 12VSb and 19VSa (Figure 5.2). For April 2007 (Figure 5.3), the total number of individual plants had increased by about 93%. The highest number of plants was at site 8CRS (815 plants/m^2) which was 570 higher than the lowest number of plants at site 22VSb (118 plants/m^2).

The dominant plant species found in the December 2006 survey was *Poa bulbosa* L. (257 plant/m^2 in site 17VSc), followed by *Torularia torulosa* (Desf.) O.E.Scultz (23 plants/m^2 in site 3CRS). However, there was a very low number of *P. bulbosa* plants (9 plants/m^2) in site 12VSb. Other plant species were also recorded in the study area in very small numbers compared to *P. bulbosa*. For example, in site 17VSc, the number of other plant species was about 35% that of *P. bulbosa*. Moreover, *P. bulbosa* was found in all sub-watershed sites. *Poa bulbosa* and *T. torulosa* were dominant plants in the area before the intervention, and were the site characteristic species (BBM Annual Report, 2005).

Rank species abundance

The autumn survey curves were steeper than those for spring, indicating that the area was more disturbed in terms of the presence of plant species with uneven proportions, i.e. a few (one or two) plants

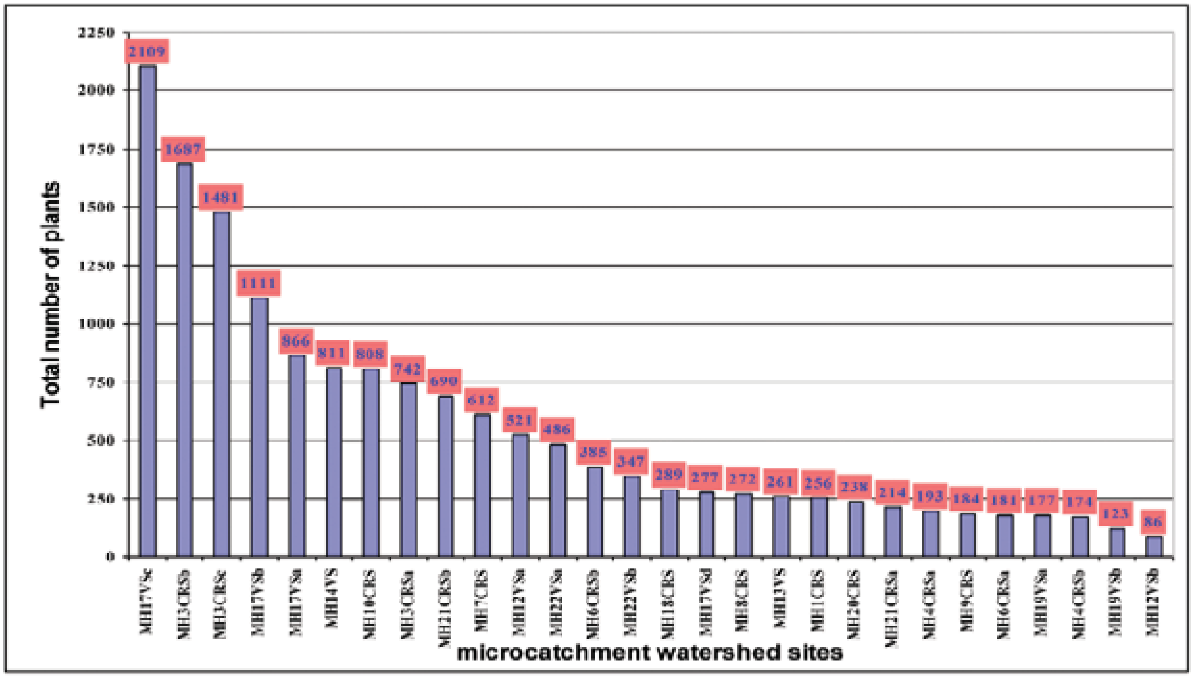

Figure 5.2. Total number of plants/m² in the Mharib intervention area during December 2006 survey.

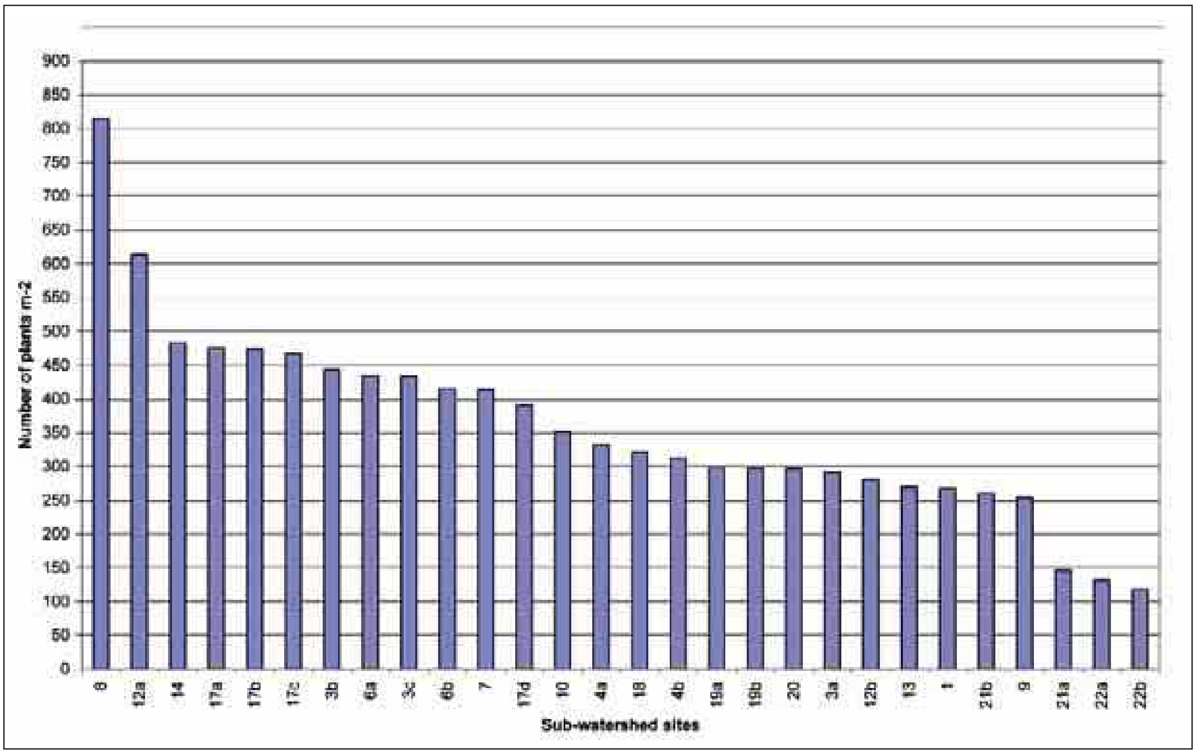

Figure 5.3. Total number of plants/m² in the Mharib intervention area during April 2007 survey.

had the most individuals in the community. This may be a result of shrubs being the main dominant species in the area in autumn. Since our sites are located in dryland, which has been subjected to a long history of disturbance (overgrazing and soil erosion), the dominant shrubs are mainly one or two species with low palatability.

MH4CRSb contained eight species and 88% of the plants were *P. bulbosa*. MH6CRSa contained six species with 60% being *T. torulosa* and 27% *Gymnarrhena micrantha Desf.* MH8CRS contained six species, being 61% *P. bulbosa* and 22% *G. micrantha*. MH17VSa contained seven species with 58% *P. bulbosa*, 19% *T. torulosa*, and 12% Anabasis syriaca Iljin. MH18CRS also contained seven species with 76% *P. bulbosa* and 11% *G. micrantha*. MH21CRSb contained 11 plant species with 50% being *P. bulbosa* and 41% *G. micrantha.*

These above sites (communities) were characterized by different slopes, which indicated the different proportions of species in these sites. Such results show the highly uneven proportionate distribution of plants among the different species in their community.

Native species in sites MH17VSb, MH17VSc, and MH8CRS in the spring survey were more evenly distributed than in automn. MH17VSb contained 27 plant species: 30% *T. torulosa*, 14% Phalaris minor Retz, 13% *Hammada eigü Iljin*, 7% *P. bulbosa* and 5% *Bassia muricata* (L.) Ascherson. MH17VSc contained 30 species: 42% *T. torulosa*, 15% Ph. minor, 14% Ha. eigü, and 8% B. muricata. MH8CRS contained 23 plant species: 30% *T. torulosa*; 10% *Schismus barbatus L.*; 8% *P. bulbosa*; 7% each of *Silene conoides L.* and *Lasiopogon muscoides L.*; and 5% each of *Ha. eigü, Holostium glutinosum,* and *Hordeum glaucum Steudel.* The total plants were represented by 2–5 plant species within the community, giving an even proportional distribution of different species.

The results showed that in the spring survey, the Species Richness (SR) increased and almost doubled compared to the autumn survey; this is reflected by the evenness of distribution of the species in the areas. Sites MH18CRS, MH19VSa, MH21CRSa, and MH21CRSb contained, even in spring, species that were unevenly distributed.

Species Richness (SR)

During the autumn survey, SR for all microcatchment watersheds ranged from 2% (five species) for MH6CRa, MH10CRS, and MH12VSb to 6% (14 species) in MH17VSc (Figure 5.4). For the spring survey, the SR was higher and ranged between 1% (seven species) for MH18CRS and 5% (35 species) for MH12VSa (Figure 5.5). There was an overall increase in SR in all sites from December 2006 to April 2007. The mean increase in SR was almost 13% over all sites, with an increase ranging from SR = 6 in MH21CRSb to SR = 33 in MH12VSa and MH17VSa. This was due entirely to the significant rainfall during the 2006/07 winter. This obtained values are similar to those of Badman (2006). The increase in SR in spring compared to autumn was a result of new species that emerged or appeared in spring.

Mainly annual plants appeared during spring as a result of the rain, consistent with the findings of (Aronson and Shmida 1992) and (Russi et al. 1992). Annual species represented 5–90% of the native vegetation recorded in the different watershed sites. Environmental factors, including both biotic and biotic stresses, largely determined the relative SR as well as the composition of the 'community' or 'taxons' at a given site.

Shannon–Wiener Diversity Index (SDI) and Shannon's Equitability (EH)

In the autumn survey, the highest SDI was at MH17VSb, while the highest evenness was at MH12VSb (Table 5.3).

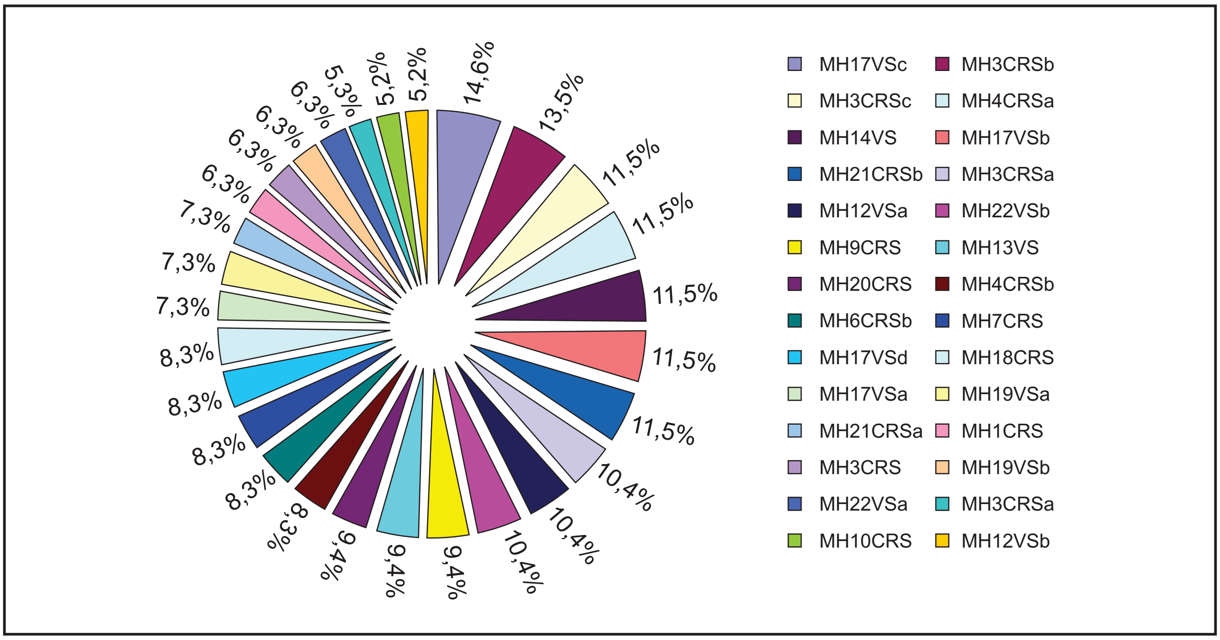

Figure 5.4: Species Richness (SR) of the microcatchment watershed sites at Mharib during the autumn survey (December 2006).

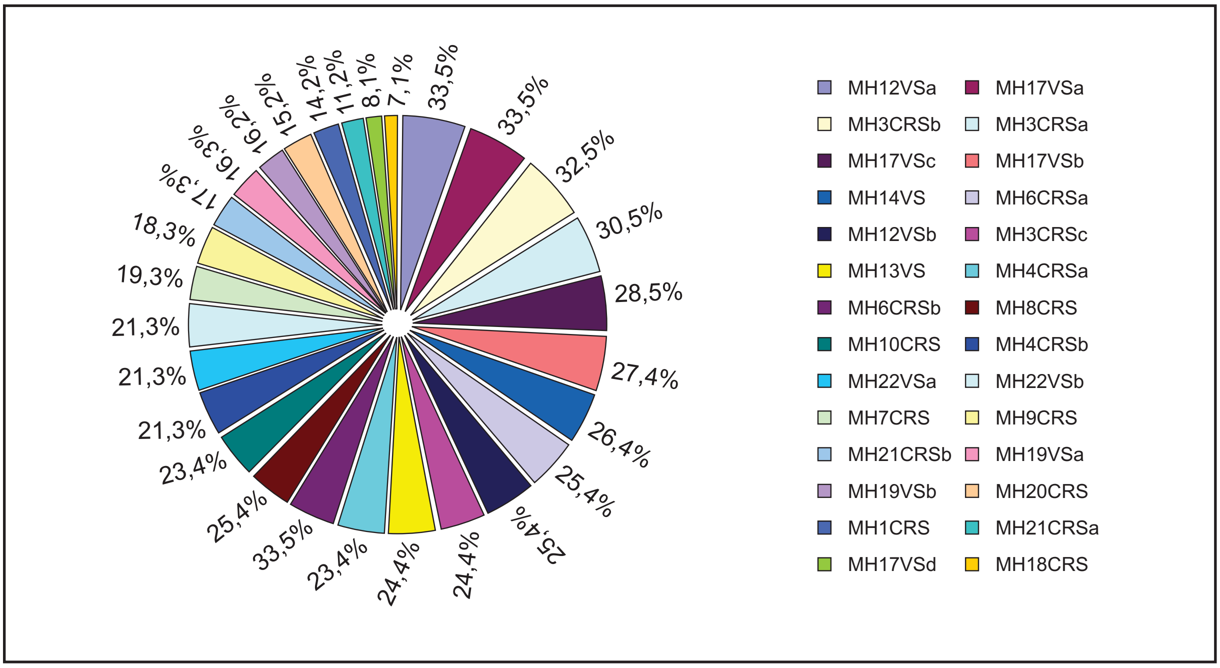

Figure 5.5: Species Richness (SR) of the microcatchment watershed sites at Mharib during the spring survey (April 2007).

Table 5.3. Shannon–Wiener Diversity Index (SDI) and Shannon's Equitability (EH) of the Mharib sites.

Site	December 2006		April 2007	
	SDI	EH	SDI	EH
MH1CRS	1.02	0.57	1.25	0.48
MH3CRSa	1.17	0.51	2.16	0.63
MH3CRSb	0.91	0.36	2.27	0.65
MH3CRSc	1.27	0.55	2.32	0.73
MH4CRSa	1.29	0.54	2.33	0.74
MH4CRSb	0.52	0.25	2.36	0.78
MH6CRSa	1.05	0.65	2.05	0.64
MH6CRSb	1.00	0.48	2.23	0.71
MH7CRS	0.78	0.37	2.29	0.78
MH8CRS	1.12	0.63	2.52	0.81
MH9CRS	0.84	0.38	2.17	0.73
MH10CRS	0.80	0.50	1.63	0.52
MH12VSa	1.31	0.57	2.51	0.72
MH12VSb	1.19	0.74	2.48	0.77
MH13VS	1.03	0.47	2.36	0.74
MH14VS	1.38	0.58	2.33	0.72
MH17VSa	1.26	0.65	2.63	0.75
MH17VSb	1.45	0.61	2.46	0.75
MH17VSc	1.19	0.44	2.02	0.61
MH17VSd	1.04	0.50	1.04	0.50
MH18CRS	0.91	0.47	0.91	0.47
MH19VSa	0.82	0.42	2.25	0.81
MH19VSb	0.75	0.42	2.25	0.81
MH20CRS	0.98	0.45	1.56	0.58
MH21CRSa	1.13	0.58	1.48	0.53
MH21CRSb	1.11	0.46	1.69	0.60
MH22VSa	1.05	0.59	2.33	0.77
MH22VSb	1.35	0.58	2.28	0.75

In the spring survey, the highest SDI was at MH19VSa (Table 5.3). This site had the second highest evenness after MH19VSb, and contained 27 plant species where 15 had similar existence percentage (around 40% of individuals). MH19VSb contained 16 species (the same SR as MH19VSa), but had very close percentages. The highest occupation was for *T. torulosa* and *G. micrantha* (13.5% each) and *Ha. eigü* (11%), with the rest in the range 3–9%. Such close percentages result in high EH. MH18CRS had the lowest SDI and hence the lowest evenness, indicating that was the more disturbed habitat among the other sub-watersheds.

Annuals–perennials ratio (AP-ratio)

The different plant species recorded in the MH22VSb site in the two survey dates were classified according to their life-cycle or description as annuals or perennials. The AP-ratio was calculated (Table 5.4). The increase in annuals in the spring compared to autumn survey was mainly due to the growth of the annuals that increased SR by 2–5-fold in some sites. This is due to the fact that perennials were already there at the two survey dates; however, annuals require cold and rain during winter to germinate and grow. The diversity of the dry areas is mainly due to the presence of annuals (not perennials) as they are larger and fluctuate in numbers due to the climatic conditions, mainly rain. Such results are consistent with those of (Aronson and Shmida 1992) and (Russi et al. 1992).

A total of 90 plant species were recorded in the present study. The numbers of annuals and perennials encountered were 64 (71%) and 26 (29%), respectively.

The dry environment in the study area resulted in more growth of annuals than perennials, as annuals can withstand dry conditions better due to their short life-cycle. Unfortunately the annuals also expose the soils to erosion by leaving the ground bare. Similarly, (Batanouny 1973) found that perennial palatable plants, which protect the soil best, are grazed and replaced by ephemerals which dry up and produce less forage, and that their roots do not protect the soil. Glover (2003) found that annual crops inefficiently utilize water and nutrients and that these result in the degradation of soil and water quality. He concluded that with a high proportional allocation of biomass to shoots, annuals grew more rapidly than perennials to complete their life-cycles before soils became very dry. Rapid growth by annuals is associated with both shallow rooting and correspondingly shallow soil-water utilization (Holmes and Rice, 1996).

Plant families

Plant species recorded in the 28th sub-watershed (Table 5.5) were classified according to their families (Zohary 1966; Al-Eisawi 1998)). A total of 24 different families and 87 species were recorded, in the following proportions: Asteraceae and Poaceae families (16% each); 15% Brassicaceae, Caryophyllaceae, and Liliaceae (8% each); Chenopodiaceae (7%); Papilionaceae (6%); and the rest were distributed among other families with small percentages of 1–3%.

In April 2007, 19 families were recorded compared to 12 in December 2006. In April 2007, Poaceae and Asteraceae families recorded the highest number of species (19%), followed by Brassicaceae (12%) and Chenopodiaceae (10%). In December 2006, Asteraceae had the highest plant percentage (20%), followed by Poaceae and Chenopodiaceae (19% each).

Forbs/herbs species

The recorded plant species (Table 5.5) were divided into 66 species of herbs (comprising 75.9%), 15 graminoides (17.2%), and six shrubs (6.9%). Graminoids' water requirements are higher than for herbs (all plant species except grasses), thus herbs can survive desert conditions.

Table 5.4. Species Richness (SR) and Annuals–Perennials ratio (AP-ratio) of different plant species recorded in MH22VSb for the two survey dates.

	December 2006		April 2007	
Site	**SR**	**AP-ratio**	**SR**	**AP-ratio**
MH1CRS	6	0.33	14	0.86
MH3CRSa	10	0.60	30	0.40
MH3CRSb	13	0.67	32	0.50
MH3CRSc	11	0.70	24	0.79
MH4CRSa	11	0.64	23	0.83
MH4CRSb	8	0.63	21	0.76
MH6CRSa	5	0.60	25	0.80
MH6CRSb	8	0.75	23	0.86
MH7CRS	8	0.75	19	0.79
MH8CRS	6	0.50	23	0.83
MH9CRS	9	0.78	18	0.89
MH10CRS	5	0.60	23	0.83
MH12VSa	10	0.70	33	0.79
MH12VSb	5	0.60	25	0.72
MH13VS	9	0.67	24	0.71
MH14VS	11	0.73	26	0.69
MH17VSa	7	0.71	33	0.70
MH17VSb	11	0.73	27	0.70
MH17VSc	14	0.67	28	0.71
MH17VSd	8	0.50	8	0.50
MH18CRS	8	0.71	7	0.71
MH19VSa	7	0.57	16	0.69
MH19VSb	6	0.67	16	0.75
MH20CRS	9	0.56	15	0.73
MH21CRSa	7	0.71	11	0.69
MH21CRSb	11	0.64	17	0.65
MH22VSa	6	0.67	21	0.81
MH22VSb	10	0.70	21	0.71

Herbs are found in larger numbers than grasses. Our study area is dryland with a long history of disturbances that have resulted in low vegetation cover, and few species (mainly unpalatable) have survived and still occupy the area. Thus, there is a small number (5% of recorded species) of shrubs. The seeds of weed species are generally aggregated around the mother plant; however, the quantity of seeds in a particular area depends on numerous factors such as the shape and the size of the parent plant, the size and shape of the seeds themselves, and the activity of

Table 5.5. List of plant species recorded in the Mharib intervention area arranged according to family, growth habit, and life duration.

Family	Growth habit	Life duration	Species
Araceae	Herb	Perennial	Biarum angustifol L.
Asteraceae (Compositae)	Herb	Annual	Aaronsohnia factorovskyi Warb. & Eig
			Anthemis haussknechtii Boiss. & Reut.
			Calendula arvensis L.
			Centaurea pallescens Delile
			Filago contracta (Boiss.) Chrtek and Holub
			Filago desertorum Pomel
			Gymnarrhena micrantha Desf.
			Koelpinia linearis Pall.
			Lasiopogon muscoides (Desf.) DC.
			Notaobasis syriaca (L.) Cass.
			Rhagadiolus stellatus (L.) Gaertn.
		Perennial	Achillea fragrantissima (Forssk.) Sch.Bip.
			Achillea santolina L.
			Scorzonera schweinfurthii (Boiss) Thiébaut
Boraginaceae	Herb	Annual	Gastrocotyle hispida (Forssk.) Bunge
			Lappula spinocarpos (Forssk.) Asch.
Brassicaceae (Cruciferae)	Herb	Annual	Alyssum damascenum Boiss. & Gaill
			Capsella bursa-pastoris (L.) Medik
			Cardaria draba (L.) Desv.
			Chorispora L.
			Dipoltaxis erucoides (L.) DC.
			Eruca sativa Mill.
			Hirschfeldia incana (L.) Lagr.-Foss.
			Malcolmia conringiodes Boiss.
			Raphanus aucheri Boiss.
			Sinapis arvensis L.
			Sisymbrium irio L.
			Torularia torulosa (Desf.) O. E. Schulz
	Semi-shrub	Perennial	Ankyropetalum gypsophiloides Fenzel
Caryophyllaceae	Herb	Annual	Gypsophila pilosa Huds.
			Herniaria hirsuta L.
			Holostium glutinosum (M.Bieb.) Fisch. & C.A.Mey
			Silene coniflora Otth.
			Silene conoidea L.

Table 5.5. (Continued).

Family	Growth habit	Life duration	Species
			Spergularia rubra (L.) J. & C.Presl
			Vaccaria pyramidata Medik.
Chenopodiaceae	Herb	Annual	Bassia muricata (L.) Asch.
			Chenopodium album L.
	Shrub	Perennial	Anabasis syriaca Iljin
			Hammada eigii Iljin
			Atriplex halimus L.
			Salsola vermiculata L.
Cistaceae	Herb	Annual	Helianthemum ledifolium (L.) Miller
Cyperaceae	Graminoids	Annual	Carex spp.
Euphorbiaceae	Herb	Annual	Euphorbia peplus L.
Fumariaceae	Herb	Annual	Fumaria densiflora DC.
			Hypecoum procumbens L.
Geraniaceae	Herb	Perennial	Erodium hirtum Willd
Iridaceae	Herb	Perennial	Gynandiris sisyrinchium (L.) Parl
Liliaceae	Herb	Perennial	Allium desertorum Forssk.
			Allium erdelii Zucc.
			Allium staminum L.
			Colchicum tunicatum Feinbrun
			Gagea chlorantha (M.Bieb.) Schult. & Schult.f.
			Gagea reticulate (Pall.) Schult. & Schult.f.
			Leopoldia longipes (Boiss) Losinsk.
Malvaceae	Herb	Annual	Malva praviflora L.
			Malva sylvestris L.
Papaveraceae	Herb	Annual	Roemeria hybrida (L.) DC.
Papilionaceae	Herb	Annual	Astragalus corrugatus Bertol.
			Astragalus cruciatus Link
			Onobrychis crista-galli (L.) Lam
			Vicia peregrina L.
			Trigonella stellata Forsk.
Plantaginaceae	Herb	Annual	Plantago coronopus L.
Poaceae	Graminoids	Annual	Bromus lanceolatus Roth
			Bromus madritensis sub sp. Delilei
			Catapodium rigidum (L.) C.E.Hubb
			Crithopsis delileana (Schult. & Schult.f.) Roshev.

Table 5.5. (Continued).

Family	Growth habit	Life duration	Species
			Echinaria capitata (L.) Desf.
			Eremopyrum bonaepartis (Sprengel) Nevski
			Hordeum glaucum Steudel
			Phalaris minor Retz
			Poa sinaica Steud
			Rostraria berythea L.
			Schismus barbatus (Loefl. ex L.) Thell.
			Stipa capensis Thunb.
		Perennial	Koeleria cristata (L.) Bertol.
			Poa bulbosa L.
Polygonaceae	Herb	Annual	Rumex cyprius Murb.
Portulacaceae	Herb	Annual	Portulaca oleracea L.
Primulaceae	Herb	Annual	Androsace maxima L.
Ranunculaceae	Herb	Annual	Adonis dentata Del.
			Ceratocepahala falcata (L.) Pers.
Umbelliferae	Herb	Annual	Tordylium aegyptiacum (L.) Lam.
Zygophyllaceae	Shrub	Perennial	Peganum harmala L.

the seed dispersal agents (e.g. wind and animals). For some species, seed survival in soils is rather short and most will germinate in the first year (Holmes and Rice, 1996).

Flora map

The plant species were mapped (Annexes 1.7–1.10) using characteristic species for each sub-watershed (to represent the particular type of species likely to be found within that community).

5.3 Impact of microcatchments water harvesting on soil seed bank

5.3.1 Introduction

According to (Roberts 1981), the term 'soil seed bank' designates the viable seed reservoir present in the soil and on its surface. (Simpson et al. 1989) defined the soil seed bank as the total amount of viable seeds (including vegetative propagules) found in the soil. Soil seed banks play a critical role in vegetation maintenance, succession, ecosystem restoration, differential species management, and conservation of genetic variability (Lemenih and Teketay, 2006). Use of soil seed bank in vegetation succession management is acknowledged as a low-cost restoration technique, since it solves many of the problems associated with collecting, storing, and sowing seeds, as well as transplanting individual seedlings raised in a nursery (Van der Valk and Pederson, 1989 as cited by Lemenih and Teketay, 2006). Assessment of the soil seed bank of a rangeland will reflect the potential of native vegetation cover of this rangeland, if the basic element of life (water) is provided.

5.3.2 Materials and methods

An experiment was conducted at Mharib intervention site located near Mharib village. The site area was around 7.2 ha and characterized by two slopes, gentle (< 5%) and moderate (8–12%). The Vallerani implement was used to form contour ridges in two shapes: continuous and intermittent. The farmers' traditional method of making furrows with a chisel plow disc was also used. *Atriplex halimus* shrubs were planted in the contour ridges of both the Vallerani machine and the traditional furrows with fixed distances (6 m for all treatments). Barley was planted in the experiment site using the local farmers' traditional planting method with 50 kg seeds/ha. The implementation started at the end of December 2005, after the rainy season began.

Treatments and experimental design: The experiment consisted of two main land slopes, slope 1 (S1: < 5%), and slope 2 (S2: 8–12%), and the sub-treatments in each slope were:

T1: WH with Vallerani intermittent contour ridges (CRVI), within catchment area (CRVIC)
T2: WH with CRVI, within ridges (CRVIW)
T3: WH with Vallerani continuous contour ridges (CRVC), within catchment area (CRVCC)
T4: WH with CRVC, within ridges (CRVCW)
T5: WH with traditional contour ridges (CRTP), within catchment area (CRTPC)
T6: WH with CRTP, within ridges (CRVCW)
T7: barley plantation (BP)
T8: control, with no intervention and no grazing (CIG)
T9: control, outside the intervention area, but protected from grazing (to study the effect of protection against the intervention plus protection)

Three transects were laid down per slope-type per sub-treatment. Fifteen composite soil samples were taken at 4 cm depth per transect for the soil seed bank analysis. Three soil samples were taken per transect for the soil analysis. The experiment was replicated three times, which resulted in 54 plots (sizes 0.05–0.4 ha). The data was analyzed using repeated measure arrangements.

Sampling procedure: Three 50-m-long transects were laid down randomly along each plot and five quadrats of 1 m^2 were marked at 10-m intervals on the transect; then a 5-cm diameter and 20-cm-long cylindrical tube was used to sample the soil to a depth of 0–4 cm from each corner of the quadrat. The four samples were mixed to form one composite soil sample per quadrat, with a soil volume of 314 cm^3 for each quadrat

(Figure 5.6). The soil was placed in labeled plastic bags according to plot number and quadrat number. Thus there were 15 composite soil seed bank samples from each plot with a total soil volume of 4710 cm^3, which is 7.8 times greater than the soil sample volumes suggested by (Roberts 1981) and (Ball and Miller 1989). A total of 810 soil seed bank samples were taken from all 54 plots. The sampling was conducted twice: in December 2006 and June 2007.

Consequently, a total of 1620 soil samples were collected for the assessment of the soil seed bank. Soil samples were placed in a large plastic bucket and washed with tap water, then sieved through 250-μm mesh, after removing stones. The soil debris was placed on paper and left to dry in the air. The dry soil debris were put back in plastic bags and stored at 4°C for further seed separation. The seeds were separated by hand, using (9×) magnifying lenses.

The separated seeds were identified (to species level when possible) using seed samples, as a key, collected from the field from previously identified plant species. Seed viability was determined by applying gentle pressure to each seed with forceps, and seeds resisting pressure were recorded as 'apparently viable', as used by several workers (Hayashi et al., 1978; Ball and Miller, 1989). For the purpose of this study, a determination of apparent viability was sufficient to make appropriate study comparisons. Seeds were counted and kept in aluminum bags in a refrigerator at 4°C.

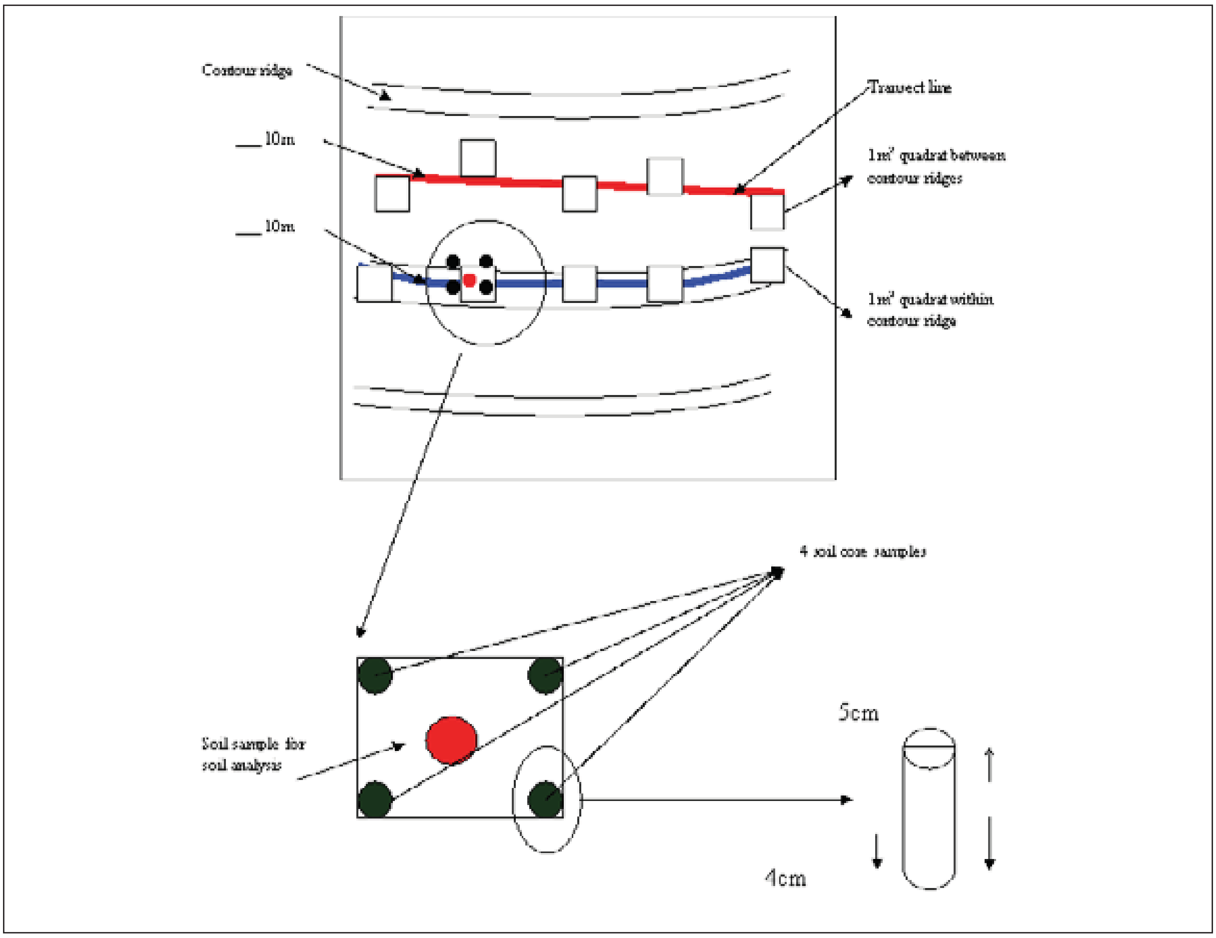

Figure 5.6: Sampling technique for soil seed bank analysis.

Table 5.6. Three-way interaction effect of slope, dates, and WH interventions on seeds extracted from the soil.

Slope	Date	WH Intervention	Mean seed number/m^2
< 5%	December 2006	T[1]: CRVIC	1637 gh*
		T[2]: CRVIW	2959 e
		T[3]: CRVCC	628 hij
		T[4]: CRVCW	2939 e
		T[5]: CRTPC	1777 fg
		T[6]: CRTPW	4211 bcd
		T[7]: Bp	694 hij
		T[8]: CIG	562 ij
		T9: C-outside the intervention	155 j
	June 2007	T[1]: CRVIC	802 ghij
		T[2]: CRVIW	4115 bcd
		T[3]: CRVCC	1010 ghij
		T[4]: CRVCW	4764 abc
		T[5]: CRTPC	1418 ghi
		T[6]: CRTPW	3748 cde
		T[7]: Bp	592 hij
		T[8]: CIG	523 ij
		T9: C-outside the intervention	432 ij
8–12%	December 2006	T[1]: CRVIC	809 ghij
		T[2]: CRVIW	5395 a
		T[3]: CRVCC	782 ghij
		T[4]: CRVCW	3369 de
		T[5]: CRTPC	880 ghij
		T[6]: CRTPW	2723 ef
		T[7]: Bp	969 ghij
		T[8]: CIG	984 ghij
		T9: C-outside the intervention	143 j
	June 2007	T[1]: CRVIC	875 ghij
		T[2]: CRVIW	4858 ab
		T[3]: CRVCC	867 ghij
		T[4]: CRVCW	4789 abc
		T[5]: CRTPC	1063 ghij
		T[6]: CRTPW	4336 abcd
		T[7]: Bp	1067 ghij
		T[8]: CIG	980 ghij
		T9: C-outside the intervention	450 ij

Note: * Values followed by the same letter are not significantly different at $P < 0.05$.

5.3.3 Results and discussion

Size of the soil seed bank

Analysis of variance (ANOVA) was performed for mean number of seeds extracted from the soil (Annex 1.11). The three-way interaction of the effect of slope, sampling date, and WH on seed number extracted from soil was determined (Table 5.6). The mean soil seed numbers in June 2007 of 17 404 and 19 285 seeds/m^2 in the gentle and moderate slopes, respectively, were about 11 and 17% higher than for the respective December 2006 values of 15562 and 16054 seeds/m^2.

The highest number of seeds recorded in June is related to the fact that different herbaceous plants shed their seeds during May–June every year and the seeds fall to the ground and enrich the soil seed bank (Thompson and Grim, 1979; Garwood, 1989; Russi et al., 1992). The number of annual plants increased in summer after the rainy season; they shed their seeds in soil and so enriched the soil seed bank. Annuals avoid the seasonal drought; they complete their life-cycle by producing and dispersing matured seeds at the beginning of the hot dry season. The seeds remain as a 'seed bank' in the soil or amidst the dry remains of dead mother plants, where they can be dispersed over many years (Shmida and Burgess, 1988; Gutterman, 1993). The perennials are always there and their seed numbers increase due to shedding from mother plants. Perennials allocate a higher proportion of their total biomass to shoots to sustain rapid whole-plant growth rates, as reflected in less of their seeds produced than of annuals.

Of the mean soil seed number/m^2, 67–73% was captured within the contour ridges, with 15–26% in the catchment area. Only 3–6% was found in the barley intervention area, 3–6% was found in the CIG control treatment, and 1–2.5% was found in the control treatment outside the intervention area. The highest seed number (38–55%) was within the Vallerani contour ridges, and the traditional plowing captured 17–23% of soil seeds. The significant increase in the soil seed bank due to using WH techniques implied that reliance on the soil seed bank for the recovery of native flora on fields abandoned after a number of years of continuous conservation may be successful. Contours create a suitable climate for the plants to grow and form seeds, and also form a sink for seeds moving down the slope from the catchment area after rain. Water will settle in the contours with the soil and the seeds it carries, as a result the soil seed bank will be larger in contours than other parts of the catchment area. Native vegetation will benefit from the water that the contours provide and increase the cover percentage and SR. Even the native plants that are well adapted to hot and dry conditions will usually benefit from supplemental water provided by microcatchments and produce more flowers and seeds than plants in open areas without treatments (Van der Valk and Pederson, 1989; Fidelibus and Bainbridge, 1994; Suleman et al., 1995; Bainbridge, 2003; Yan et al., 2006).

Vallerani intermittent contour ridges (CRVI) intervention captured a higher number of seeds/m^2 (19–35% of soil seeds) within the ridges, whereas Vallerani continuous contour ridges (CRVC) captured 19–27%. The catchment area of the Vallerani interventions recorded 9–15% of the soil seeds compared with 5.5–11% recorded for traditional plowing. The CRVI catchment area captured 5–11% of the seed number and the CRVC catchment captured 4–6%. The highest mean seed number/m^2 was within the ridges of the Vallerani intermittent contour ridges treatment in December 2006 (5395 seeds/m^2), which was not significantly different from those recorded within the ridges of the CRVI intervention; or within the ridges of the CRVC and traditional contour ridges interventions in June 2007 (4858, 4789, and 4336 seeds/m^2, respectively) in the moderate slope. Moreover, values for the moderate slope did not significantly differ from the amount of seeds recorded within the ridges of the gentle slope of the CRVC intervention (4764 seeds/m^2) recorded in December 2006.

The higher value of mean seed number/m^2 in the CRVI over the other structures was a result of the deeper contours made by the Vallerani machine compared to traditional plowing. CRVI gave a higher seed number/m^2 over the CRVC, possibly due to the smaller basins made by CRVI, which enabled retention of a greater amount of soil moisture. This is consistent with results of Suleman et al. (1995), who found that soil moisture can be significantly increased with microcatchments of 4 and 5 m in length. This supports the positive effect of the intermittent structure of the contours that have smaller dimension than continuous structures.

The amount of seeds in the soil seed bank in the barley plantation did not significantly differ from that for either of the control treatments. The highest mean seed number was for the barley intervention. The lowest was for the control outside the intervention area, which only captured 3% of seeds (423 and 450 seeds/m^2 for gentle and moderate slopes, respectively, in June 2007) compared to CRVI.

Cultivation affects the soil seed bank by damaging or breaking seeds directly, or by bringing buried seeds to the surface and exposing them to predators, desiccating winds, high temperature, direct solar radiation, or inducing them to germinate and die – as a result the soil seed bank under barley was smaller than for other treatments. Such results agree with other findings (Bowers, 1987; Bainbridge, 2003; Lemenih and Teketay, 2006) showing that such environmental factors as high temperature and direct solar radiation on bare soils of farm fields may induce rapid loss of seed viability and consequently reduce woody species composition in the soil seed bank. Cultivation moved the layer of soil of about 5–10-cm depth upward and seeds in the soil were subjected to high light and temperature, in addition to loss of soil moisture – such conditions result in the death of a large amount of seeds.

Protection is not the only solution for rangeland rehabilitation, as shown by the size of the soil seed bank in the control outside the intervention area but protected from grazing; this soil seed bank was smaller than for the control treatment inside the intervention area which had the benefit of both the WH intervention and protection from grazing. Although the control treatment inside the intervention area had no contour structure, it benefitted from the catchment areas of the other treatments as it was randomly distributed between them.

The average number of seeds in the soil seed bank during December 2006 (Table 5.7) ranged from 16 seeds/m^2 for *Bromus lanceolatus* Roth., *Capsella bursa-pastoris* (L.) Medik, and *Plantago* coronopus L. to 206 165 seeds/m^2 for *Herniaria hirsuta* L. For samples collected in June 2007 (Table 5.8) the soil seed bank ranged from 31 seeds/m^2 for *Ankyropetalum gypsophiloides* Fenzel to 128 254 seeds/m^2 for *He. hirsuta*. Clearly *He. hirsuta* was the major component of the soil seed bank during the study period: representing 39 and 48% of the total and the annual soil seed banks, respectively, in December 2006 samples; and correspondingly 22 and 25% in June 2007. *Schismus barbatus* (Loefl. ex L.) Thell. ranked third (54 510 seeds/m^2) during December 2006, and formed 10 and 13% of the total and annual soil seed banks, respectively; it ranked second (77 927 seeds/m^2) during June 2007 and formed 13 and 15%, respectively, of the total and annual soil seed banks.

The high soil seed bank of *He. hirsuta* and *Sc. barbatus reflects* the dominance of the Caryophyllaceae and Poaceae families, which produce large numbers of very small seeds shed from mother plants (Gutterman 1993). Large numbers of such seeds moved to soil cracks and under

Table 5.7. Average seed number (no./m²) of annual and perennial plant species in the soil seed bank during December 2006.

Species (annuals)	Average seed (no./m²)	Species (annuals)	Average seed (no./m²)
Herniaria hirsuta L.	206 165	Poa sinaica Steud.	267
Gymnarrhena micrantha Desf.	79 311	Eremopyrum bonaepartis (Sprengel) Nevski	252
Schismus barbatus (Loefl. ex L.) Thell.	54 510	Rumex cyprius Murb.	236
Filago desertorum Pomel	33 215	Alyssum damascenum Boiss. & Gaill	236
Torularia torulosa (Desf.) O. E. Schulz	18 196	Roemaria hybrida (L.) DC.	220
Androsace maxima L.	11 434	Trigonella stellata Forskal	220
Hordeum vulgare L.	3397	Astragalus spp.	204
Hordeum glaucum Steud.	3366	Ankyropetalum gypsophiloi-des Fenzel	189
Eruca spp.	2501	Malva sylvestris L.	189
Ceratocepahala falcata (L.) Pers.	2280	Fumaria densiflora DC.	173
Helianthemum ledifolium (L.) Miller	2076	Sisymbrium irio L.	173
Aaronsohinia factorovshyi Warb. & Eig	1746	Vaccaria pyramidata Medik.	142
Sinapis arvensis L.	1714	Phalaris minor Retz	110
Lasiopogon muscoides (Desf.) DC.	1526	Gypsophila pilosa Huds.	94
Malcolmia conringiodes Boiss	1258	Echinaria capitata (L.) Desf.	94
Portulaca oleracea L.	1038	Asperugo procumbence L.	79
Gynandiris sisyrinchium (L.) Parl	802	Tordylium aegyptiacum (L.) Lam.	63
Anthemis spp.	535	Hypecoum procumbens L.	47
Adonis dentata Del	472	Silene conoides L.	47
Hirschfeldia incana (L.) Lagr.-Foss.	456	Rostraria berythea L.	47
Chenopodium album L.	330	Bromus lanceolatus Roth	16
Euphorbia peplus L.	315	Capsella bursa-pastoris (L.) Medik	16
Astragalus cruciatus Link.	283	Plantago sp.	16
Poa bulbosa L.	40 874	Leopoldia longipes (Boiss) Losinsk.	409

Table 5.7. (Continued).

Species (annuals)	Average seed (no./m²)	Species (annuals)	Average seed (no./m²)
Anabasis syriaca Iljin	37 792	Atriplex halimus L.	157
Hammada eigii Iljin	6763	Allium erdelii Zucc.	110
Achillea fragrantissima (Forskal) Schultv Bip	2689	Gagea spp.	63
Bellevalia spp.	2265	Erodium hirtum Willd.	31
Allium desertorum Forssk.	2233	Peganum harmala L.	31
Astragalus cruciatus	1478	Cardaria draba (L.) Desv.	16

stones and were protected from wind dispersal, and so became assets in the soil seed bank. The greater size of the soil seed bank for some species such as *He. hirsuta* and *G. micrantha* is mainly due to the fact that such plants are characterized by a long delay in dispersal (Zohary, 1962).

These seeds mature in May–June, but are found in largest numbers in October. Such seeds are protected by the dry body of the mother plant, a survival mechanism of the dryland species for protection against being eaten by ants or dispersed by wind. So during October–November when few rain drops fall on the soil surface a microhabitat is created for the seeds to leave the mother plant for the soil surface ready for germination. Not all seeds are shed by the mother plant, a reasonable percentage are kept for the next season in the case of rainfall being insufficient for growth after germination.

The majority of the identified seeds were annuals; around 82% in December 2006, and 90% in June 2007 (Tables 5.7 and 5.8). Seed of perennial species increased by 41% in June 2007 compared with December 2006. Poa bulbosa formed the highest proportion of the soil seed bank (43% in June 2007 and 37% in December 2006). Two species recorded in June 2007 (*Cardaria draba* (L.) *Desv. and Peganum harmala* L.) were not recorded in December 2006; and two species, K*oeleria cristata* (L.) Pers. and *Achillea sp*., were not found at all.

The highest seed density in the soil seed bank was recorded for He. hirsuta (48% in December 2006 and 25% in June 2007) for all interventions, except for both of the control treatments.

For control treatments, whether inside or outside the interventions, the highest soil seed banks were for *P. bulbosa* with 43 and 37% in December 2006 in June 2007, respectively, and for *G. micrantha* with 18 and 7%, respectively (Table 5.9).

The highest average seed number (26% of the total soil seed bank) was obtained within the ridges of the WH with CRVI, followed by the traditional contour ridges intervention (20%), then for CRVC (18%). The soil seed bank was 50–60% higher within the contour ridges compared to that in the catchment area. The barley plantation showed higher seed numbers for *He. hirsuta* (6% of the total soil seed bank); however, the highest soil seed bank was for *P. bulbosa* (1%) in the control treatment with no intervention and no grazing. The soil seed bank in the control (outside the intervention area) had the lowest soil seed bank, mainly of *G. micrantha* and *represented* only 0.13% of the soil seed bank.

Table 5.8. Average seed number (no./m²) of annual and perennial plant species in the soil seed bank during June 2007.

Species (annuals)	Average seed (no./m²)	Species (annuals)	Average seed (no./m²)
Herniaria hirsuta L.	128 254	Gynandiris sisyrinchium (L.) Parl.	1007
Schismus barbatus (Loefl. ex L.) Thell.	77 927	Sinapis arvensis L.	865
Torularia torulosa (Desf.) O. E. Schulz	71 684	Anthemis spp.	771
Poa sinaica Steud.	44 366	Euphorbia peplus L.	755
Filago desertorum Pomel	41 614	Fumaria densiflora DC.	755
Gymnarrhena micrantha Desf.	35 055	Astragalus cruciatus Link.	723
Ceratocepahala falcata (L.) Pers.	24 251	Rumex cyprius Murb.	661
Androsace maxima L.	15 082	Aaronsohinia factorovshyi Warb. & Eig	661
Hirschfeldia incana (L.) Lagr.-Foss.	11 559	Chenopodium album L.	488
Hordeum glaucum Steud.	8335	Astragalus spp.	440
Malcolmia conringiodes Boiss	7911	Rhagadiolus stellatus (L.) Gaertner	346
Eruca spp.	5945	Hypecoum procumbens L.	283
Sisymbrium irio L.	5174	Trigonella stellata Forskal	267
Rostraria berythea L.	5017	Plantago coronopus L.	252
Dipoltaxis erucoides (L.) DC.	3947	Chorispora spp.	252
Alyssum damascenum Boiss. & Gaill	2689	Stipa capensis Thunb.	236
Bassia muricata (L.) Ascher-son	2626	Bromus madritensis sub sp. delilei	236
Roemaria hybrida (L.) DC.	2422	Asperugo procumbence	204
Hordeum vulgare L.	2391	Echinaria capitata (L.) Desf.	204
Silene conoides L.	2375	Portulaca oleracea L.	189
Lasiopogon muscoides L.	2328	Vaccaria pyramidata Medik.	173
Helianthemum ledifolium (L.) Miller	2202	Notaobasis syriaca (L.) Cass.	142
Adonis dentata Del	1730	Carex L.	142
Malva sylvestris L.	1683	Spergularia rubra (L.) J. & C. Presl.	142

Table 5.8. (Continued).

Species (annuals)	Average seed (no./m²)	Species (annuals)	Average seed (no./m²)
Phalaris minor Retz	1636	Gypsophila pilosa Huds.	126
Eremopyrum bonaepartis (Sprengel) Nevski	1557	Bryonia cretica L.	126
Catapodium rigidum (L.) C.E. Hubb.	1211	Capsella bursa-pastoris (L.) Medik	79
Bromus lanceolatus Roth	1148	Lappula spinocarpos (Forssk.) Asch.	47
Cardaria draba (L.) Desv.	1007	Ankyropetalum gypsophi-loides Fenzel	31
Poa bulbosa L.	20587	weed bulb	1227
Gagea spp.	11984	Allium desertorum Forssk	849
Anabasis syriaca Iljin	8005	Bellevalia spp.	912
Hammada eigii Iljin	4105	Achillea spp.	991
Allium erdelii Zucc.	2501	Erodium hirtum Willd	582
Koeleria cristata (L.) Pers.	1132	Atriplex halimus L.	472
Achillea fragrantissima (For-skal) Schultv Bip	2092	Leopoldia longipes (Boiss) Losinsk.	315

Table 5.9. Summary of the effect of different intervention on the soil seed bank.

Intervention	Species of maximum seed number	Maximum seed (no./m²)	SR
T^1: CRVIC	Herniaria hirsuta L.	77 650	44
T^2: CRVIW	Herniaria hirsuta L.	187 343	67
T^3: CRVCC	Herniaria hirsuta L.	62 877	46
T^4: CRVCW	Herniaria hirsuta L.	134 988	69
T^5: CRTPC	Herniaria hirsuta L.	54 354	50
T^6: CRTPW	Herniaria hirsuta L.	142 354	63
T^7: Bp	Herniaria hirsuta L.	42 876	41
T^8: CIG	Poa bulbosa L.	7640	47
T9: C – outside the intervention	Gymnarrhena micrantha Desf.	932	26

Table 5.10. Average seed number (no./m²) of annual and perennial plant species in the soil seed bank during June 2007.

Slope	Date	WH Intervention	Mean of plant no./m²
< 5%	December 2006	T^1: CRVIC	61 klmno*
		T^2: CRVIW	87 ijklm
		T^3: CRVCC	80 ijklmn
		T^4: CRVCW	148 efgh
		T^5: CRTPC	33 no
		T^6: CRTPW	109 ghijkl
		T^7: Bp	32 no
		T^8: CIG	30 no
	April 2007	T^1: CRVIC	150 defg
		T^2: CRVIW	231 b
		T^3: CRVCC	71 jklmno
		T^4: CRVCW	202 bcd
		T^5: CRTPC	87 ijklm
		T^6: CRTPW	162 cdef
		T^7: Bp	60 klmno
		T^8: CIG	68 jklmno

5.4 Effect of microcatchments on the native vegetation

5.4.1 Materials and methods

For three consecutive periods (December 2006, April 2007, and April 2008) the flora in the experimental site was surveyed, to determine the effect of different WH techniques on the native vegetation. The experiment was a randomized complete block design using repeated measures for analysis, with three replicates.

The treatments in each slope were the same as used in assessment of the soil seed bank without the ninth treatment (i.e. the control outside the intervention area, but protected from grazing). The survey was carried out using the Belt Transect Method (Schmutz et al. 1982). One transect was laid down per land slope per sub-treatment. Five quadrats were placed along each transect at 10-m intervals. A total of 48 transects and 240 quadrats were surveyed for the experimental site.

5.4.2 Results and discussion

Total plant species number

An ANOVA was performed for the effect of the two slopes, the eight different interventions, and the three sampling dates: December 2006, April 2007, and April 2008 (Annex 1.12).

The three-way interaction effect of slopes, sampling dates, and interventions are shown in (Table 5.10). The CRVI intervention resulted in the highest plant number within the ridges, followed by the CRVC, and then traditional contour ridge interventions. The highest plant number was recorded in April 2007 with 1108 and 1031 plants/m² in the moderate and gentle slopes, respectively; followed by December 2006 with 774 plants/m^2 in the moderate slope; then April 2008 with 765 and 721 plants/m^2 in the moderate and gentle slopes, respectively; and the lowest value was 580 plants/m^2 in December 2006 in the gentle slope. This may be due to the higher amount of rainfall in April 2007 (111.2 mm) than in April 2008 (84.2 mm). Native vegetation measurement (vegetation cover, plant number, plant height, and biodiversity parameters such as SDI and SR) were highest under Vallerani contour ridges within contours intervention.

This is likely due to the Vallerani machine producing contours that are deeper and so collecting more moisture than other treatments (Suleman et al., 1995). Moisture availability is the major reason behind the higher vegetation cover, taller plants, and higher biodiversity values. In addition, the presence of shrubs can improve the natural vegetation.

The Vallerani contour ridges intervention produced the highest plant number (58–66%) of the total plants recorded in the area, whereas the traditional plow intervention produced only 11–21% of the plants.

Vallerani contour ridges within the ridges intervention produced higher plant number/m^2 (42–52%) compared to the Vallerani catchment area (23–31%). This is consistent with results of Rice (2004) showing that a desert water-harvester could concentrate and collect water from precipitation. ACSAD (2003) reported that microcatchment WH results in improved vegetative cover and fodder shrub plantation, and leads to restoration of the rangelands and increases runoff collection in semi-arid and arid regions.

Contours preserve more moisture, and provide a suitable habitat for as shrubs planted in the contours and other plants to grow (Tielbörger and Kadmon, 1997; Holzapfel and Mahall, 1999; Facelli and Temby, 2002).

Between the contour ridges the Gramineae family was more represented, possibly since the rapid growth of annual species gave them more time to complete their life cycle, in addition to producing more seeds and so more grass growth if moisture was available. The intermittent structure provides more moisture than the continuous or the traditional plowing.

Relative dominance of grasses was higher in the intermittent interventions, possibly because more water was preserved by such structures. For the other treatments, including the traditional plowing, the relative dominances were very close to each other, as a result of the high diversity of the area (i.e. the high number of plant species that characterize the drylands).

The Vallerani intermittent contour ridges recorded higher plant numbers/m^2 (15–29%) compared with Vallerani continuous contour ridges within contours (20–26%), since the deeper contours formed by the Vallerani machine when implementing the intermittent structure. This result shows the higher effect of Vallerani machine over the traditional plowing. Vallerani intermittent WH, within contours (T2: CRVIW) had higher seed numbers/m^2 compared to the Vallerani continuous, within contours, confirming the positive effect of the intermittent contour structure.

The barley intervention had the lowest plants/m^2 (4–6%) compared with the other interventions, and with no significant difference to the control treatment (5–6.6%). The highest total plant number (284 plants/m^2) was recorded within the ridges of the Vallerani intermittent contour ridges treatment, in samples collected in April 2007 in the moderate slope (8–12%). The lowest total plant number was for the barley plantation (27 plants/m^2) in samples collected in the gentle slope during April 2008.

Table 5.10. (Continued).

Slope	Date	WH Intervention	Mean of plant no./m²
< 5%	April 2008	T[1]: CRVIC	30 no
		T[2]: CRVIW	210 bc
		T[3]: CRVCC	59 klmno
		T[4]: CRVCW	162 cdef
		T[5]: CRTPC	114 fghij
		T[6]: CRTPW	82 ijklmn
		T[7]: Bp	27 o
		T[8]: CIG	37 mno
8–12%	December 2006	T[1]: CRVIC	60 klmno
		December 2006	184 bcde
		T[3]: CRVCC	97 hijkl
		T[4]: CRVCW	163 cdef
		T[5]: CRTPC	35 mno
		T[6]: CRTPW	161 cdef
		T[7]: Bp	42 mno
		T[8]: CIG	32 no
	April 2007	T1: CRVIC	130 fghi
		T2: CRVIW	284 a
		T3: CRVCC	60 lmno
		T4: CRVCW	228 b
		T5: CRTPC	62 jklmno
		T6: CRTPW	218 b
		T7: Bp	60 klmno
		T8: CIG	66 jklmno
	April 2008	T1: CRVIC	60 klmno
		T2: CRVIW	212 bc
		T3: CRVCC	108 ghijk
		T4: CRVCW	164 cdef
		T5: CRTPC	67 jklmno
		T6: CRTPW	85 ijklm
		T7: Bp	32 no
		T8: CIG	37 mno

Note: *Values followed by the same letter are not significantly different at *P*< 0.05.

Plant height

Slopes, interventions, sampling dates, and their interaction showed significant ($P < 0.05$) effects on plant height (Annex 13). In April 2008, the highest mean plant height (8 cm) was on the moderate slope. In December 2006, the lowest plant height (3 cm) was on the moderate slope. In April 2007, the greatest average plant height (16 cm) was recorded for plants with traditional plowing within contour ridges on the moderate slope; followed by 15 cm for plants at the Vallerani contour ridges.

The lowest plant heights were under the Vallerani catchment intervention (maximum of 7 cm). The barley plantation had greater plant heights than the control treatment (6 and 5 cm, respectively). For samples collected in April 2008 in the moderate slope, the Vallerani intermittent contour ridges on the ridges intervention had plant heights of 13 cm, as did Vallerani continuous contour ridges.

The lowest plant heights were for plants in December 2006 (Table 5.11), and in general plants under barley and the control treatments were shorter plants with few exceptions. Most plant heights for the other treatments did not differ significantly from each other.

Species richness and species evenness of the experiment site

SR and species evenness were measured using data collected in December 2006, April 2007, and April 2008 (Annexes 1.14–1.16) to determine where to measure the SDI and EH. The highest values (SR = 57 species) were in April 2007, while April 2008 had SR = 46, and December 2006 had SR= 47.

Therefore, depending on SR results, diversity parameters of the effect of different slopes and interventions were calculated for April 2007 data, in which was also recorded the highest species evenness.

High SDI was recorded for plants within the ridges in the Vallerani intermittent contour ridges intervention (SDI = 3.21) (Table 5.12), with high species evenness within the site (EH = 0.81) as well as high SR (52 species) in the gentle slope. For the moderate slope, the highest diversity values (SDI = 2.89, EH = 0.73, and SR = 52) were for species within the ridges in the Vallerani intermittent contour ridges intervention.

Plant species within the ridges of the Vallerani continuous contour ridge intervention had high average diversity with SDI = 2.6, EH = 0.74, and SR = 36; and SDI = 2.5, EH = 0.68, and SR = 40; in the gentle and moderate slopes, respectively. This compared with the corresponding catchment area values of SDI = 1.7, EH = 0.59, and SR = 17; and SDI = 1.89, EH = 0.62, and SR = 22.

The average SDI in the Vallerani contour ridges was about 15 and 9% higher in the gentle and moderate slopes, respectively, compared with the traditional plowing; the corresponding increments in EH were 11 and 4% for gentle and moderate slopes compared with traditional plowing. SR was about 19 and 2% higher for Vallerani contour ridges in the gentle and moderate slopes, respectively, compared with traditional plowing.

The control, with no intervention and no grazing, had higher SDI (16%) and EH (13.6%) and SR (8.7%) compared with barley plantation intervention on the gentle slope. The reverse applied in the moderate slope where the barley had the higher SDI (7.4%), EH (4.2%), and SR (12%).

5.5 Regenerating native vegetation cover using WH techniques

5.5.1 Introduction

This component concentrated on the possibility of collecting plant seeds from the Mharib area and cultivating them under Mharib conditions. Two strategies for regen-

Table 5.11. Effect of slope, sampling date, and WH interventions on mean height of native plants (cm).

Slope	Date	WH intervention	Mean plant height (cm)
< 5%	December 2006	T^1: CRVIC	2 lmno
		T^2: CRVIW	3 ghijklmnp
		T^3: CRVCC	3 jop
		T^4: CRVCW	7 nefghijklmn
		T^5: CRTPC	4 flmnp
		T^6: CRTPW	3 hop
		T^7: Bp	3 fghijklmn
		T^8: CIG	2 lmno
	April 2007	T^1: CRVIC	5 efghijklmn
		T^2: CRVIW	8 bef
		T^3: CRVCC	7 efghiklmn
		T^4: CRVCW	12 abc
		T^5: CRTPC	8 ceghijk
		T^6: CRTPW	7 efgijklmn
		T^7: Bp	5 efghijklmn
		T^8: CIG	4 fghijklmn
	April 2008	T^1: CRVIC	4 efghijklmn
		T^2: CRVIW	12 acd
		T^3: CRVCC	5 efghijklmn
		T^4: CRVCW	6 efghijklmn
		T^5: CRTPC	4 flmnp
		T^6: CRTPW	6 efghijklmn
		T^7: Bp	2 lmno
		T^8: CIG	3 ijklmnp
8–12%	December 2006	T^1: CRVIC	2 npq
		T^2: CRVIW	6 efghijklmn
		T^3: CRVCC	3 mpq
		T^4: CRVCW	9 ce
		T^5: CRTPC	3 kop
		T^6: CRTPW	7 efghijklmn
		T^7: Bp	4 fghijklmn
		T^8: CIG	4 fghijklmn

Table 5.11. (Continued).

Slope	Date	WH intervention	Mean plant height (cm)
8–12%	April 2008	T1: CRVIC	7 efghijklm
		T2: CRVIW	13 abc
		T3: CRVCC	7 efghijkln
		T4: CRVCW	15 a
		T5: CRTPC	7 efghijlmn
		T6: CRTPW	16 a
		T7: Bp	6 efghijkmno
		T8: CIG	5 efghijklmn
	December 2006	T1: CRVIC	8 bcdefgh
		T2: CRVIW	13 abc
		T3: CRVCC	7 efghijkln
		T4: CRVCW	13 ab
		T5: CRTPC	6 efghijlmn
		T6: CRTPW	6 efghijklmn
		T7: Bp	3 lpq
		T8: CIG	4 fghijklmn

Note: * Values followed by the same letter are not significantly different at P < 0.05.

Table 5.12. Shannon–Wiener Diversity Index (SDI), Shannon's equitability (EH), and species richness (SR) of the different interventions in the two slopes recorded for April 2007.

Date	WH intervention	SDI	E_H	SR
April 2007	T^1: CRVIC	1.70	0.60	17
	T^2: CRVIW	3.21	0.81	52
	T^3: CRVCC	1.83	0.64	17
	T^4: CRVCW	2.36	0.71	28
	T^5: CRTPC	1.53	0.53	18
	T^6: CRTPW	2.33	0.71	27
	T^7: Bp	1.73	0.57	21
	T^8: CIG	2.06	0.66	23
April 2008	T^1: CRVIC	2.25	0.68	28
	T^2: CRVIW	2.89	0.73	52
	T^3: CRVCC	1.59	0.55	18
	T^4: CRVCW	2.37	0.67	34
	T^5: CRTPC	1.83	0.62	19
	T^6: CRTPW	2.31	0.65	34
	T^7: Bp	2.31	0.72	25
	T^8: CIG	2.14	0.69	22

eration (cultivation) of the native plants were applied using different WH techniques:

1. Direct seeding, in which collected seeds were directly broadcast in the experimental site in all treatments.
2. Transplanting, in which seeds were first germinated in a greenhouse, and seedlings transplanted to the experimental site and planted in all treatments.

5.5.2 Materials and methods

The two regeneration methods were tested in Mharib location . The experiment was analyzed using a split-plot arrangement, with land slope (S1: < 5% and S2: 8–12%) as the main effect, the sub-treatment [T_1: WH with CRVI, within catchment area (CRVIC); T_2: WH with CRVI, within the ridges (CRVIW); T_3: WH with CRVC, within catchment area (CRVCC); T_4: WH with CRVC, within the ridges (CRVCW); T_5: WH with traditional contour ridges (CRTP), within catchment area (CRTPC); T_6: WH with CRTP, within ridges (CRTPW); T_7: barley plantation (BP); and T_8: control, with no intervention and no grazing (CIG)] as the sub-main treatments and the two regeneration methods (direct seeding and transplanting) as the sub-sub-main treatments.

Direct seeding method

Two experiments were implemented to test the regeneration ability of the collected plant species by direct seeding.

The first experiment was begun on 26 December 2006 with 53 native plant species collected and obtained from Al Muwaqar station and from private collections in Mharib location during 2006.

Experiment layout Small rectangular plots (area 600 cm^2) with 10 cm between plots from all sides were marked on the ground in each sub-treatment. Each plot was marked by labeling a piece of wood, 50-cm long and 5-cm wide and stacked beside the field where the seeds were planted for each plant species. Of each plant species, 20 seeds were planted randomly in the plots. In each plot, one species' seeds were sown, and the soil surface was scratched to form a thin soil layer to cover the planted seeds. A total of 53 small plots were prepared in each sub-treatment per slope for the 53 native plant species and replicated three times.

Data was collected every two weeks on germination date, germination percentage, and seedling height.

The second experiment was carried out for seeds of native plant species collected during June 2006 to July 2007 from the Mharib area. Seeds were cleaned and stored at 4°C, later to be directly seeded in the area. In this experiment only 10 plant species were used according to different characteristics of these species:

- *Koelpinia linearis* Pall. – a medicinal plant (Medicinal and Herbal Project 2008) that has good growth and seed production in the Mharib region.
- *Poa bulbosa* – a perennial grass adapted to the area, and has been recorded at high percentages in the survey.
- *Schismus barbatus* (L.) Thell. – a grass species highly adapted to the area and recorded in high percentages in the survey. Despite being an invasive species, it is good forage.
- *Hordeum glaucum* Steud. – another adapted grass species with high feed value.
- *Bromus lanceolatus* Roth. – a grass species showing good growth in the first experiment.
- *Astragalus cruciatus* Link. – a medicinal plant (Medicinal and Herbal Project 2008), and adapted weed species to the area, which produces a large number of seeds.
- *Hirschfeldia incana* (L.) Lagr.-Foss. – a weed species adapted to the area, which produces good vegetation cover.
- *Androsace maxima* L. – a large number of seeds is produced by this species.
- *Roemeria hybrida* (L.) DC. – a medicinal plant (Medicinal and Herbal Project 2008) and annual herb, with good veg-

etative growth and attractive flowers. *Gagea reticulata* (Pall.) Schult. & Schult.f. – a bulbous plant; however, we tried to grow its seeds. It has unique flower colors.

Experiment layout Ten shallow furrows (1.5 m long and 0.25 m wide) were made across the land slope in each sub-treatment, instead of the rectangular plots used in the first experiment, as they conserve more water. On 28 January 2008, due to delays in rain, seeds of the 10 plant species were directly sown into the sub-treatments. A total of 50 seeds of each plant species were sown per furrow. Seeds were covered with a fine soil layer to protect them from wind or ant damage. Fortunately, a snowfall occurred 2 d after planting.

Data were collected on emergence rate and seedling growth, number of emerged seeds, emergence percentage, seedling length, and number of harvested seeds.

Transplanting

Two experiments were carried out to study the possibility of seeds collected from plants from the Mharib area grown by the transplanting method and using different WH techniques.

The first experiment commenced on 16 January 2007. Seeds of 48 native plant species from Al Muwaqar Station and private collections were germinated in a greenhouse at NCARE. Seeds were monitored for emergence date and percentages, and seedling length during their life-cycle in the greenhouse. Only 21 species of 48 germinated in the greenhouse, and only 10 native species were successfully transferred to the experimental site on 18 February 2007.

Experiment layout Transferred plants were planted near the direct-seeded plants in the sub-treatments, following the same plant species code as for the direct seeding. The plants were monitored for growth, seedling height, and the final growth stage reached.

The second experiment commenced on 12 November 2007 for some native species collected from the Mharib site on June and October 2007 in the lath house (house made of lath) in Al Majidiyya village. Seeds of 17 native plant species were planted in plastic bags that contained soil from the site mixed with clay soils to increase water holding capacity.

Three seeds were planted per bag, with 48 bags per species, giving 144 seeds per species and 816 plastic bags for the whole experiment. The bags were watered and kept in the lath house at Al Majidiyya for germination. Emergence dates, number of emerged seeds, and seedling height when transferred to the field were recorded. Only four species produced sufficient numbers of seedlings, and these were transplanted into the experiment site: *Hordeum glaucum* Steud., *Bromus lanceolatus* Roth, *Astragalus corragatus* Bertol., and *Schismus barbatus* (L.) Thell. Plants were transferred on 13 March 2008 by planting one plant from each of the four species in each sub-treatment. Transplanted seedlings were irrigated at transplanting time. The plants were monitored during their life-cycle: flowering and fruiting dates, and seedling height were recorded. Seeds produced by each species were harvested and counted.

Data analysis Data was analyzed using the SAS version 9 applying a split-plot arrangement (SAS, 2002). The effect of slope, WH intervention, and rehabilitation method on seedling height, emergence percentage, survival rate, and seed production were measured.

5.5.3 Results and discussion

Response of plant species to direct seeding method

Seeds of 53 plant species were directly sown in the study area on 26 December 2006. The first emergences were recorded on 3 April 2007 for 17 species. This delay in emergence can be related to low rainfall during December–April, as reported by (Bowers 1987) and (Bainbridge 2003). The delay in emergence can also be related to some soil characteristics, such as formation of surface crust that can prevent seedling emergence, particularly those with small seeds.

Some species such as Melilotus indicus (L.) All., Hordeum glaucum Steud., Malva praviflora L., Vicia peregrina L., Androsace maxima L., Alyssum damascenum Boiss. & Gaill, Astragalus corragatus Bertol, and Medicago turbinate (L.) survived until the end of May (25 May 2007 – the final survival record). However, A. damascenum formed immature seeds (very small in size and very thin) and the other species produced no seed. This could be explained by high temperature observed late in spring. In fact, Bainbridge (2003)found that high surface temperature results in the death of plants and hence declining of the vegetation cover. Seed viability could also affect the results. The seeds for the first experiment were collected from Al Muwaqar station and private collections where storage condition may vary and so result in decreased seed viability and vigor. This in turn could affect seed germination and survival rate and eventually lead to seed death.

Maximum emergence recorded on 3 April 2007 was ≤ 75% (*Avena sterilis* L.) with the lowest for *Anthemis* sp. (15%). Seedling lengths increased very slowly until plants died at the end of May 2007. The maximum seedling length (8.6 cm) was for *Ho. glaucum* on 29 April 2007.

For the experiment conducted during the 2007/08 season, the maximum emergence on 28 January 2008 was 14% for *Koelpinia linearis Pall., P. bulbosa,* and A*stragalus cruciatus* Link. The minimum emergence percentage was 6% for *Gagea chlorantha* (Bieb) Schult. Fil. All sown species showed good survival percentages, except *G. chlorantha,* in which growth terminated after 16 March 2008, and may be due to the fact that *G. chlorantha* is a perennial bulb and it is difficult to grow healthy bulbous plants from seeds. The *G. chlorantha* seeds germinated (although a very low proportion), but did not continue growing. This agrees with (Bowers 1987) in that each species responded individually to the transplanting process. It is important to note that the greatest seedling length was 18 cm for *P. sinaica,* a grass species, while the lowest was 3 cm for *Astragalus cruciatus* Link. The better results obtained durin this season, as compared to the ones of 2006/07, may be due to the planting being in January 2008, after 48.8 mm of opening rain in early January 2008. This provided sufficient moisture for seeds to germinate and grow early as explained by (Cox et al. 1982), who stated that direct seeding would succeed if there were sufficient rainfall. Most of the emerged seedlings survived and reached maturity (i.e. seed production). The growth period from January until the end of April was characterized by low–medium temperatures during March and April (14.3 and 17.8°C, respectively) and insufficient rain to support plant growth (0.4 and 0.0 mm, respectively).

The maximum survival percentage on 8 April 2007 was for K. *linearis* (44%), even though it had short stems which did not exceed 6 cm and this affected certainly the total production including grains. However, it was able to produce 43 seeds/m^2. The highest seed production was for *P. sinaica* (137 seeds/m^2), possibly due to the high adaptation of this species to the area. The lowest seed production was for the *Androsace maxima* L. (1 seed/m^2), possibly since this species did not grow > 5 cm in length, and the seeds were formed inside a capsule at the top of the plant. When the plant matured, the capsule opened and the seeds were shed due to any slight motion, by animal, wind, or even when harvested. The seeds were very small in size and difficult to collect from the ground after they had been shed.

Effect of WH intervention on seedling emergence and survival rate for the planted species using direct seeding

The ANOVA (Annex 1.15) showed a significant effect of the three studied factors on seed emergence, seedling length, and survival rate of planted species. The interaction between these factors was only significant (*P* < *0.05*) for the first survival rate, third seedling length, and fourth survival rate.

The effects of the two slopes, WH interventions, and two experiment dates on emergence percentages and survival rates are shown in (Table 5.13). There were significant differences among the different interventions. There was a highly significant (*P*< *0.01*) effect of the within contour ridges over the other interventions on the different parameters recorded in the two slopes and the two experiment years.

For example, for within contour ridges intervention there were higher emergence percentages (65–71%) compared with the contour ridges catchment area. The Vallerani contour ridges intervention recorded higher emergence percentages (41 and 23%) in gentle and moderate slopes, respectively, compared to traditional plowing in 2006/07; while the corresponding increments were 17 and 1% in in 2007/08.

The intervention contours (either Vallerani or traditional plowing) had emergence percentages of 4–8-fold that of barley plantations or control (no intervention, no grazing).

The average survival rate was 30% higher in the moderate compared to the gentle slope. The within contour ridges intervention had higher (82%) or equal (78%) survival rates in the gentle and moderate slopes, respectively, compared to the catchment area in the gentle slope (78%). The Vallerani intervention survival rate was higher (74 and 43%) in the gentle and moderate slopes, respectively, compared with traditional plowing.

The effect of the two slopes, different interventions, and the two experiment dates on mean number of harvested seed is shown in (Table 5.14). Harvested seed was significantly higher (*P* < *0.05*) for plants in Vallerani continuous contour ridges in the gentle slope than in the moderate slope with Vallerani intermittent contour ridges. Plants within contour ridges produced 8% higher seed weight than those in the catchment area in gentle slope while within contour ridges and moderate slope they produced 79% higher seed weight than those in the catchment area. Plants in the Vallerani contour ridges produced higher weights of seeds (g/m^2) by 53% and 18% in the gentle and moderate slopes, respectively, compared with plants in traditionally plowed contours.

There were no significant differences in weight of seeds produced by plants in the Vallerani intermittent contour ridges and those in Vallerani continuous contour ridges (11% in gentle slope and 27% in moderate slope). The barley plantation treatment had no significant effect on the seed weight produced by plants compared with plants in the control (no intervention, no grazing.

Behavior of the plant species in response to transplanting method

Ten native plant species were transplanted into the site on 18 February 2007. The plants were well established in the greenhouse and were transferred to the field after 3.6 mm of rain. The temperature at the time of transplanting was moderate (9°C). The highest seedling length at the time of planting was 14.5 cm for *B. lanceolatus* and *Ho. glaucum,* while the shortest was 3.5 cm for Phalaris minor Retz. The first parameter (survival rate) was measured on 4 March 2007 and at this time the maximum survival percentage was 100% for all species, except for Ho. glaucum (82%), *Medicago turbinate* (L.) All. (86%), *Onobrychis crista-galli* (L.) Lam (91%), and *Vicia peregrina* L. (86%). The average survival

Table 5.13. Effect of slopes, WH interventions, and planting date on emergence percentages and survival rate using direct seeding.

Slope	Date	WH intervention	Emergence (%)	Survival rate 1st	Survival rate 2nd	Survival rate 3rd
< 5%	2006/07	T1: CRVIC	5.97 ef	0.78 ghi	0.0014 f	0.0003 f
		T2: CRVIW	21.27 a	9.61 a	1.86 cd	0.69 def
		T3: CRVCC	7.15 e	1.29 ghi	0.0003 f	0.0001 f
		T4: CRVCW	21.27 a	6.67 cd	0.69 ef	0.10 f
		T5: CRTPC	5.29 fgi	1.37 fghi	0.10 f	0 f
		T6: CRTPW	11.18 d	2.84 ef	0.10 f	0 f
		T7: Bp	3.53 hk	0.78 ghi	0 f	0 f
		T8: CIG	1.96 jlm	0.49 hi	0 f	0 f
	2007/08	T1: CRVIC	1.63 jklm	2.27 efgh	3.07c	3.07 c
		T2: CRVIW	5.3 efgh	10.2 a	12.8a	12.93 a
		T3: CRVCC	1.67 jklm	2.13 efgh	2.13cd	2.13 c
		T4: CRVCW	3.13 hijlm	9.4 ab	11.33ab	11.33 ab
		T5: CRTPC	0.77 m	1.93 efghi	2.27cd	2.27 c
		T6: CRTPW	4.10 fghj	9.27 ab	9.87b	9.87 b
		T7: Bp	1.13 lm	1.67 efghi	1.93cde	1.93 cd
		T8: CIG	0.9 lm	1.3 fghi	1.73cde	1.73 cde
8–12%	2006/07	T1: CRVIC	5.65 fg	2.27 efgh	0.0003 f	0.0001 f
		T2: CRVIW	18.33 b	10.2 a	1.28 de	0.59 ef
		T3: CRVCC	6.08 ef	2.13 efgh	0.10 f	0.001 f
		T4: CRVCW	18.24 b	9.4 ab	0.69 ef	0.10 f
		T5: CRTPC	5.78 efg	1.93 efghi	f	0 f
		T6: CRTPW	12.75 c	9.27 ab	0.10 f	0.10 f
		T7: Bp	3.73 hk	1.67 efghi	0f	0 f
		T8: CIG	0.98 m	1.3 fghi	0f	0f
	2007/08	T1: CRVIC	1.23 lm	2.17 efgh	2.13 cd	2.13 c
		T2: CRVIW	4.50 fgh	9.23 ab	10.33 b	10.33 b
		T3: CRVCC	1.23 lm	2.47 efg	2.33 cd	2.33 c
		T4: CRVCW	3.6 ghjl	8.2 abc	9.93 b	9.87 b
		T5: CRTPC	1.1 lm	2.17 efgh	2.07 cde	2.07 c
		T6: CRTPW	4.13 fghj	8.87 ab	10.0 b	10.0 b
		T7: Bp	1.03 lm	1.4 fghi	1.87 cde	1.93 cd
		T8: CIG	1.07 lm	1.33 fghi	1.83 cde	1.80 cde

Note: *Values followed by the same letter are not significantly different at $P < 0.05$.

Table 5.14. Effect of slopes and WH interventions on harvested seed (g/m²) using direct seeding in 2007/08.

Slope	WH intervention	Harvested seed (g/m²)
< 5%	T^1: CRVIC	5 d
	T^2: CRVIW	27 a
	T^3: CRVCC	55 d
	T^4: CRVCW	24 ab
	T^5: CRTPC	5 d
	T^6: CRTPW	21 bc
	T^7: Bp	3 d
	T^8: CIG	2 d
8–12%	T^1: CRVIC	4 d
	T^2: CRVIW	22 abc
	T^3: CRVCC	5 d
	T^4: CRVCW	18 bc
	T^5: CRTPC	4 d
	T^6: CRTPW	16 c
	T^7: Bp	4 d
	T^8: CIG	3 d

Note: *Values followed by the same letter are not significantly different at $P < 0.05$.

percentage for *Melilotus indicus* (L.) All. was (94%), and the average mean percentage for *Silene coniflora* L was ≤ 53%. The maximum initial seedling length (13.4 cm) was for *Ho. glaucum.*

Transplanting of native species, produced from seeds collected from the same area to be restored, produced satisfactory results. Such good results agree with those of Bainbridge (2003), who found that the vegetation rehabilitation in arid lands usually required transplanting to re-establish plants; and that it should be done with seed collected from the site to be rehabilitated. The growth of *Peganum harmala* L., *Ph. minor,* and *Polygonum equisetiforme* Sm. ceased before 29 March 2007 (the final record for these species was on 17 March 2007), when their average survival rates were 13, 2, and 14%, respectively. After two weeks, B. *lanceolatus, Ho. glaucum, Medicago turbinate,* and *V. peregrina* failed to survive. The other plant species were dead when monitored on 13 April 2007. This is likely due to the high temperatures experienced after transplanting (Bowers 1987; Bainbridge 2003).

For the second experiment (2007/08), the growing seedlings were transferred to the experiment site on 13 March 2008 due to delays in rain. Four of the 17 native species were planted in the experiment site. Seedling length and survival rates were recorded at two-week intervals, until harvesting of seeds on 20 April 2008. All four species had 100% survival on 13 March 2008. However, by the end of the season (10 April 2008), the survival rate had declined to 28, 22, 16, and 8% for *B. lanceolatus, Ho. glaucum, Schismus barbatus* (*Loefl. ex L.*) Thell. and *Astragalus cruciatus* Link., respectively.

The highest seed number produced (26 seeds/m²) was for *Schismus barbatus,* and the lowest (8 seeds/m²) for *A. cruciatus.*

Table 5.15. Effect of slopes, WH interventions, and planting dates on the survival rate using transplanting.

Slope	Date (growing season)	WH intervention	Survival rate		
			1st	2nd	3rd
<5%	2006/07	T1: CRVIC	52.23 cde	19.63 c	5.13 c
		T2: CRVIW	41.70 def	14.90 c	4.47 c
		T3: CRVCC	50.80 cdef	17.83 c	3.00 c
		T4: CRVCW	32.53 f	10.50 c	1.43 c
		T5: CRTPC	45.70 cdef	16.57 c	6.27 c
		T6: CRTPW	46.73 cdef	16.47 c	6.07 c
		T7: Bp	56.13 bcde	23.77 c	5.47 c
		T8: CIG	48.20 cdef	11.07 c	1.03 c
	2007/08	T1: CRVIC	75.00 ab	75.00 b	75.00 b
		T2: CRVIW	100.00 a	100.00 a	100.00 a
		T3: CRVCC	100.00 a	100.00 a	100.00 a
		T4: CRVCW	100.00 a	100.00 a	100.00 a
		T5: CRTPC	91. 67 a	91.67 ab	91.67 a
		T6: CRTPW	100.00 a	100.00 a	100.00 a
		T7: Bp	100.00 a	100.00 a	100.00
		T8: CIG	100.00 a	100.00 a	100.00 a
8–12%	2006/07	T1: CRVIC	44.50 cdef	14.27 c	2.33 c
		T2: CRVIW	62.97 bc	24.33 c	5.50 c
		T3: CRVCC	40.73 def	13.10 c	2.73 c
		T4: CRVCW	39.267 ef	15.67 c	5.00 c
		T5: CRTPC	46.03 cdef	19.30 c	4.50 c
		T6: CRTPW	59.00 bcd	19.73 c	5.10 c
		T7: Bp	47.20 cdef	14.27 c	2.93 c
		T8: CIG	40.70 def	12.23 c	1.33 c
	2007/08	T1: CRVIC	100.00 a	100.00 a	100.00 a
		T2: CRVIW	100.00 a	100.00 a	100.00 a
		T3: CRVCC	100.00 a	100.00 a	100.00 a
		T4: CRVCW	100.00 a	100.00 a	100.00 a
		T5: CRTPC	100.00 a	100.00 a	100.00 a
		T6: CRTPW	100.00 a	100.00 a	100.00 a
		T7: Bp	100.00 a	100.00 a	100.00 a
		T8: CIG	100.00 a	100.00 a	100.00 a

Note: *Values followed by the same letter are not significantly different at $P < 0.05$.

Effect of WH intervention on seedling emergence and survival rate for transplanted species

ANOVA of the effect of slopes, transplanting dates, and the different interventions on rehabilitation using transplanting is illustrated in Annex 1.16.

There was a highly significant effect *($P < 0.001$)* of the two dates at all growth stages, except for initial seedling length (Annex 1.18).

The effect of slope was significant *($P < 0.05$)* at all growth stages, except for the initial stage and the first seedling length. The interventions had no significant effect on the transplanting method, except for the second seedling length (Annex 1.17).

The effect of the three-way interaction of slopes, interventions, and experiment dates on survival rate is shown in (Table 5.15). Plants in the 2007/08 season had taller seedlings and higher survival rates than those planted in 2006/07 at all growth stages in the two slopes. There were no significant differences between the different interventions, even though, the within contour ridges showed higher survival rate (18% in the first growing season and 12% in the second growing season) compared with the catchment area in the gentle slope. For the moderate slope, the within contour ridges recorded a higher (although non-significant) survival rate (18.9% in the first season only) compared with the catchment area. Planting the contours with shrubs improved the microhabitats and enabled native plants to re-grow on the site, similar to previous findings (Hassan and West, 1986; Tilbörger and Kadmon, 1986; Aguiar and Sala, 1994). There was no significant difference between the survival rate of plants in Vallerani interventions at $P < 0.05$ compared with traditional plowing for the gentle slope (the real difference was small and not significant but higher for traditional plowing than the Vallerani intervention by 4 and 2% in the first and second growing seasons, respectively). This difference was also small in the second growing season (for the first growing season only, the survival rate was higher by 11% for plant species planted in traditional plow compared with that planted in the Vallerani interventions).

The survival of plants in the barley plantation treatment was 14% higher (non-significant), only in the gentle slope in the first growing season, compared with the control (no intervention, no grazing).
The effect of slopes, interventions, and experiment dates on the seed harvested is shown in (Table 5.16). Plants within contour ridges produced a significantly greater ($P < 0.05$) weight of seed than those in the catchment area (by 45 and 46% in the gentle and moderate slopes, respectively).

The weight of seeds produced from plants in the catchment area was higher than those within Vallerani interventions (by 27 and 32% in gentle and moderate slopes, respectively). Plants in the Vallerani intermittent contour ridges produced a greater weight of seeds (by 24%) than those in Vallerani continuous contour ridges in the gentle slope only (although non-significant); and there were no differences for the moderate slope.

5.6 Seed propagation/multiplication of potential native plant species

5.6.1 Materials and methods

Native plant species were tested for their seed multiplication. The seeds used were from those collected during the study period from Mharib and Al Majidiyya areas, NCARE soil seed bank, and Al Muwaqar Station (University of Jordan). On March 2007, seeds of 26 native plant species (Table 5.17) were sown into a greenhouse. Only eight species (Table 5.17) survived,

Table 5.16. Effect of slopes, WH interventions, and planting date on harvested seed (g/m²) for the transplanting method.

Slope	WH intervention	Harvested seed (g/m²)
< 5%	T1: CRVIC	6 bcde
	T2: CRVIW	15 a
	T3: CRVCC	5 bcde
	T4: CRVCW	7 bcd
	T5: CRTPC	5 cdef
	T6: CRTPW	7 bc
	T7: Bp	4 defg
	T8: CIG	2 fg
8–12%	T1: CRVIC	3 efg
	T2: CRVIW	8 b
	T3: CRVCC	5 bcdef
	T4: CRVCW	5 bcde
	T5: CRTPC	2 fg
	T6: CRTPW	5 cdef
	T7: Bp	3 efg
	T8: CIG	1 g

Note: *Values followed by the same letter are not significantly different at $P < 0.05$.

and they were transplanted under drip irrigation to the field at Mobis Station (NCARE) on September 2007.

Plants were monitored for growth. Seeds were harvested on December 2007 (unusually high temperatures enabled the plants to produce seeds) and again on April 2008. Seeds were counted and 100-seed weights recorded.

5.6.2 Results and discussion

The highest harvested seed weight (38.4 g/m²) was for *Sinapis alba* L. (Table 5.18). The highest number of seeds harvested (41 064 seeds/m²) was for *Schismus barbatus* (Loefl. ex L.) Thell., followed by *Eremopyrum bonaepartis* (Sprengel) Nevski (13 783 seeds/m²).

5.6.3 Conclusions

Natural vegetation is diverse and variably distributed according to site differences. Annual plant species dominated the study area, and can be used as indicators of degradation in the Mharib region.
A combination of WH intervention and protection from grazing is essential to improve the natural vegetation cover.
Microcatchment WH had a significant effect on increasing the native vegetation of the study area by improving biodiversity as well as the size of the soil seed bank.
Plots with the intervention of Vallerani intermittent contour ridges were best at improving and preserving the native vegetation in terms of high SR, high total number of plants, and the size of the soil seed bank.

Table 5.17. Plant species used their seeds for multiplication.

Number	Species	Number	Species
1	Adonis dentata Del.	14	Hypecoum procumbens L.
2	Adonis palaestina Boiss.	15	Hirschfeldia incana (L.) Lagr.-Foss.
3	Allium erdelii Zucc.	16	Hordeum glaucum Steud.
4	Alyssum damascenum Boiss. & Gaill.	17	Leopoldia longipes (Boiss.) Losnik.
5	Androsace maxima L.	18	Catapodium rigidum (L.) C.E.Hubb.
6	Anthemis palestina Boiss.	19	Malva sylvestris L.
7	Astragalus annularis Forssk.	20	Phalaris minor Retz.
8	Astragalus asterias Hohen	21	Poa sinaica Steud.
9	Eremopyrum bonaepartis (Sprengel) Nevski	22	Roemeria hybrida (L.) DC.
10	Erodium hirtum Willd	23	Schismus barbatus (L.) Thell.
11	Eruca sativa Mill.	24	Silene coniflora Otth.
12	Gagea reticulata (Pall.) Schult. & Schult.f.	25	Sinapis alba L.
13	Helianthemum ledifolium (L.) Mill.	26	Sisymbrium irio L.

Note: Plant species in bold are those species that manage to survive and were transferred to Mobis Station (NCARE).

Table 5.18. Total seed weight, 100-seed weight, and total number of seeds of eight native plant species at Mobis Station (NCARE) in 2006/07.

Plant Species	Total seed weight (g)	100-seed weight (g)	Total number of seeds
Androsace maxima L	0.9653	0.0400	2413
Sinapis alba L.	38.38	0.4474	8578
Eremopyrum bonaepartis (Sprengel) Nevski	21.7490	0.1578	13 783
Hordeum glaucum Steud.	14.8271	0.6101	2430
Catapodium rigidum (L.) C.E. Hubb.	3.1800	0.1075	2958
Alyssum damascenum Boiss. & Gaill	4.4731	0.3334	1342
Poa sinaica Steud.	3.9491	0.050	7898
Schismus barbatus (Loefl. ex L.) Thell.	16.7953	0.0409	41 064

Direct seeding was a good practice for native vegetation rehabilitation, due to low cost and effort required, but cannot guarantee germination due to rainfall variability and soil surface crust formation. However, transplanting was more promising, even with higher costs and greater effort required.

Native plants can be multiplied under controlled conditions, and the seeds produced form a valuable source for rangeland rehabilitation

.
There are some difficulties concerning the regeneration of native plant species, concerning timing and follow up.
The soil seed bank survey indicated potential for the study area if other conditions can be improved, mainly conservation of soil moisture. In addition to this, management (protection from grazing) is essential.

5.6.4 Recommendations

Areas where the interventions have been implemented should be protected, to enable collection of native seeds for regeneration.
More detailed studies are required to improve the regeneration methodology for herbaceous plant species in order to rehabilitate degraded rangelands.

Emphasis should be on perennial plant species for rangeland sustainability.
Seeds from this study were deposited in the seed bank at NCARE, adding to the collection of seeds from natural plants.

Conservation of this material will form a good resource for future work on multiplication and regeneration of native rangeland plant species.

The mechanized Vallerani intermittent microcatchment WH technique should be applied on a large scale (of technology transfer) in rangelands that receive 100–200 mm rainfall.

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Chapter 6

Mechanization of transplanting shrubs seedlings and contours laser guiding for Vallerani system

Chapter 6: Mechanization of transplanting shrubs seedlings and contours laser guiding for Vallerani system

I. Gammo and T. Oweis

6.1 Introducing a mechanized transplanting option to the WH system

6.1.1 Introduction

Many water harvesting (WH) technologies have been successfully tested over many years, including such techniques as small-scale WH with contour furrows and microcatchments of different shapes and sizes (Hatten and Taimeh 2001). The mechanization of WH using the Vallerani implement has been evaluated in the Badia ecosystem. Drought-tolerant forage shrubs (Gammoh and Oweis, 2011)(most commonly *Atriplex spp*) have been successfully established under these WH systems. Nevertheless, the establishment of forage shrubs has encountered problems associated with the following:

Shrub establishment techniques use transplants > 6 months old. This increases the cost of their nursery, transport, field preparation, and planting, as augering 40 cm × 40 cm × 40 cm holes is required. A lot of manual work and time is required, and if rainfall is delayed, then plants need supplemental irrigation to survive until the first effective rain. The survival rate of such transplants in dry seasons might drop to 60–70% (Abu Zanat 1995).

Direct seeding has problems related either to soil crusting/silt sedimentation resulting in high emergence resistance or to reducing the ability of young emerged seedlings to survive through dry periods to the next rain.

The large-scale implementation of WH systems is slow and costly, as the system is not fully mechanized. Some establishment operations still depend on manual work due to the absence of specialized machinery for WH techniques.

6.1.2 Objectives and expected outputs

In relevance to the project objectives and expected outputs, the reported research aimed at introducing a mechanized transplanting technique to the WH system to reduce costs and time of establishment of fodder shrubs, thus improving overall system capacity and making large-scale implementation more feasible. Therefore, the expected output is to improve WH and re-vegetation techniques with less cost and time of establishment for fodder shrubs.

The specific objectives of the research work presented here are:
To study the feasibility of establishment of *Atriplex* plants of young (1–2–month-old) seedlings instead of > 6-month-old plants.
To determine the best conditions under which the transplanting technique will be most successful. This includes: (a) time of transplanting, (b) placement of the seedling inside the WH catchment, and (c) the water regime to support the plants expressed in the volume of harvested water (i.e. length of the runoff area).

To modify the traditional transplanter unit to cope with the specific structure of the WH furrow (planting the inclined shape of the furrow ridge), and attach this unit to a plow so that the opening of the furrow and transplanting of the seedlings are performed in one pass of the tractor.

6.1.3 Methodologies and approaches

The work was divided into two stages: the first involved the first two objectives mentioned above, while the second concerned the modification of the transplanter.

In the first stage a field experiment was designed and implemented in the 2006/07 rainy season.

Site conditions and plant material

The chosen site for this experiment was inside the University of Jordan (UOJ) Research Station in Muwaqqar; 400 m above sea level, and located 30 km south east of Amman. The coordinates are 266o-270 o East, 130 o -135 o North (Royal Geographic Center plate No NH37-A-1). Good facilities and more protection of the sites are provided there for monitoring and control. The site is representative of the arid region of Jordan (the Badia), where annual rainfall average is 100–150 mm.

The WH structure was prepared in the first week of December 2006. The area of the experiment was around 0.8 ha with a uniform slope of 3–4%.

The catchments are continuous tied furrows worked by Vallerani plow that made a wide (> 50 cm) and deep (> 30 cm) cut with a ridge of ~ 50 cm height from the bottom of the furrow.

In specially fabricated trays, 1000 *Atriplex* seedlings were grown from seeds at three different dates (one month before transplanting date). Each tray consisted of 100 pots, and each pot was cubic with dimensions of 4 cm × 4 cm × 4 cm.

Exactly 864 seedlings were chosen to be planted 1 m apart inside the catchments. Each plot catchment had a length of 24 m; 12 seedlings were planted in the bottom of the catchment and 12 on the bottom 1/3 of the ridge. Transplanting was done manually.

Treatments and experimental design

a) Main treatments (reflect time ofplanting)

T1: Transplanting before first rainfall. This is the common practice followed, aimed at getting the benefit from every rainfall event in the season. However, as the time of the first rain is not known, there is a risk of young seedlings wilting unless watered regularly. This treatment was performed on 24 December 2006 and, fortunately, the first rainfall was 3.4 mm on 26 December 2006, followed by 27 mm on 27 December 2006.

T2: Transplanting few days after a good runoff event, and when soil is workable. This ensures sufficient moisture in the soil from previous rain events for use by plants. There is no need to support young seedlings with water to the next rain. This treatment was performed on 28 January 2007 after a rainy week of 19 mm of rainfall and a good runoff event (11 mm) on 21 January 2007.

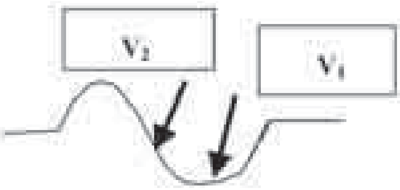
T3: Transplanting in spring at the beginning of the warm season. The speed of growth in warm conditions should enable young plants to develop their roots quickly to the safe wet soil layer before the top soil dries out. Any rain that occurs later will give even more benefit. This treatment was performed on 11 March 2007. The total rain that fell after this date until the end of March 2007 was 26 mm, of this 13 mm on 15 March 2007 initiated one effective runoff event.

b) Sub-treatments (reflect harvested water regime)

t1: 4 m – length of harvesting area
t2: 8 m – length of runoff area
t3: 12 m – length of runoff area

c) Split variables (reflect placement of plant inside the furrow)
V1: Transplanting in the bottom of the furrow close to the ridge (wetter).
V2: Transplanting above the bottom 1/3 of the ridge (less sediment).

Experimental design was chosen to be split RCBD in 4 replicates.



Parameters assessed

Survival percentage through survival count, was assessed monthly until the end of dry season.

Estimated volume of the plant, by measuring the height and width of each plant at the end of the growing season, then calculating the volume using the mathematical equations of the volume of either a cylinder or a cone, depending on the shape the plant developed during growth. A cylindrical shape was usually developed by plants of one or two longitudinal shoots, and of less than 10 cm width. Volume given by V_{cyl}:

$$V_{cyl} = \pi r^2 l$$

where r is cylinder base radius and l is cylinder height Inverted cone shape for plants of ≥ 3 shoots and of > 10 cm upper part width. Volume given by V_{cone}:

$$V_{cyl} = \pi r^{-} l$$

where b is cone base diameter and a is cone height.
The plant volume was calculated for each surviving plant and then average plant volume of each plot was calculated for surviving plants only, where the average plant volume in a plot was equal to the sum of plant volumes over the number of survived plants in that plot.

Although it is more common to use biomass as a parameter of plant productivity under different treatments and variables, it was thought that assessing plant volume would be adequate for this purpose for the following reasons:

By the end of the growing season, the plants will be still young and not mature enough to be grazable
The plants will be monitored and evaluated for > 1 year;, therefore non-destructive methods of assessing biomass should be followed

Transplanter modification

Instead of building a special transplanter, it was decided to modify a traditional one as used to plant other seedlings (e.g. tomato, sweet pepper, and lettuce) to perform the transplanting under the WH structure conditions and requirements. The modifications included:

- Changing the slot-opening device with the local fabricated one that can work deeper than the depth-wheel adjustment permits, as the slot should be opened in the inclined ridge of the catchment at below natural ground level.
- Adding protecting boards to the slot opener to prevent soil from falling down from the ridge over the seedling before it rests inside the slot.
- Reducing the distance between the slot opener and the covering wheels to a minimum.
- Changing the adjustment range of the depth-wheel design so it can be raised higher. This allowed the unit to go deeper.
- Adding a covering disc to improve the seedling soil pot covering.
- Changing the pressing device design and location on the transplanter and

lowering the left pressing wheel to contact the lower side of the ridge.

- Changing the hitching system of the transplanter so it can be hitched to a regular square-section tool bar. This included the fabrication of new brackets and clamps.

The modified transplanting unit was attached to a WH furrow-opening plow (designed previously at UOJ). The new integrated furrow opener and transplanting unit were able to open a continuous deep furrow and transplant *Atriplex* seedlings inside the furrow in one pass of the tractor. This dramatically reduced the amount of work usually needed to open WH furrows and plant *Atriplex* in them.

6.1.4 Results and discussion

Survival percentage

The survival percentage was monitored nearly every month, through the growing and dry seasons, to detect changes under different treatments and sub-treatments. The targeted readings are considered those obtained after that period, which were taken on 9 September 2007, therefore the statistical analysis was performed only for those readings.

Establishment of *Atriplex* by transplanting young seedlings could be successful. The percentage of surviving plants through the growing and following dry seasons (calculated on 9 September 2007; Table 6.1) had range 37–80% (for T_1 and T_2, respectively). This clearly justifies the adoption of such a technique, instead of the costly (labor and time consuming) use of six-month-old *Atriplex* plants. Moreover, such a result indicates the success of mechanizing the transplanting technique.

Although the planting before the rainy season (T1) was expected to give best results, it showed the least survival percentage. This could be attributed to freezing weather that struck in January 2007, when the minimum temperature ranged from –2 to –4°C for 3 d during 1–3 January 2007, and from –1 to –3°C for 8 d during 13–20 January 2007.

Table 6.1. Survival percentages under different treatments, sub-treatments, and split variables by the end of the dry season.

Survival Percentage on 9 Sept 2007									
Date of planting	**T_1 = 24 Dec 2006**			**T_2 = 28 Jan 2007**			**T_3 = 11 Mar 2007**		
Spacing	t_1=4 m	t_2= 8 m	t_3=12 m	t_1=4 m	t_2=8 m	t_3=12 m	t_1=4 m	t_2=8 m	t_3=12 m
Placement V_1	35.4 fg	33.3 fg	37.5 e–g	79.2 ab	81.3 ab	75.0 a–c	39.6 dg	79.2 ab	54.2 b–f
Placement V_2	35.4 fg	39.6 d–f	41.7 c–f	91.7 a	72.9 a–d	81.3 ab	64.6 a–cef	70.8 a–ce	58.3 a–f
Average treatment	T_1 = 37.2 B			T_2 = 80.2 A			T_3 = 61.1 AB		
Average spacing	t_1 = 57.6 A			t_2 = 62.9 A			t_3 = 58.0 A		
Average placement	V_1 = 57.2 A V_2 = 61.8 A								

Note: LSD values for treatments, sub-treatments, split variables, and their interaction were 30.4, 12.6, 7.7, and 32, respectively.

Starting from 16 March 2007 the decrease in survival percentage was the greatest (39%) under T_3 (transplanting in spring), the least (13.5%) under T_2 (transplanting few days after first good runoff event), and 24% under T_1 (transplanting before the season). The large drop in survival rate under T_3 could be attributed to the inability of some young seedlings planted in spring to develop roots deep enough to reach the wet zone before the top soil dried out. The survival percentage, in general, was clearly not affected by the spacing between furrows (length of runoff area) (Figure 6.1). The furrow spacing had a significant effect on soil water storage in relatively deep layers, which the young seedlings' roots had not reached yet at this growth stage. Furrow spacing is expected to have an effect under conditions of higher annual rainfall and higher intensities of rainfall events that initiate runoff.

The seedling placement inside the catchment had no significant effect on the survival percentage throughout the growing season and the following dry season

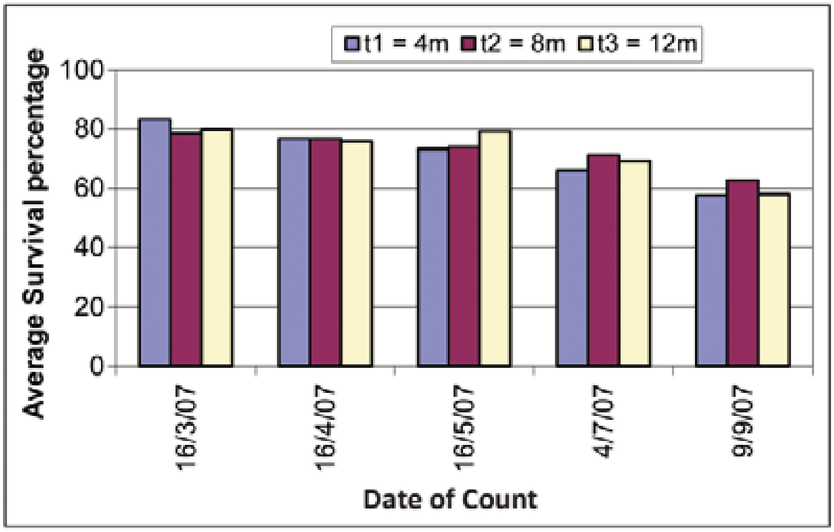


Figure 6.1. Effect of furrow spacing on survival through the dry season.

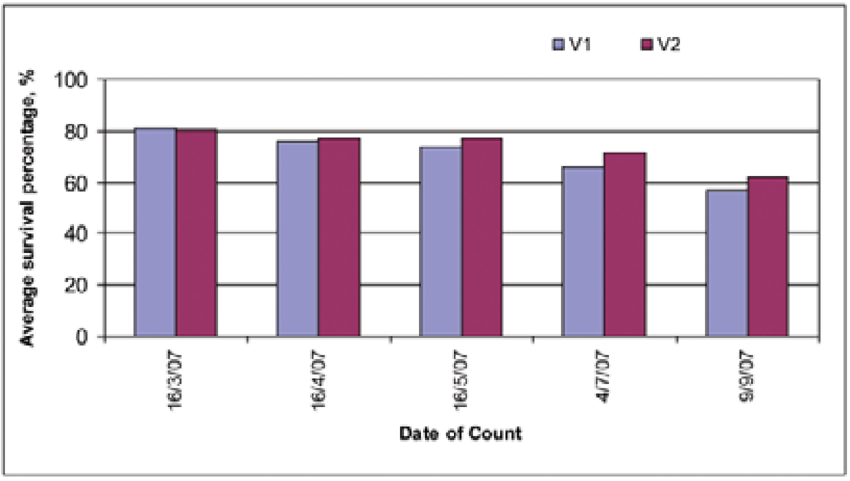


Figure 6.2. Effect of plant placement inside the catchment on survival through the dry season.

(Figure 6.2). Nevertheless, when drought stress increased from June onward, the drop in survival percentages for V_2 and V_1 were 19 and 23%, respectively, showing an advantage to V_2.

Average plant volume

- Planting before the first rainfall (T_1) proved to have the best effect on plant growth; although the survival rate for these plants was less than for plants planted after the first good rainfall with runoff (T_2). The survived plants that were planted one month before (T_1) seem to have benefited from rainfall between the two dates of planting.
- Average plant volume under T_3 (planting in spring) was the lowest, although the plants' survival percentage was better than for T_1. This can be attributed to the fact that plants could not develop their roots fast enough to reach deeper soil layers before the top soil dried out.
- There was no significant effect of the length of runoff area (t1 = 4 m, t2 = 8 m, and t3 = 12 m) on the plant volume under relatively low rainfall intensities and moderate slopes. The difference in the volume of water harvested from different runoff areas would be expected to affect the water regime in the catchment under conditions of high rainfall intensities and steeper slopes.
- The overall average plant volume when planted in the bottom 1/3 of the ridge (V2) was 537 cm^3 (Table 6.2) compared to 296 cm^3 when planted in the bottom of the furrow (V1). This can be attributed to the looser soil and deeper root development in the root zone on the ridge, which was more protected than soil in the bottom of the furrow.

6.1.5 Conclusions

Transplanting young seedlings (1–2 months old) was successful for establishment of forage shrubs in marginal rangelands or steppe regions (the Badia) under WH systems. This practice can substitute the traditional practice of using transplants aged > 6 months.
The benefits obtained from this modified technique are:

a. Ease of mechanization of planting, as the small size of young seedlings makes handling by the transplanter possible. This excludes augering and manual digging operations usually needed when planting older transplants in WH structures.
b. Faster operation, especially when large-scale implementation is needed.

Table 6.2. Average plant volumes (cm^3) under different treatments, sub-treatments, and split variables.

	Spacing / Plant placement	t_1 = 4 m		t_2 = 8 m		t_3 = 12 m		
		V_1	V_2	V_1	V_2	V_1	V_2	Av. Treatment
Date of planting	T1 = 24 Dec 2006	318.6 bc	729.2 ab	515.7 a–c	733.3 ab	350.4 bc	1087 a	622.3 A
	T2 = 28 Jan 2007	450.5 a–c	668 a-c	550.2 a-c	624 a-c	333.4 bc	699.6 a–c	554.3 A
	T3 = 11 Mar 2007	45.4 c	65.5 bc	58.9 bc	106 bc	46.2 c	126.3 bc	74.7 B
	Av. Sub-treatment	t1 = 379.5 A		t2 = 431.3 A		t3 = 486.8 A		
	Av. plant placement	V1 = 296.6 A			V2 = 537.6 B			

c. Reduction of time and cost at the nursery stage.
d. Ease of handling and transporting seedlings from the nursery to the field.

The earlier that forage shrubs are planted at the beginning of the rainy season, the more the plant can benefit from water harvested, which reflects positively on its productivity. However, there will be a higher risk of delay in rainfall and harsh weather conditions affecting the vulnerable young seedlings.

Transplanting after the first good rainfall events reduced the risk of drying out and proved to be beneficial for survival of plants.

Planting young seedlings in early spring is risky, especially if there are no good rainfall events afterwards. Nevertheless, good results are expected if good rainfall events occur in March–April, which is common in the Badia environment.

The transplanting unit can be attached to a furrow opener, making one integral machine that can perform both operations of opening the WH structure and planting the shrubs in one pass. This should dramatically reduce the time and cost of establishment.

Planting in the bottom 1/3 of the ridge showed better plant growth, thus it is recommended to change the common practice of placing the shrubs in the bottom of the catchment furrow and plant them in the lower half of the ridge.

6.2 Introducing a tractor laser-guiding system

6.2.1 Introduction

With the purpose of re-vegetating low rainfall areas in the Jordanian and Syrian Badia, numerous WH systems and techniques have been tried and investigated and positive achievements demonstrated over thousands of hectares. Such techniques have included small-scale water microcatchments opened on the contour lines of sloped areas (contour furrowing). Nevertheless, a major problem with large-scale implementation of WH structures is low capacity of machinery.

By opening continuous and intermittent furrows at a rate of 15–20 ha/d, the Vallerani mechanized system provided a solution for the machinery problem. Given the harsh topographic conditions of the Badia, such capacity is acceptable for large-scale implementation. Nevertheless, the system did not reach its potential capacity due to the slow surveying and marking of contour lines which precede the furrowing. A three-person team can mark contour lines at most at 50 ha/d.

Consequently, it was thought to add an auto-guiding system, which enables the tractor to follow the contour lines ‘on-the-go’. Many auto-guiding systems were suggested for this purpose, but most were expensive and/or complicated. The most appropriate one found was the laser guiding system (LGS)(Gammoh and Oweis, 2011).

6.2.2 The use of laser guiding in land leveling

Rice farmers were the first to recognize the importance of effective land leveling to improve yields and conserve water, so they switched from costly and time-consuming traditional leveling methods to the ones involving LGS in cut and fill operations performed by a tractor and a hydraulically controlled grading blade or bucket. This is now commonly used in agricultural applications in Australia, Japan, and the United States. The same concept is being increasingly used in mining and road construction applications.

How it works

The LGS consists of:

- A laser transmitter that transmits a rotating laser beam. The laser transmitter mounted on a tripod allows the laser beam to sweep above the tractor unobstructed with the plane of light above the field.
- A laser receiver mounted on a mast on the grading blade that is hitched to the tractor (Figure 6.3) intercepts the laser beam, detects the position of the laser reference, and sends a signal to a control box.
- An electrical control box which interprets the signal from the receiver, magnifies it, and produces an actuating signal.
- An electro-hydraulic control valve receives the signal from the control box and controls oil flow in order to raise or lower the leveling bucket or blade. Lowering and raising of the blade is the actual leveling action performed by the tractor.

6.2.3 Introducing laser guiding to contour furrowing

Application description

The application is a heavy-load tillage that consists of opening deep (30–60 cm) continuous or discontinuous furrows using the Vallerani or similar plow on the contour lines on slopes of grade 1–7%. If working on one hilly field, passes might be ≤ 300 m in length, but if the situation allows, the tractor might continue its pass and switch to the neighboring hill if it can follow the same contour line. The distance between two successive furrows could be 4, 6, 8, or 12 m. Therefore, the respective falls in elevation between them are:

On a 2% slope: 8, 12, 16, and 24 cm
On a 4% slope: 16, 24, 32, and 48 cm
On a 6% slope: 24, 36, 48, and 72 cm

Scenario of guiding

In contour furrowing, the LGS can detect and measure the difference in elevation between the current tractor position (while traveling) and the reference point in the field and convert this reading to a display on a panel in front of the tractor operator, who can then easily steer the tractor to keep this difference unchanged and maintain the tractor's track on the contour line. In this case, the devices required are a laser transmitter mounted on a tripod, a laser receiver (of specific length) mounted on a mast (either manually or electrically operated), and an electrical control panel with visual and sound display.
The transmitter transmits a laser beam, which is intercepted by the laser receiver mounted on a mast on the tractor (not on the implement), and sends a signal to the control panel. The control panel interprets the signal from the receiver and displays a visual and sound signal. The signal should indicate not only the matching of levels, but also how far (up or down) the levels do not match so the tractor driver can decide whether to steer left or right to maintain travel on the contour. This is true as far as the beam is intercepted by

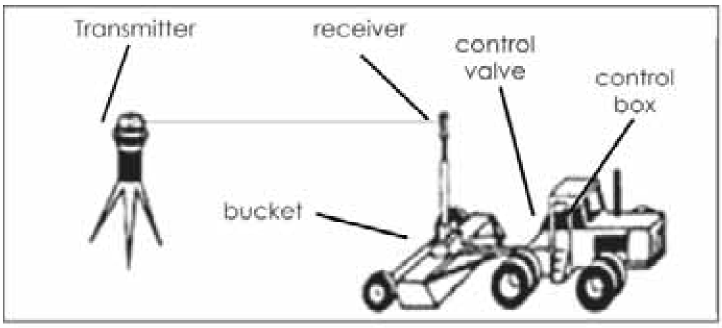


Figure 6.3. Laser guiding system used for land leveling.

the receiver. Therefore, the length of the receiver determines the difference in elevation that the receiver can detect and determines the time that the display can show a reading on the display.

There are five possible guiding situations that a driver might face while driving on a contour line and each has an appropriate response to maintain travel on the contour. A skilled driver should work within the first three possibilities: a–c (Figure 6.4).

When switching to the next downhill (uphill) contour line, if the receiver can still intercept the laser beam the driver can continue plowing without any adjustments. If not, the receiver should be raised (lowered) on its mast until the signal is displayed and travel can then continue.

When it is not possible to raise or lower the receiver due to insufficient length of the mast, the transmitter with its tripod should be relocated downhill (uphill) so the receiver can intercept the laser beam.

Calculations

In order to investigate and negotiate the specifications of laser equipment with the manufacturer, the scenario of guiding in contour furrowing was analyzed and the parameters A, B, and C (Table 6.3) were calculated. These calculations were used also to determine the feasibility, capacity and the appropriateness of the laser guiding system in practical implementation of contour furrowing under conditions that prevail in the Badia.

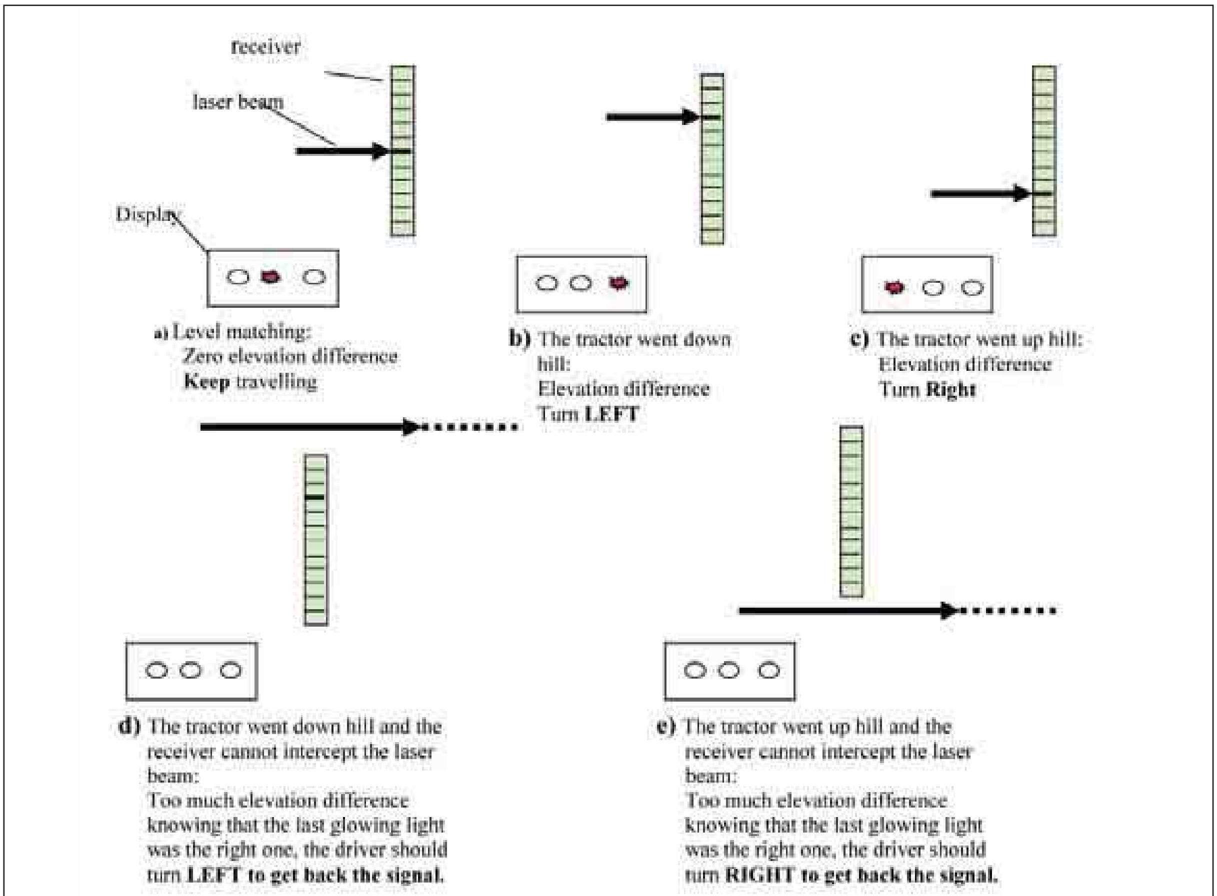


Figure 6.4. Five possible guiding situations met while driving on a contour line.

Table 6.3. Number of furrows that can be made 'on-the-go'.

Furrows spacing	Slope											
	to 2%			to 4%			to 6%			to 8%		
	A	B	C	A	B	C	A	B	C	A	B	C
4 m	8	4	15	16	2	7–8	24	1–2	5	32	1	3–4
6 m	12	2–3	10	24	1–2	5	36	1	3–4	48	1	2–3
8 m	16	1–2	7	32	1	3–4	48	1	2–3	64	1	1–2
12 m	24	1	5	48	1	2–3	72	1	1–2	96	1	1

The fall in elevation when moving from the uphill furrow to the next downhill furrow in cm.

A = percentage slope × furrow spacing

The number of furrows that can be made without any need to readjust the position of the receiver on the mast.

B = L/A (Rounded), where

L - Length of photocells on the receiver L = 31 cm (according to manufacturer specifications)
The number of furrows that can be made without any need to lower the transmitter on the tripod or to relocate it downhill.
C = D / A (Rounded), where Adjustable difference in alleviation between the transmitter and the receiver on the mast according to ordered devices D = 120 cm
The parameters B and C are good indicators of ease and feasibility of performing the furrowing 'on-the-go'. The higher they are the less action is required by the operator while traveling.

Example of capacity calculation

The area that will be covered when working 8-m-spaced furrows on a 4% slope before the position of the transmitter needs to be changed can be calculated as follows:

From Table 6.3, C = 4 furrows can be made without the need to relocate the transmitter.
If four furrows of length 300 m and 8-m spaced and 1-m furrow width, then the area worked without the need to relocate the transmitter will be 300 m × 9 m × 4 = 10 800 m^2 = 1.08 ha

The calculations were based on the specifications and features of the cheapest available laser devices that can be bought and provide acceptable performance of the guiding system. Performance enhancement is certainly possible, but it will be either of additional cost by buying devices of upgraded specifications, or by encouraging the manufacturers to produce devices that suit this particular application.

Nevertheless, with the minimum performance parameters, the laser guiding system proved to be an adequate solution for implementing large-scale applications such as WH contour furrowing.

6.2.4 Disadvantages and suggested enhancements

Unlike land-leveling applications, coverage area should be larger

Suggestion:
Use laser transmitter of higher transmitting range

Frequent re-adjusting of receiver position on the mast, every 1–3 contour furrows, depending on slope

Suggestion:
Use longer receiver
Use electrically adjustable mast, so the driver can relocate the receiver while driving

Frequent relocation of the transmitter, every 3–6 contour furrows

Suggestions:
When the transmitter is on the uphill side, the receiver mast should be selected as tall as possible and the transmitter tripod adjustable as low as possible, and vice versa when the transmitter is on the downhill side.

Notice from the calculation (example above), that in making four furrows the fall in elevation will be: 4 × 32 cm = 128 cm. This is the minimum difference in heights required between the transmitter and receiver, knowing that the adjustable difference in elevation between the transmitter and the receiver on the mast is D = 120 cm (i.e. 8 cm less than the fall in elevation). In this case, the transmitter tripod can be lowered by an additional > 8 cm to plow the fourth furrow 'on-the-go' without needing to change the transmitter position.

When working uphill–downhill, the mast should be mounted at the highest point possible on the tractor, and the transmitter tripod at the lowest point possible.
When working downhill–uphill, the mast should be mounted at the lowest point possible on the tractor, and the transmitter tripod at the highest point possible.
Field work should be performed in long-contour furrows rather than short ones, e.g. by switching from one hill to another adjacent.
Use of a dual-grade transmitter.

Shaking and vibration of equipment while traveling due to undulating soil surface might affect mast rigidity and control box operation

Suggestion:
Heavy duty and shock absorbing mounts should be used

6.2.5 Benefits of LGS

Time and effort saving: In large-scale implementation of WH structures, it is critical to start and finish land preparation before the first rain. This will help in timeliness and improve WH systems management.

Cost reduction: Traditional land surveying costs (surveyors and equipment) is higher than the cost of LGS – especially over many years, and considering that the targeted areas of interventions are of low productivity.

Ease of operation: Traditional surveying needs at least two skilled surveyors; however, the LGS can be operated by one person with minimum training.

High accuracy: Tractor drivers move between marks made by surveyors in straight lines, which affects the accuracy of tracing the contour lines. However, while in LGS the operator is guided to trace the contours continuously. This ensures even elevation inside the catchment and thus even distribution of harvested water along the catchment. In addition, LGS avoids occasional confusion of close adjacent surveyors' marks by the driver and driving toward the wrong mark.

The LGS can be also used as surveying equipment with even farther range of coverage than traditional surveying equipment, and can guide as many surveyors or receivers as necessary.

6.3 References

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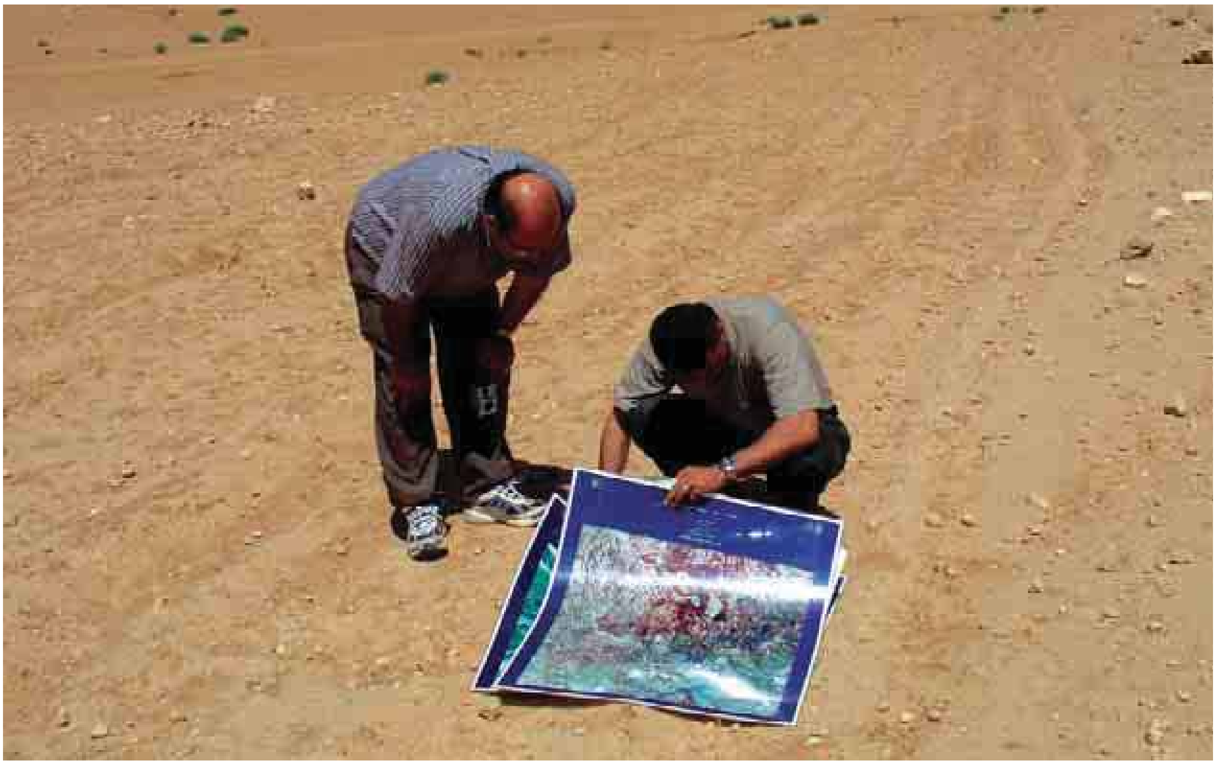
Chapter 7

Database development management in a GIS environment



Chapter 7: Database development management in a GIS environment

F. Ziadat, S. Mazahreh, L. Al Mahasneh and M. Aboushi

7.1 Introduction

The rangelands of West Asia and North Africa are the grazing grounds for the Bedouin with their flocks of sheep, goats and camels and are known as *al Badia* in the Middle East region. Average annual rainfall in the *Badia* ranges between 50 and 250 mm (Haddad 2006). Despite its scarcity, rainwater is generally poorly managed and much of it is lost through runoff and evaporation. To improve production in these areas, there is a need for the sustainable management of natural resources – land and water (FAO 1983). The challenge is how to enhance productivity and halt land degradation in these marginal environments (Oweis et al. 2006).

Rainwater harvesting can improve the productivity of rainwater and maintain productive and sustainable agro-pastoral systems in marginal environments. To develop successful and sustainable integration of rainwater-harvesting techniques within existing agro-pastoral systems, the International Center for Agricultural Research in the Dry Areas (ICARDA), in cooperation with agricultural research organizations in Jordan, established a *Badia* Benchmark Watershed in 2004. ICARDA is using benchmark sites to develop, test, adapt, and evaluate improved genetic and natural resources management practices and technologies under 'real life' conditions. It is anticipated that the findings and approaches developed by this *Benchmark* project will be adopted and implemented by future similar development projects (Oweis et al. 2006, Ziadat et al. 2006).

During the four years of project activities, information has been continually collected and delivered. Some information was spatial and some non-spatial (attribute data). The integration and management of both types of information played a crucial role in facilitating these activities. Linking spatial data to attribute information was also important for certain types of analysis needed to carry out project activities. Furthermore, the project includes multi-disciplinary teams with plant specialists working with soil scientists, GIS specialists, socio-economists, and other team members. The organization of the database needs to facilitate interactive communication between these teams for the better exploitation of project results.

The aim of establishing a comprehensive and dynamic database is to provide information in a suitable format to allow the analyses and procedures needed by the project to be carried out. The data should also be suitable for future use beyond the lifetime of this particular project. The following steps were followed to achieve this objective:

- Receive information from various components of the project in different formats
- Undertake analysis and manipulation to arrange the data in formats and structures satisfying the needs of the various project components
- Monitor and correct the geo-referencing issues of all the data collected
- Undertake analysis and manipulation to arrange the data in formats and structures satisfying the needs of the various project components.

The project data is of two types. The first represents data collected by the *Badia* Benchmark project from previous research and from other national institutes and organizations. The second is the data collected by the project itself from the intervention sites implemented at Mharib and Majidyya villages. This report describes the establishment of the project database and associated activities. The objective is to provide a methodology for documenting information generated from similar projects, implemented on farmers' fields and extending over large areas.

The report focuses on three main activities:

i. Establishing a GIS database for the intervention sites, which defines each site in terms of its geographic location and extent and includes a method for providing a unique label for each site. This was used by all team members when collecting various types of data from the intervention sites
ii. Establishing a dynamic link to all available data and information (using an HTML-based application)
iii. Preparing forms for data collection (parameters to monitor indicators), entry and analysis, during different seasons.

7.2 Establishing GIS database for the intervention sites

Thirty-five intervention sites were implemented by the project. These were located at two villages, Mharib and Majidyya, 45 km southeast of Amman, Jordan. Each intervention site was visited and the coordinates of the boundaries were recorded using the GPS device (Garmin 12XL). The coordinates were recorded using geographic latitudes and longitudes (WGS 1984 datum). All GPS data were entered into an Excel worksheet together with labels for each site. Latitudes and longitudes were then converted to the Jordanian Transverse Mercator coordinate system (JTM) to enable integration with the other layers related to the study area, such as:

- Satellite images: merged LandSat and SPOT images.
- Digital elevation model, derived from topographic map (scale 1:50,000)
- Streams, derived from the topographic map (scale 1:50,000)
- Contour lines, derived from the topographic map (scale 1:50,000)
- Suitability maps for different water harvesting techniques
- Cadastral map from the Department of Land and Surveying

Further details are presented in Ziadat et al. (2006). The GPS points of each site were displayed in the GIS and each site was drawn as a polygon by on-screen digitizing between the collected points.

Maps were prepared showing the dimensions, location, and label for each site. The unique key used to label sites is as follows (an example is shown in Figure 7.1):

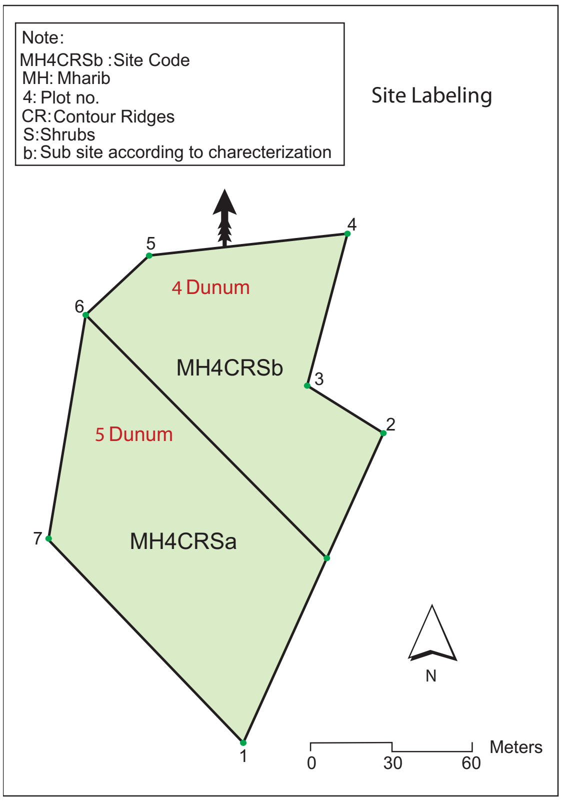


Figure 7.1. Unique site name for each intervention site.

- Site name: MH: Mharib, MJ: Majidyya
- Plot No.: 1, 2, …..,22.
- Water Harvesting technique: Contour Ridges = CR, Contour Strips = CS, Narrow Strips = NS, Vallerani = V.
- Plant type: Shrubs = S, Barley = B.
- Sub -Site according to biophysical characterization (mainly slope): (a, b, c, d, e, f, g, h,i)

The mapping process included a general description and subdivision of the sites where water harvesting structures were implemented (Figure 7.2). (Figure 7.3) shows the intervention sites for both villages. These sites are presented in more detail together with their labels in (Figure 7.4) for Mharib (22 sites) and (Figure 7.5) for Majidyya (13 sites). The area of each intervention site was calculated (Table 7.1) in dunums (1 hectare = 10 dunums).

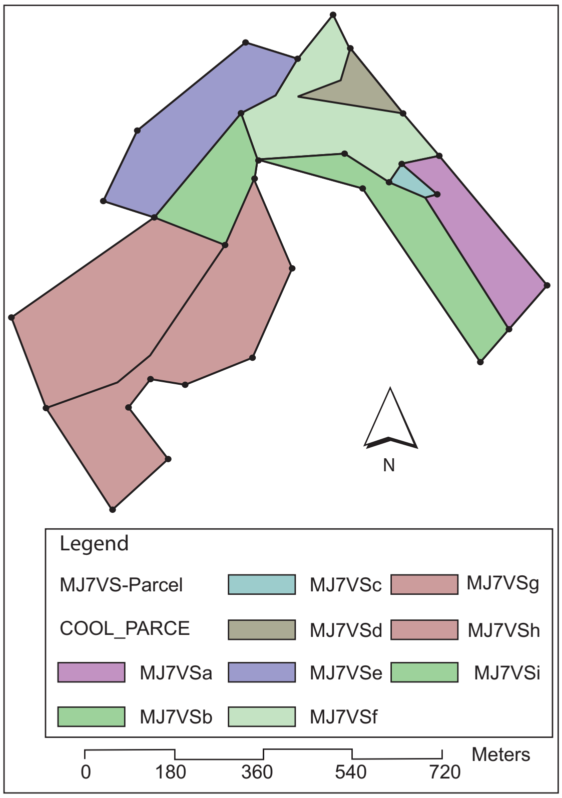


Figure 7.2. Digitizing between GPS points to delineate site boundaries in Majidyya (labels are explained in Figure 7.1).

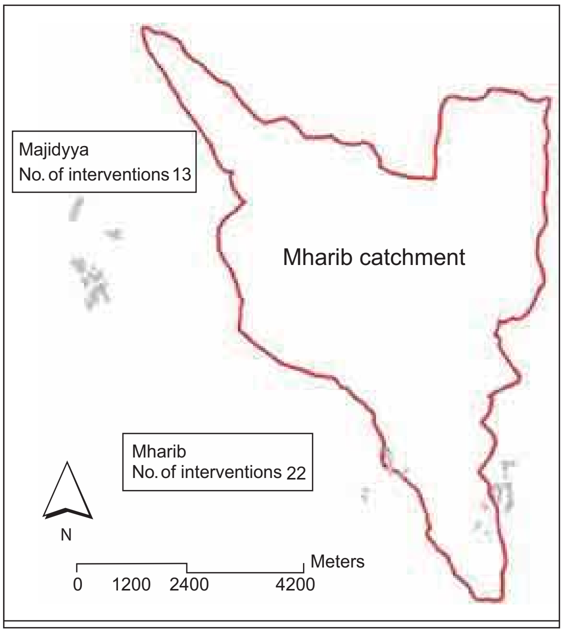


Figure 7.3. Intervention sites for Mharib and Majidyya, 2005/06

New intervention sites selected by the project team during the 2006/07 season were added to the existing sites at Mharib and Majidyya. Six sites (three sites in each village) were characterized and geo-located on the field using GPS (Figure 7.6). These sites are presented in more detail together with their labels in (Figure 7.7). The area (in dunums) of each intervention site is shown in (Table 7.2).

7.3 Database structure

The database of the *Badia* Benchmark project includes data collected from different sources, classified into different categories based on the type of data. HTML (HyperText Markup Language) was used to build the database. HTML is the predominant markup language for web pages. It allows images and objects to be embedded and can be used to create interactive forms. It provides a means of creating structured documents by denoting structural semantics for text such as headings, paragraphs, lists, links, quotes, and other items. It can embed scripts

Table 7.1. Site labels and their areas, 2005/06.

Site label	Area (dunum)	Site label	Area (dunum)
Mharib		Majidyya	
MH1CRS	6.0	MJ5CRSa	5.2
MH2NSB	6.2	MJ5CRSb	19.3
MH3CRSc	19.6	MJ12CRS	10.6
MH3CRSa	9.4	MJ9CRSb	5.4
MH3CRSb	36.1	MJ9CRSa	9.3
MH4CRSa	4.9	MJ8CRS	11.1
MH4CRSb	4.1	MJ1CSBa	30.7
MH6CRSa	2.3	MJ1CSBb	52.1
MH6CRSb	3.3	MJ2CSB	7.2
MH7CRS	1.3	MJ4NSB	19.1
MH8CRS	3.3	MJ6NSB	7.3
MH9CRS	1.8	MJ10NSBb	14.2
MH12VSb	6.1	MJ10NSBa	21.1
MH12VSa	20.8	MJ11NSBa	8.2
MH13VS	6.1	MJ11NSBb	16.1
MH14VS	17.3	MJ3CRSa	20.6
MH18CRS	10.7	MJ3CRSb	11.6
MH19CRSb	2.1	MJ3CRSc	10.8
MH19CRSa	8.4	MJ7VSd	4.1
MH22VSb	10.3	MJ7VSe	20.7
MH22VSa	10.1	MJ7VSh	33.0
MH10CRS	12.4	MJ7VSb	16.9
MH11CSBa	6.2	MJ7VSc	1.1
MH11CSBb	10.9	MJ7VSa	13.2
MH15CSB	5.3	MJ7VSf	20.9
MH16NSB	4.3	MJ7VSg	35.8
MH17VSb	16.5	MJ7VSi	10.6
MH17VSa	17.2	MJ13NSBa	22.6
MH17VSd	5.3	MJ13NSBb	7.8
MH17VSc	45.1		
MH20CRS	2.9		
MH21CRSa	4.9		
MH21CRSb	11.7		
MH5CSB	17.4		
Total	350.3	Total	466.6

Note: 10 dunum = 1 hectare.

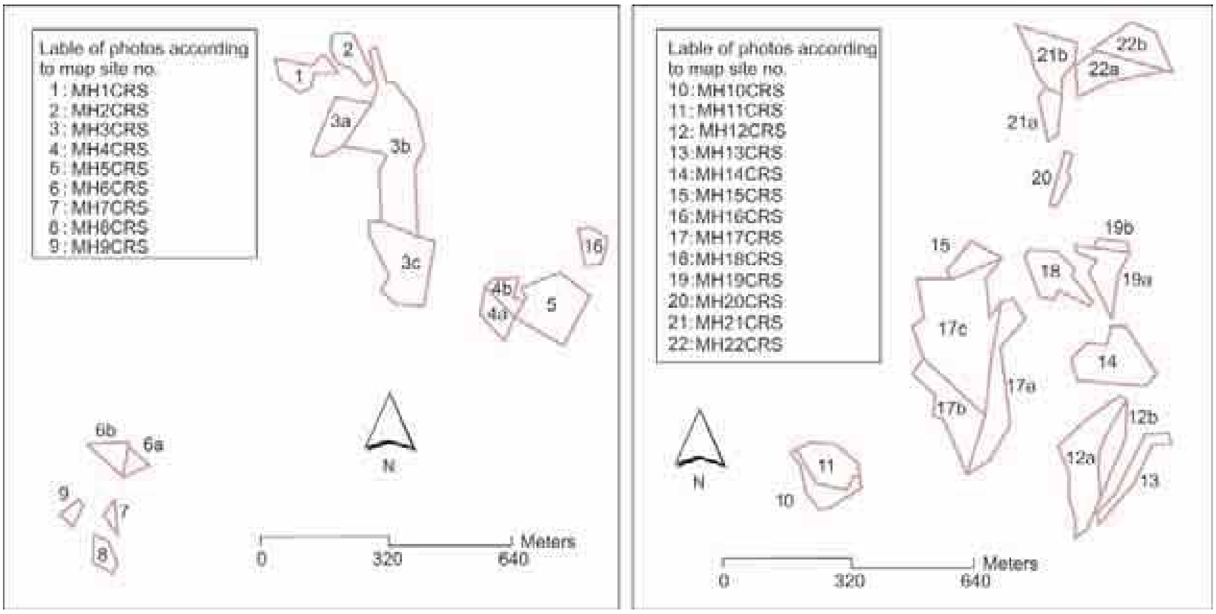


Figure 7.4. Intervention sites for Mharib, 2005/06.

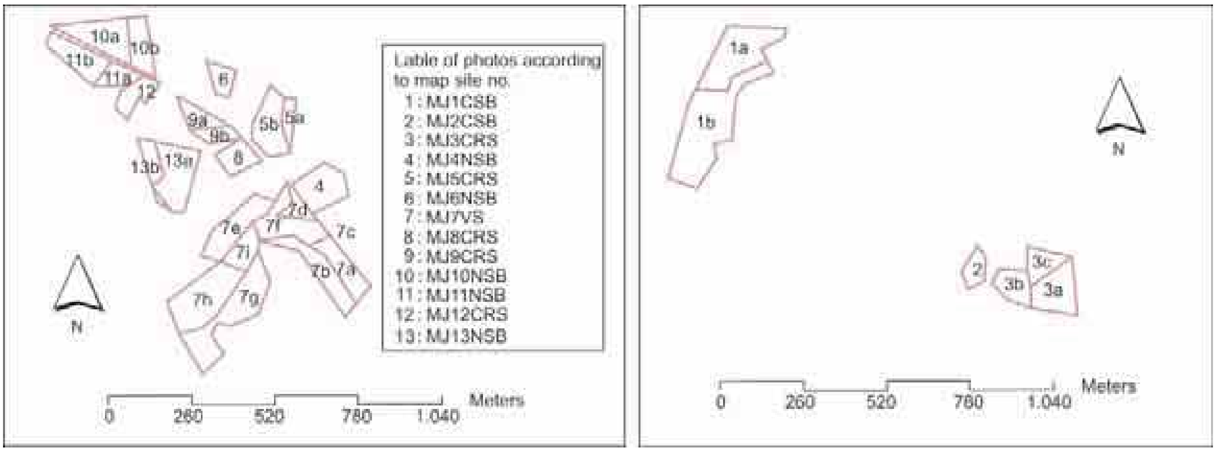


Figure 7.5. Intervention sites for Majidyya, 2005/06.

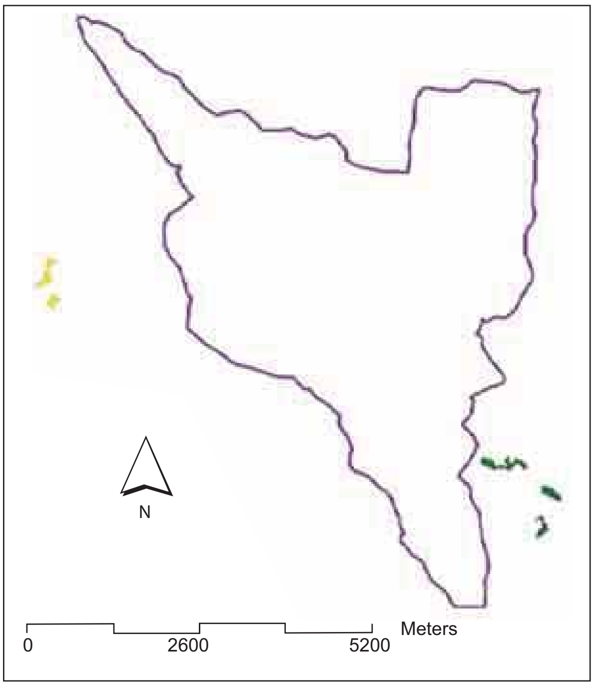
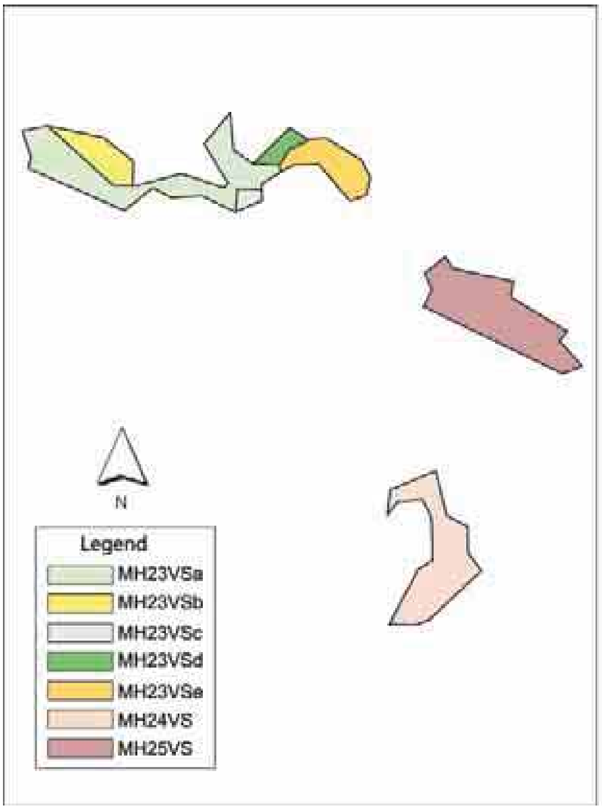


Figure 7.6. Intervention sites for Mharib and Majidyya, 2006/07.

Table 7.2. Site labels and areas for the new sites, 2006/07

Mharib		Majidyya	
Site label	**Area (dunum)**	**Site label**	**Area (dunum)**
MH23VSb	20.2	MJ14	26.3
MH23VSc	4.1	MJ15	55.2
MH23VSd	8.8	MJ16	41.4
MH23VSa	79.6		
MH23VSe	27.8		
MH25VS	78.2		
MH24VS	60.1		
Total	278.8	Total	122.9

Note: 10 dunum = 1 hectare.



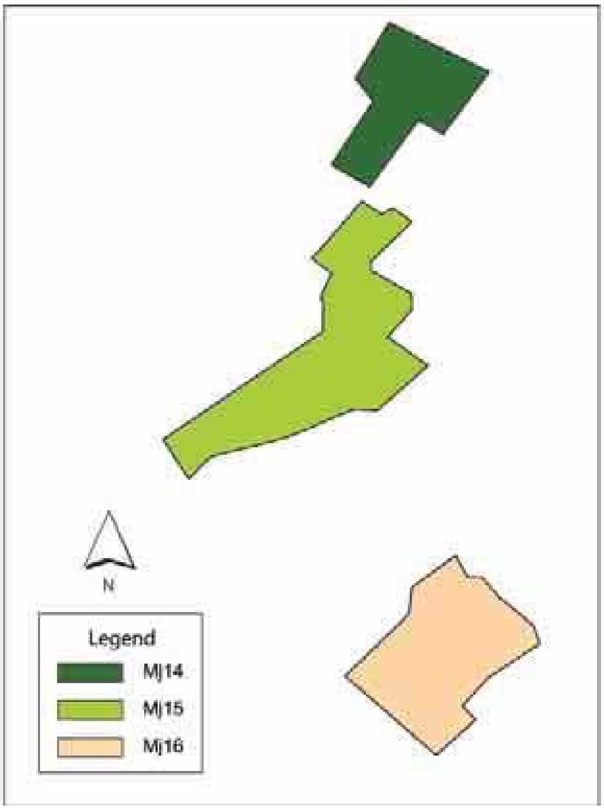


Figure 7.7. Intervention sites for Mharib and Majidyya, 2006/07.

in languages such as JavaScript which affect the behavior of HTML webpages. All related information can be accessed and displayed using the hyperlink to the main page of the project database. Therefore, all information is organized in a way that describes its content, relevant titles and documents. The structure of the database was designed to distinguish the data based on: (i) stages of the project to which the data belong; (ii) project component; and (iii) data type (reports, maps, tables, images, others). The general view of the design is shown in (Figure 7.8). Details of the content and hierarchy for each of the database components in the figure are presented in the (Annex 2).

7.3.1 Dynamic link to access available data

The main goal for establishing this link is to provide the project researchers with easy access to all available information collected during the project. For example, a researcher might want to know about the performance of various water harvesting interventions and to link them with the biophysical conditions (Tables 7.3-7.6) under which they operate and with the socio-economic characteristics of the owners (Table 7.5). This would help in understanding the conditions for the success or failure of various interventions.
Two basic requirements were considered in building this link: first the system should be user-friendly, promoting the wide utilization of the available data, and, secondly, the system should guarantee the privacy and security of the database, especially when disseminated via the internet, eg. through the project website.
The project's data were subdivided into two types. The first represents data collected by the *Badia* Benchmark project from previous research and from other national institutes and organizations.

Further additions to these data would be very limited. The second type groups the data collected by the project from the intervention sites implemented at Mharib and Majidyya villages. These dynamic, continuously collected data had to be kept separate from the first kind of data

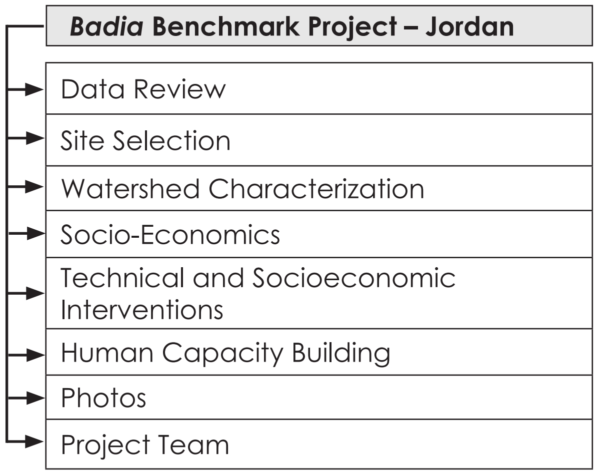


Figure 7.8. Database components.

(Figure 7.9) shows an example of the link between the main pages of the database, where all components are listed. The user has to press the button representing the data she/he is interested in, and the relevant data will be shown. In this example, the researcher chose 'data review' (by pressing the button), and the database has come up with all available data types under this component on the same page. The user has clicked the button labeled 'socio-economic studies' and then chose 'lessons learned'; the relevant data is presented and ready for the researcher to use in different ways. This structure together with all available information is ready for delivery to any authorized researcher.

7.3.2 Data collection forms for waterharvesting sites

These forms aim to bring together all project teams and components through a unified data collection and organization procedure. This facilitates data retrieval by researchers within or outside the project, as well as the analysis and understand-

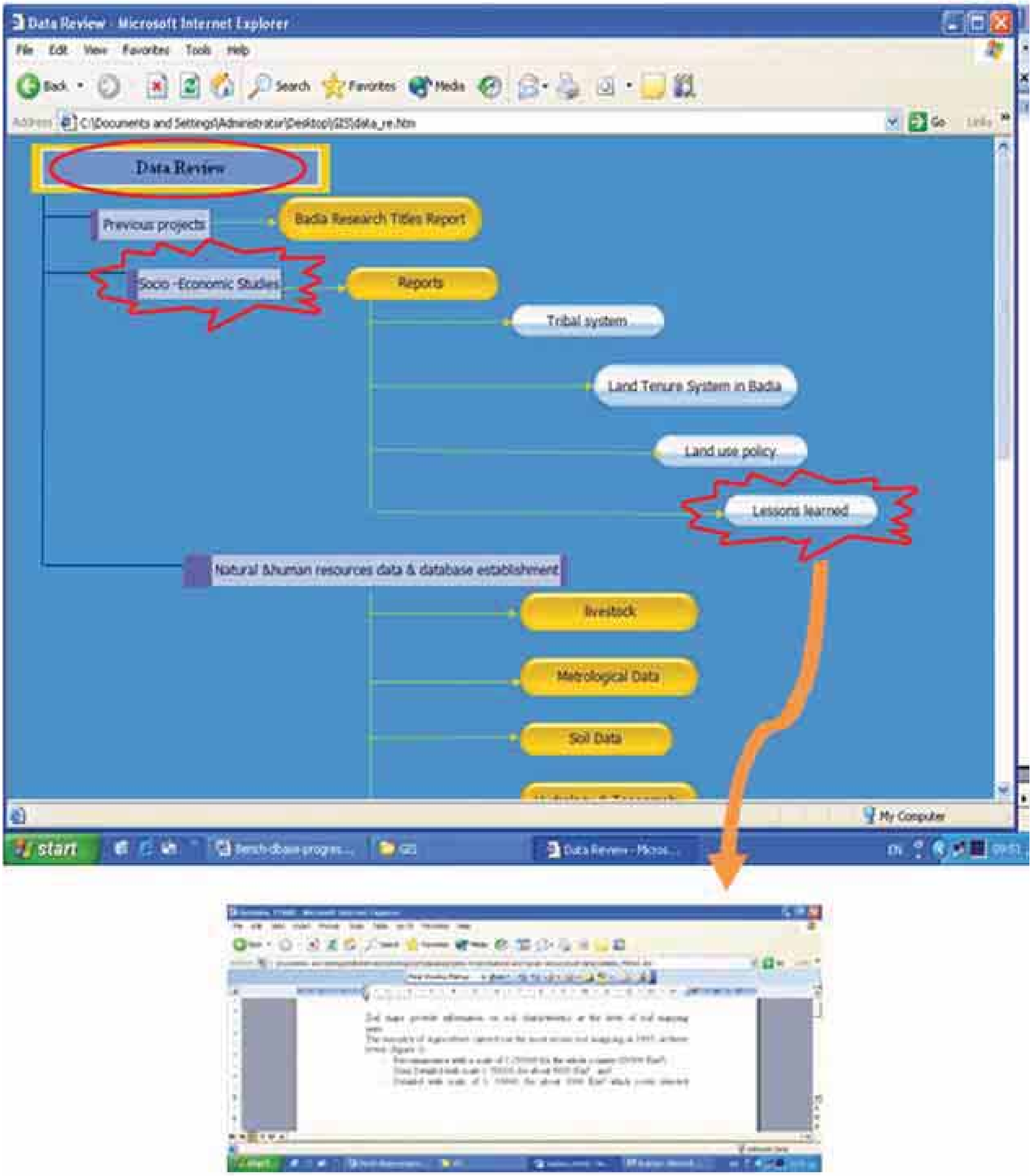


Figure 7.9. Example of database link to various components and data formats.

ing of project findings. The project team is multi-disciplinary; plant specialists work with soil scientists, GIS specialists, socio-economists, and others. Organization of the database facilitates communication between these teams and better use of project results.

It was agreed to design the database using the Microsoft Excel worksheet format, because of its ability to carry out various database functions (entry, storage, retrieval and analysis) and its wide use and familiarity among team-members.
We anticipate that the findings and approaches developed by this project will be implemented by future similar development projects. A short-term objective of establishing such a database is to facilitate modeling tools for use by the project or others.

The key parameter linking all types of information for each site is the site label identified in the field (explained in the previous section). This label is unique for each site and used by all researchers to document any data about the intervention sites. An Excel file was generated for each intervention site. The data recorded in this file were subdivided into two main categories.

i. The first presents the site characteristics, collected at the beginning of the implementation (biophysical and socio-economic characterization of the site). These data are collected for one time, and therefore no updating is expected for this type of information.
ii. They were grouped together on one sheet in the Excel file (sheet name: 'site characterization', Figure 7.10).
iii. The second category includes data that were collected during the growing season to monitor the progress and performance of the intervention site. These were organized on two types of sheets.

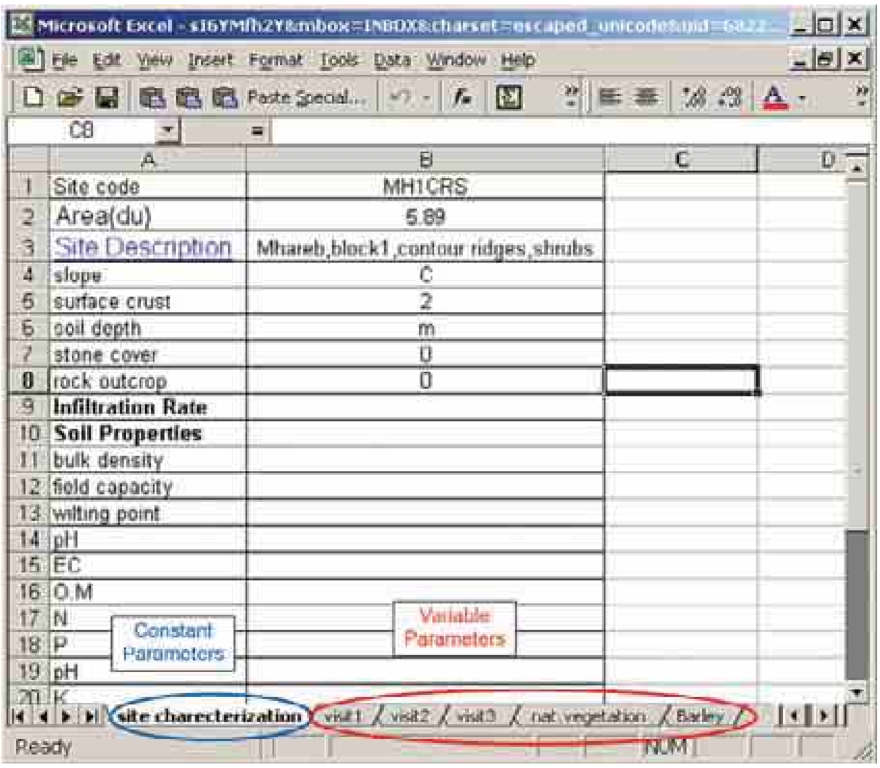


Figure 7.10. Data collected at each intervention site.

- One for each of the successive visits undertaken by team members to each intervention site. This sheet records the data collected while in the field (sheet name: 'visit', Figure 7.10). The number of visits is unlimited. If more than one visit is undertaken, the researcher has to copy the sheet and use it to add additional visits.
- The second type of data are the data collected to describe the natural vegetation and barley crop status for each site (sheet names: 'nat. vegetation' and 'barley', Figure 7.10). These data were separated because of the specificity of the data collected; these parameters were not collected by the other teams. These data were used to compare the performance of the intervention site (barley or forage shrubs) with that of the natural vegetation. The parameters collected for each site are explained in (Tables 7.3–7.6).

Finally, all the data collected are available to project researchers in two forms. First, as Excel files in the format described above. Second by the generation of a summary Excel file. This file includes the whole data for all intervention sites (Figure 7.11). Each intervention site is presented as one row (record) in the summary file, where all collected data are organized in columns (fields). The purpose is to facilitate comparison among intervention sites.

Table 7.3. Parameters recorded at each intervention site (Excel sheet 'site characterization').

Excel sheet	Parameters
Site Characterization	Site code Area Site description Slope Surface crust Soil depth Stone cover Rock outcrop Infiltration rate Bulk density Field capacity Wilting point pH Electrical conductivity Organic matter Nutrients: N,P, K $CaCO_3$ Soil texture: sand%, silt%, clay%, texture class

Table 7.4. Parameters recorded at each intervention site (Excel sheet 'natural vegetation').

Excel sheet	Parameters
Natural Vegetation	Species per quadrate Count Total Frequency Abundance Density Proportion SDI

Table 7.5. Parameters recorded at each intervention site (Excel sheet 'visit').

Excel sheet	Parameters
Visit	Date
Soil and water parameters	Wetted depth Location details Vegetation and rangeland management
Fodder shrubs parameters	Catchment/cultivated area Plant density Dry matter (kg/ha) Survival% Browse (kg dm/ha) Herbage (kg dm/ha) Forage (kgdm/ha) Stocking rate (sud/ha)
Natural vegetation parameters	Total no. of families Total no. of plant species Vegetation cover % Vegetation biomass Stone cover % Root mat characteristics
Barley Parameters	Crop stage Grain yield (kg/ha) Straw yield (kg/ha) Dry matter (kg/ha) Average plant height No. of tillers per plant
Livestock parameters	No. of grazing days Dry matter intake of livestock Dry matter production Barley equivalents of dry matter production for each No. of animals grazing the plots by age Time of grazing Area of barley stubble grazing Area of Atriplex grazing No of plants grazed per hectare Hand feeding Change in the livestock number in the community Animal performance and stoking rate Rangeland productivity and biomass Rangeland species richness Livestock watering

Table 7.5. (Continued).

Excel sheet	Parameters
Machinery parameters	Returns (JD/dunum or JD/hr) Running cost (JD) Annual cost of fuels Annual lubricates cost Annual repairs and maintenance cost annual spare parts Annual operator costs Seasonal operators Fixed costs (depreciation, garage cost, insurance cost, interest rate on invested capital, operator cost)
Socio-economic parameters	Return (JD) Quantity of production (grain, hay, biomass) Prices or estimated values of outputs Variable cost: Seedling and/or seeds, compound chemical fertilizer, organic fertilizer, pesticides, electricity, fuel, maintenance, sacks, water, hired machinery, tillage costs, cost of spraying, manual hired labor Interest on variable cost Gross margin, fixed cost, family labor, total cost, net profit, costs of water, return to water, construction cost, land acquisition, operation and maintenance costs

Note: JD = Jordanian dinar

Table 7.6. Parameters recorded at each intervention site (Excel sheet 'barley').

Excel sheet	Parameters
Barley	Barley variety Seeding rate Planting date Planting depth Planting method Previous crop Experimental design No. of treatments No. of replicates Plot size Distance between rows Length of row No. of rows Fertilizer (type, quantity, date of application) Growth stage Harvesting (date of harvesting, method, harvested area)

7.4 Conclusions

The systematic procedure followed in collecting and organizing these data has led to the establishment of a comprehensive and dynamic database for the whole project. To achieve this, the collaboration of all project components and researchers was necessary to deliver the data as they become available. The database has been used successfully by different researchers within the project. It provides easy access to uniformly formatted spatial and non-spatial data, which can easily be viewed and explored.

It also facilitates the navigation of data and components, which has helped in exploring new database applications.

The benefits go beyond the use within this particular project to providing a comprehensive database for the whole *Badia* region in Jordan, which is representative of the arid regions of WANA. It is anticipated that any future research and/or development project will use this database and continuously develop the structure and content to benefit the efforts of land resources management in the dry areas.

7.5 References

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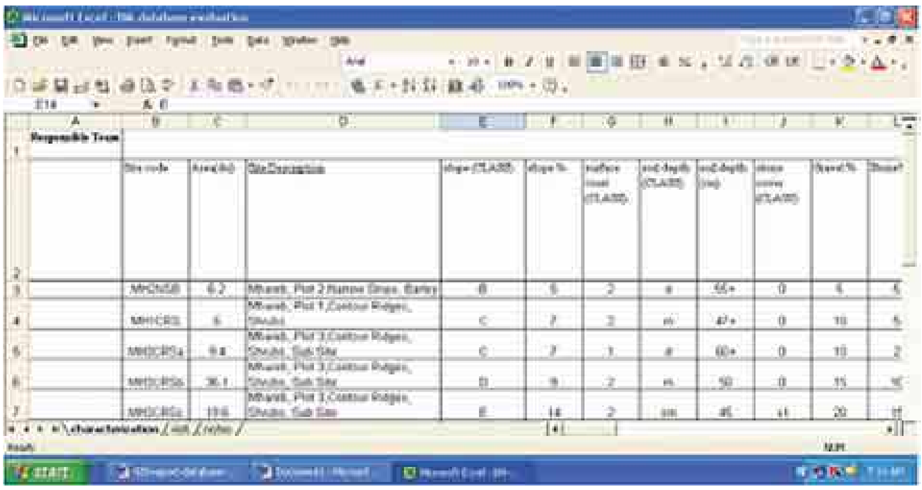

Figure 7.11. Example of summary file, which includes all intervention sites.

Chapter 8

Adaption, environmental impact and economic assessment of water harvesting practices in the Badia benchmark site

Chapter 8: Adaption, environmental impact and economic assessment of water harvesting practices in the Badia benchmark site

S. Akroush, K. Shideed and A. Bruggeman

8.1 Economic analysis of water harvesting techniques

8.1.1 Benefit–Cost Analysis of water harvesting techniques

Introduction

The shortage of water in arid zones represents the most serious obstacle to poverty reduction because it limits the extent to which poor producers of crops and livestock can take advantage of opportunities arising from emerging markets, trade, and globalization. Water shortage in arid zones limits the variety and quantity of crop and livestock products a smallholder can produce, thus narrowing their range of options. Furthermore, poor smallholder producers seldom use productivity-enhancing inputs, such as improved seed varieties and fertilizers, due to high risks associated with variability of water available for plant growth. This, together with the fluctuations in yields, makes it hard for poor farmers to participate in emerging market economies.

The term 'arid' here is used to refer to conditions where annual rainfall is in the range 100–250 mm, and/or potential evapotranspiration exceeds rainfall most of the time and/or the rainfall regime is highly variable in quantity, timing, and distribution. Arid areas experience seasons that we term a 'dry year' when below average, or a 'wet year' when above average. Below average seasons are characterized by rainfall below the long-term mean and/or unevenly distributed within the season, while above-average seasons have rainfall above the long-term mean and also more evenly distributed. If the seasonal rainfall is above average, but unevenly distributed within a growing season to meet crop water requirement during critical growing stages, then the season is still 'below average' because yield is affected as in the case of below-average rainfall season. Water harvesting (WH) has been used in many arid areas to reduce water shortages. In arid areas, the effect of erratic rainfall on crop yield is apparent, and efficient rainwater management seems to be a key to solutions.

The Badia region in Jordan suffers from severe water shortages that arise from many factors, e.g. low rainfall and uneven distribution, high losses due to evaporation and runoff, and increased demand on water due to population growth. One problem in the region is soil crust formation, which reduces water infiltration; however, surface crusts are an important characteristic for WH technology (Abu-Awwad and Shatanawi, 1997). The susceptibility to seal is common in many arid and semi-arid soils, where the soil surface is characterized by low organic matter, high silt contents, and low aggregate stability (Abu-Awwad, 1997)

WH has been used for many years in different areas worldwide to solve the problem of water scarcity in arid and semi-arid areas (Abu-Awwad and Shatanawi, 1997). Runoff farming, which includes concentrating rainfall water on a small area, effectively increases the amount of water to about 2–4 times the normal annual precipitation, is highly recommended for the production of many crops.

The purpose of rainwater management in an arid region includes conserving moisture in the root zone, storing water in the soil profile, and harvesting excess runoff for supplemental irrigation of rainfed crops. Because only a portion of the rainwater can be stored in the soil profile, the excess runoff water needs to be harvested in farm structures to meet the irrigation requirements of crops and other water-consuming activities in the area such as livestock watering.

Small ruminants in Jordan depend mainly on rangeland and cereal stubble grazing as a major feed source. However, farmers usually supply their sheep with barley grain and wheat bran as supplemental feed, but in insufficient quantities due to the high cost. Cereal straw is an important source for winter-feeding; however, it has a low protein and high fiber content. During the hand-feeding period, the majority of ewes are in late pregnancy, when their nutritional requirement is at its peak. Therefore, additional sources of feeding play a crucial role in attaining the main goal of increasing agricultural output, productivity, and farmers' incomes. Barley cultivation is the re-establishment and use of native and exotic fodder shrubs and trees such as saltbushes (*Atriplex* spp.). Saltbush (*Atriplex halimus*), a shrub native to Jordan, is an important species used for rangeland reclamation in Mediterranean desert shrublands. It provides valuable fodder during long dry seasons and droughts.

Some farmers have regenerated small areas of rangeland with fodder shrub species to reduce the risk of feed shortage and in some cases to make productive use of unproductive land. Vallerani techniques of mechanized WH have succeeded in efficiently and successfully establishing productive plant communities that provide grazing for livestock. Evidence from farmers suggests that, in some cases, the profits from fodder shrub pasture may be greater than that for annual species native pastures on unaffected land. Adoption, however, has not been widespread, perhaps because of the risk of financial losses in pioneering new farming systems. This lack of widespread confidence may be partly addressed by providing information to growers on the economics of fodder shrub pasture, based on rigorous analysis. Economic information can also be useful to researchers to help identify the characteristics of new grazing systems that needed to maximize net returns to producers.

8.1.2 Description of WH techniques

The design capacity of a WH structure is normally determined by the expected value of peak runoff for the anticipated life of the structure. The peak value is determined from historical records. In practice, especially in arid regions, it may not be possible to harvest all runoff from a catchment for various reasons, indicating lack of suitable sites for reservoirs in adequate quantity, scarcity of roads for carriage of heavy earthmoving equipment, unwilling participation of local people, inequitable distribution of water, private ownership of land, and scarcity of funds.

Contour ridges

Contour ridges are established using a mold-board plow. The ridges are mainly used for planting shrubs, but planting barley within the ridge where the shrub is planted is also adopted. Three different spacing between the constructed ridges in the field, along with planting shrubs, intercropping, three levels of plant density for shrubs, and different types of shrubs are also used.

Runoff strips

Barley is planted in strips using an appropriate seed drill, with unplanted strips between as a catchment area. The catchment area allows rainfall water to be harvested in the barley strip, which will maximize the available water for barley, and enabling it to produce reasonable straw and grain yields. The ratio between the planted strip and the catchment area (i.e. cultivated:catchment) is suggested to be 2:2, 2:3, or 2:4. However, adjustment to these ratios is made according to the width of the seed drill and to the land and soil characteristics. The planting is done as much as possible following the land contour, which requires a skillful driver.

8.1.3 Demonstrated technologies

Barley cultivation

At Mharib site 1, ten contour ridges (CR) spaced 10 m apart were established for planting fodder shrubs. The contour ridges had dimension of 0.5-m wide and 0.5-m high, and the total length of contour ridges was around 1300 m.
At Mharib site 2, six contour strips (CS), 40-m each and spaced 6-m were established for barley cultivation. The 6-m width of the strip was divided into a 4-m runoff area and a 2-m cultivated area (i.e. 2:1).
At the same site, 22 contour ridges, each 40 m in length and 2-m spaced were established for barley cultivation. The dimensions of the contour ridges were 0.5 m wide and 0.5 m deep.

At Al-Majidiyya, 14 contour strips with 6-m spacing were established for barley cultivation. The length of the strips was in the range 30–50 m. The ratio of runoff to cultivated area was 2:1.

Fodder shrubs

Trials were conducted during the last two decade in Jordan to examine the potential value of grazing fodder shrubs pastures. The focus of these studies was to determine the dry matter and protein contents of species, for grazing by livestock. The results have shown that saltbush contained relatively high levels of protein throughout the year. El-Shatanawi and Turuk (2002) concluded that introducing saltbush fodder shrubs into dryland of Jordan would supplement the nutritional requirement and possibly minimize the need for grain supplements during summer and autumn. Saltbush is drought resistant and can be grazed during drought years, but water should be available to prevent Na toxicity (El-Shatanawi and Turuk, 2002).

Sheep usually need feed supplementation for six months in a normal year and nine months during drought years. The crude protein content of saltbush (*Atriplex halimus* L.) is high, and would be a good protein source for livestock during dry summer and autumn periods. Protein is one of the most limiting nutrients for range livestock production and its supplementation is cost effective, because it improves forage intake and digestibility.

The two common techniques for re-vegetation of degraded rangelands are direct seeding and transplanting. Because of drought risk and high variability of precipitation, direct transplanting of seedlings are preferred to seeding as a technique for rangeland rehabilitation (Abu-Zant et al., 2006). Mechanized transplanting is a widespread tool for rehabilitation of degraded rangelands. One of these tools is the Vallerani system (VS). The VS proved to be a successful mechanized tool for rehabilitation of degraded steppe and Badia rangelands in Syria, Egypt, and Nigeria (Abu-Zant et al., 2006). It can allow the economical construction of 400 microcatchments (bunds)/h with a subsequent high rate of shrub establishment if large areas are involved (Abu-Zant et al., 2006).

Three types of microcatchments were established at the study site: the Vallerani contour ridges (VCR), the Vallerani bund structures (VBS), and the traditional pits (TP). The VCR, VBS, and TP were established at both slopes (8% and 16%) and spaced at 4 and 8 m. All planted seedlings received 5 L of water immediately after planting.

The plant densities were 625 and 313 shrubs/ha for the VCR compared to 893 and 446 shrubs/ha for the VBS for microcatchment spacings of 4 and 8 m, respectively. Several contour lines spaced 4 and 8 m were delineated at ground and traditional pits spaced at 3 m were opened using an auger and then *Atriplex* seedlings were planted. The traditional pits planted with *Atriplex* seedlings were considered controls.

8.1.4 Assumptions and bases for calculating cash flows

Several assumptions for the calculation of cash flow underpin the financial and economic study, and thus the analysis, conclusion, and criteria that indicate the feasibility or not of the project.

The economic analysis of this study is based on the following assumptions:
Age of shrubs is 15 years. The first two years are called the establishment years and zero years, when no yield is obtained (for the range shrubs).

Discount rate. The interest rate of loans are used as the opportunity cost for the investment in the local communities and estimated at 10%.

Maintenance costs for planting shrubs with WH are included in the economic analysis. Return is calculated on a per hectare basis. The total costs of planting of shrubs and barley are broken into establishment cost (in the case of using WH techniques) and the cost of planting in addition to annual maintenance costs. The establishment costs included the cost of planning and establishing the contours (in the case of planting barley) and included the cost of planning and establishing contours and digging bores for planting range shrubs. Details of cost items are presented in annex 3. The expected return of planting shrubs and barley was obtained, based on the simple simulation model used to predict the return of planting range shrubs and barley for the estimated project life span of 15 years.

Three discount measures of the benefit–cost analysis (BCA) were used in the economic evaluation of WH techniques: internal rate of return (IRR), Net Present Value (NPV), and Benefit–Cost Ratio (BCR).

Financial analysis estimated the financial internal rate of return (FIRR) at 29% in the case of barley cultivation with WH, and about 28% in the case of planting shrubs with WH. The lowest value of FIRR among all values of the different techniques was for barley cultivation (farmers' practice) and reached 11.2%, indicating it was economically feasible as the FIRR was greater than the opportunity cost of capital investment in the community, which is 10%. This confirms the feasibility of investment in WH techniques in dry areas in Jordan.

For all of the different techniques, the NPV > 0, and all the BCR > 1 (Table 8.1). Despite the results of economic analysis based on the IRR showing that planting barley with WH was more feasible than planting shrubs with WH, the environmental impacts related to planting rangeland shrubs could alter this result.

Table 8.1. Financial and economic BCA results for different WH techniques in the study area.

WH technique	Financial BCA (Discount rate 10%)			Economic BCA (Discount rate 10%)		
	BCR	NPV (JD/ha)	EIRR %	BCR	NPV (JD/ha)	FIRR %
Traditional pits	20.2	162	7.4	3.55	1.75	97
Shrubs with WH	28	277	13	4.96	2.5	208
Barley farmer practice	11.2	74	7.8	1.26	1.17	52
Barley with WH	29	109	17	1.31	1.16	63

Source: calculated from BCA results for different WH techniques.

8.2 Results of environmental impact of WH techniques

8.2.1 Organic matter indicator

Introduction

Soil organic matter (OM) consists of a variety of components. These include, in varying proportions and many intermediate stages, an active organic fraction including micro-organisms (10–40%), and resistant or stable OM (40–60%), also referred to as humus.

OM existing on the soil surface as raw plant residues helps to protect soil from the effect of rainfall, wind, and sun. Removal, incorporation, or burning of residues exposes the soil to negative climatic patterns and removal or burning deprives soil organisms of their primary energy source.

OM within the soil serves several functions. From a practical agricultural stand point, it is important for two main reasons: (i) as a 'revolving nutrient fund'; and (ii) as an agent to improve soil structure, maintain tilth, and minimize erosion.

As a revolving nutrient fund, OM serves two main functions:

As soil OM is derived mainly from plant residues, it contains all the essential plant nutrients. Therefore, accumulated OM is a storehouse of plant nutrients.

The stable organic fraction (humus) absorbs and holds nutrients in plant-available forms.

OM releases nutrients in a plant-available form upon decomposition. To maintain this nutrient-cycling system, the rate of OM addition from crop residues, manure, and any other sources must equal the rate of decomposition, and take into account the rate of uptake by plants and losses by leaching and erosion.

Where the rate of addition is less than the rate of decomposition, soil OM declines. Conversely, when addition is higher than decomposition, soil OM increases. The term 'steady state' describes a condition where the rate of addition equals the rate of decomposition.

Crop production worldwide has generally resulted in a decline in soil OM levels and, consequently, a decline in soil fertility. Converting rangelands and forestlands to arable agriculture results in the loss of about 30% of the organic carbon (C) originally present in soil profile. On reasonably fertile soils with a reliable water supply, yields on long-term arable agriculture systems have been maintained at very high levels by applying substantial amounts of fertilizer and other soil amendments. In low-input agriculture systems, yields generally decline rapidly as nutrient and soil OM declines. However, restoration is possible through the use of fallow lands, integrated crop–livestock and agroforestry systems, and crop rotations.

Traditional mold-board plow and disc-tillage cropping systems tend to cause rapid decomposition of soil OM, leaving soil susceptible to wind and water erosion, and creating plow pans below the cultivation depth. By contrast, reduced or zero-tillage systems leave more biological surface residue and provide environments for more soil aggregates, which better withstand raindrop impact. Water can infiltrate more readily and rapidly into the soil with reduced tillage and this helps protect soil from erosion. In addition, OM decomposes less rapidly under reduced tillage systems.

The relatively low levels of active OM fractions in zero-tillage systems have highlighted the extreme dependence of such systems on the maintenance of a high level of surface protection by crop residues. Residue accumulation, including cover crops and crop residues, increases the levels of some soil nutrients and soil organic C. The active fraction of OM plays a very important role in aggregate stability and rainfall infiltration. Building up active C levels in the soil in rainfed cropping systems may have a greater impact in reducing surface crusting and improving rainfall infiltration capacity than would simply changing to zero-tillage systems. Management practices designed to maximize C inputs and to maintain a high proportion of active C should be seen as essential steps toward more sustainable cropping systems (Bot and Benites, 2005).

To estimate the environmental impact of using microcatchment WH, OM content in soil must be estimated. Soil OM is an important indicator of environmental effects (through its role in environmental benefits of increased soil fertility) of the introduction of fodder shrub plantations and increased vegetation cover.

Procedure followed:
Numerous literature and work has been devoted in the Jordanian Badia to estimating soil OM, but none has estimated the OM in soil due to the implementation of WH techniques.

A detailed soil survey for Muwagar Station in Mharib was implemented in 1989 (Taimeh 1989), to determine the kind of soils in the area. OM was one of the soil features studied and reported. This survey is taken as baseline data.

Soil samples were taken during the 2006/07 season from the Muwagar Station to determine how much accumulation of OM was achieved by implementing WH techniques and planting *Atriplex* since the survey of 1989.
Fifteen soil samples were taken from two map-units from the station (the station was divided into 16 map-units in the survey of 1989). The station was planted with *Atriplex* and was protected (i.e. no grazing activity).

The distribution of samples and the OM analysis in the samples are shown in (Table 8.2). Six samples were taken within the contours planted with *Atriplex* and from the two map-units, two samples were

Table 8.2. Soil OM (percentage of soil samples) at Muwagar Station in April 2007. Soil depth: 1–15 cm.

Sample no.	Location	OM (%) 30 April 2007	Average OM (%)
1	Within the contour, map-unit 1 (planted with *Atriplex*)	1.34	
2	Within the contour, map-unit 1 (planted with *Atriplex*)	0.61	
3	*Within the contour, map-unit 1 (planted with Atriplex)*	1.47	1.14
4	Near the contour 2 M away, map-unit 1	1.73	
5	Near the contour 2 M away, map-unit 1	1.60	1.67
6	Uncultivated area within map-unit 1	0.96	
7	Uncultivated area within map-unit 1	0.51	
8	Uncultivated area within map-unit 1	1.09	1.04
9	Uncultivated area within map-unit 1	1.60	
10	Uncultivated area within map-unit 1	1.02	
11	Within the contour, map-unit 2 (planted with *Atriplex*)	1.86	
12	Within the contour, map-unit 2 (planted with *Atriplex*)	1.15	
13	Within the contour, map-unit 2 (planted with *Atriplex*)	1.41	1.47
14	Out of station (native vegetation)	0.32	0.26
15	Out of station (native vegetation)	0.19	

taken at a distance of 2 m from the contour, five samples were taken from the cultivated area within the station, and finally two samples were taken from outside the borders of the station and represented the natural vegetation.

The percentage of OM in soil varied according to place, management practices, and vegetation cover (Tables 8.2 and 8.3). On average, soil OM was estimated at 1.26% for contour ridges planted with *Atriplex* and natural vegetation, while it was estimated at 0.56% in the soil surveys conducted in 1989 in map-unit 1 and about 1.08% in map-unit 2. However, samples taken outside of the station (i.e. unprotected area) gave the least value of 0.25%, which implies that not using an appropriate management system caused deterioration of soil and substantially decreased the percentage of OM.

The OM accumulation over time (i.e. 18-y-period) was estimated in 2007 using the data of 1989.

The difference between the 2007 estimates and those of the baseline indicates the annual change of OM over the coming 20 years. The average annual increase of OM was estimated at 0.025% during 1989–2007 (Table 8.3).

OM was estimated at 1.54% in Mharib before implementing the project of WH techniques (2004/05 season). This value was used as a baseline to generate the accumulated organic percentage for the coming 20 years (Table 8.4).

The analysis of soil samples from Muwagar Station (Table 8.2), showed that OM content was high with of planting rangeland shrubs with WH and estimated at 1.305%, this decreased sharply to 0.26% in the uncultivated and unprotected areas. The WH techniques clearly increased soil OM and improved soil characteristics. The percentage of OM was converted to quantity of OM (t/ha) through a mathematical equation which takes into consideration soil profile volume of 15-cm depth and a soil bulk density of 1.32 t/m^3 in the study area. The procedure followed is described below:

Soil volume/ha = 10000 m^2 × 0.15 m
= 1500 m^3
Bulk density for soil profile = volume × soil bulk density (of silty clay loam)
= 1500 × 1.32 = 1980 t, the weight of soil profile at 15-cm depth (ICARDA, 1997)
OM (t/ha) = OM (%) × Weight of soil profile
Applying the equations above enabled the calculation of 26.1 t/ha for planting *Atriplex* with WH and 20 t/ha for the native vegetation within the Muwagar Station borders (Table 8.5). The difference between the two is due to the effect of applying WH techniques. However, the OM quantity for the uncultivated and un-

Table 8.3. Increase in OM during 1989–2007 at Muwagar Station.

Location	Average OM (%) in 2007	Difference from 1989 survey (OM%)	Change in OM (%)/y
Within contours (1)	1.14	0.58	0.032
Near the contour	1.67	1.11	0.062
Uncultivated area	*1.04*	0.48	0.027
Within contours (2)	1.47	0.39	0.022
Native vegetation outside station	0.26	–0.3	-0.017
Average	1.116	0.452	0.025

Source: calculated from the results of soil samples of Muwagar area.

Table 8.4. Predicted soil OM percentage in Mharib for the coming 20 years as a result of using microcatchment WH techniques.

Year	OM (%)	OM (t/ha)
2004	1.54	30.03
2005	1.565	30.52
2006	1.590	31.01
2007	1.615	31.49
2008	1.640	31.98
2009	1.666	32.49
2010	1.691	32.97
2011	1.716	33.46
2012	1.741	33.95
2013	1.766	34.44
2014	1.791	34.92
2015	1.816	35.41
2016	1.841	35.90
2017	1.866	36.39
2018	1.892	36.89
2019	1.917	37.38
2020	1.942	37.87
2021	1.967	38.36

Table 8.5. Calculated OM percentage and quantity (t/ha).

Location	OM (%)	OM quantity (t/ha)
Planting *Atriplex* on contour ridges with WH techniques (inside the station)	1.305	26.1
Uncultivated area (native vegetation) inside the station	1.04	20
Uncultivated area (native vegetation) outside the station and unprotected from grazing	0.260	5.2

planted area with range shrubs was only 5.2 t/ha.

Adamant et al. (2007) predicted changes of soil organic carbon (SOC) stocks between 2000 and 2030 at the national scale for Jordan using the Global Environment Facility Soil Organic Carbon (GEFSOC) Modelling System. These estimates of SOC stocks and changes under different land-use systems can help determine vulnerability to land degradation. Such information is important for countries in arid areas with high susceptibility to desertification.

(Adamant et al. 2007) concluded that based on the land use management scenarios suggested in the research project and the century output of the GEFSOC Modelling System, a decrease in the C stocks in the Badia was expected in 2030 compared with 1990. Also, in the northern plands, the C stocks in 2015 would be higher compared to 2000, but lower by 2030, due to a projected increase in urbanization. Only the Jordan Valley was predicted to have more C stocks in 2015 and 2030 because of an increase in citrus and banana trees at the expense of vegetables. In general, there was a linear relationship between rainfall and SOC in Jordan. The Jordan Valley is an exception due to its complexity and the use of irrigation water.

8.2.2 Soil erosion indicator

Based on rainfall data of the last thirty years (1973–2006), the amount of soil erosion was predicted as the result of the use of different techniques of WH and agricultural practices. The simulation model (Badia Model) used to predict the level of soil erosion showed that soil erosion was highest in the case of planting barley without WH and estimated a cumulative quantity of 53 t/ha by the year 2021. This is because farmers annually cultivate land that is prone to degradation and erosion, in addition to exposing it to soil drift by wind during the remaining months of the year.

The expected cumulative soil erosion level for different techniques was lowest for shrub plantations with WH and planting barley with WH, reaching 85 t/ha (Table 8.6). These techniques reduce soil erosion, emphasizing the importance of using WH techniques for cultivation of barley and shrubs. The role of WH techniques was shown to be important in reducing desertification in the targeted areas, through reducing soil erosion, and thus increasing productivity, and maintaining the sustainability of natural resources that are the most important resource for livelihoods in the Jordanian *Badia*.

Table 8.6. Expected cumulative soil erosion for different WH techniques during 2007–2021 (t/ha).

Year	Soil erosion (t/ha)			
	Barley farmers' practice	**Barley with WH**	**Shrubs with WH**	**Traditional pits**
43.20	41.28	41.28	41.76	2007
43.39	41.49	41.49	41.94	2008
43.48	41.58	41.58	42.02	2009
45.36	43.41	43.41	43.83	2010
45.96	43.99	43.99	44.38	2011
46.41	44.44	44.44	44.81	2012
46.54	44.57	44.57	44.92	2013
46.59	44.63	44.63	44.97	2014
46.66	44.68	44.68	45.02	2015
46.82	44.87	44.87	45.17	2016
46.82	44.87	44.87	45.17	2016
47.41	45.48	45.48	45.74	2018
49.92	47.85	47.85	48.15	2019
50.35	48.32	48.32	48.56	2020
53.03	50.85	50.85	51.13	2021

Source: calculated from Badia Model.

8.2.3 Water use efficiency

To indicate the efficient use of rainwater by WH techniques implemented during the rainy seasons, the annual rainfall over 30 years for the period 1973–2006 was divided into three groups representing seasonal conditions (Table 8.7).

The seasonal conditions were defined as described below. If annual rainfall was greater than 'Average rainfall (over 30 years) + 1 standard deviation', then the season was considered a good season. For the period considered, the average annual rainfall was 253.87 mm. When annual rainfall was less than the 'Average rainfall (in the past 30 years) + 1 standard deviation', the season was considered a dry season. In this case, the average rainfall was 99.3 mm. The rest of the values were considered as normal rainfall (average 154.59 mm in this case).

The WUE of WH techniques differed during drought, normal, and good years (Table 8.8). The WUE was higher using WH techniques when planting shrubs, especially in drought years. This demonstrates the ability of these techniques to allow adaptation of shrubs to drought and increase the level of production. Their application is therefore important in terms of optimizing the use of the limited amount of rainwater and to provide a minimum quantity of fodder in drought seasons.

The improvement of WUE and the increased productivity are the most important goals of agricultural policy in Jordan due to water scarcity in the country. The estimated per capita share of water is only about 160 m^3/y, the lowest share of individuals in the region. Since Jordan relies heavily on rain for agriculture and raising livestock, any improvement in efficiency of rainwater use (i.e. through the application of WH techniques) is an important indicator of improved livelihoods, particularly for the poor due to their limited opportunities.

8.3 Environmental benefits of different WH techniques

8.3.1 On-site cost of soil erosion

According to the opportunity cost approach (Barbier, 1996) the on-site cost of soil erosion is the loss in long-term profitabil-

Table 8.7. Seasonal conditions and average long term annual rainfall (mm) for 1973–2006.

Season condition	Average rainfall (mm)
Drought season	99.3
Good season	253.9
Normal season	154.6

Source: calculated from Badia Model.

Table 8.8. Expected WUE of rainfall during drought, normal, and good seasons.

Season condition	WUE (kg/m^3)			
	Drought year	Good year	Normal year	Average
Barley farmers' practice	0.2663	0.2775	0.2692	0.2710
Barley with WH	0.2594	0.27	0.2625	0.2640
Shrubs with WH	0.2694	0.2825	0.2717	0.2745
Traditional pits	0.2563	0.2650	0.2592	0.2602

Source: calculated from Badia Model.

ity of the farming system from not investing in an economically worthwhile alternative farming system. The on-site cost of soil erosion is, therefore, the difference between the present values of the net financial returns of alternative land use systems with different extents of erosion. The steps to estimate the on-site cost associated with a unit of soil loss include: (1) quantifying the soil loss due to erosion; (2) calculating the financial NPV of alternative land use systems; and (3) comparing the NPV and soil loss across alternative land-use systems, and deriving the cost per unit of soil loss based on the opportunity cost (Dung, 2001).

The following discussion focuses on the NPV calculation for different WH techniques and the derivation of the opportunity cost per ton of soil lost due to erosion.

Financial profitability of different WH techniques of the land use systems

A. Choice of discount rate and time horizon
The NPV calculation requires the determination of an appropriate discount rate.

The real rate of discount is a much-debated issue (Enters, 1998). The selected discount rate obviously influences the results of the CBA. In this study, a discount rate of 10% was chosen for the NPV calculation.

This is the estimated opportunity cost of capital in the study area. In addition, the NPVs of the land use systems were also calculated at discount rates of 12, 25, 20, and 25% to examine the sensitivity of findings to the choice of discount rate. The life of a WH technique is estimated at 15 years (as assessed by professionals) to ensure their sustainability and continuity.

8.3.2 NPVs of the different land-use systems and WH techniques

The NPVs of the different land use systems and WH techniques were all positive, even at a discount rate of 20% (Table 8.9). The shrubs with WH system showed higher profitability than other systems, followed by the traditional pits. Financial profitability is one of the most important criteria in a farmer's land-use choice. Since the time horizon may differ between farmers, it is valuable to look at the cumulative NPVs of the different land-use systems and WH techniques over time (Figure 8.1).

8.3.3 Estimated cost of soil erosion

The on-site cost of soil erosion is the loss in the long-term profitability of a farming system from not investing in an economically worthwhile alternative system, i.e. it is the forgone present values of the net financial returns of (rejected) alternative land use systems with different extents of erosion (Dung, 2001). A farmer may, however, want to find out the yearly income loss equivalent to the forgone NPV. Therefore, it is relevant to measure on-site cost of soil erosion using the value of annualized income (Table 8.10). The cost of soil erosion for planting traditional pits compared with

Table 8.9. Financial NPV for different land-use systems and WH techniques.

Techniques	Financial NPV (JD/ha)				
	Discount rate 10%	Discount rate 12%	Discount rate 15%	Discount rate 20%	Discount rate 25%
Shrubs with WH	277	246	189	121	76
Traditional Pits	162	132	97	55	28
Barley with WH	109	96	76	52	34
Barley farmers' practice	74	57	36	11	–6

Source: results of BCA of different WH techniques.

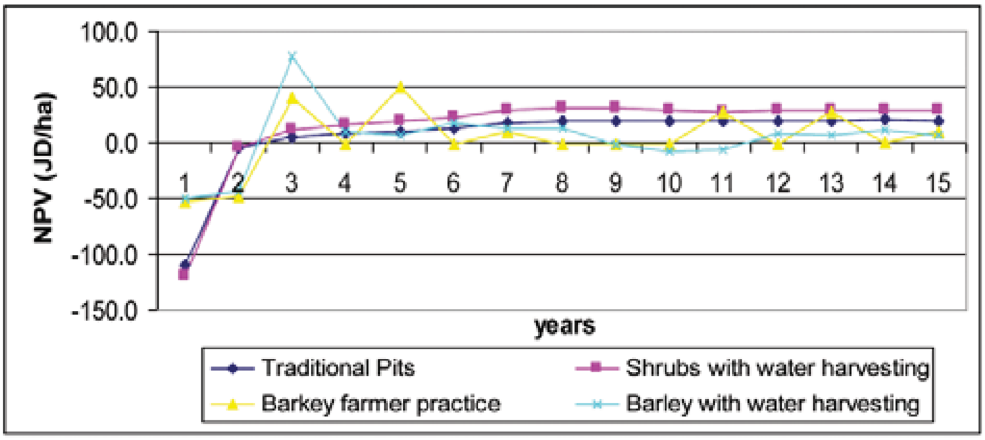

Figure 8.1. Cumulative NPV of different land-use systems and WH techniques (JD/ha).

Table 8.10: Soil erosion and the annualized income of the different WH techniques and land uses.*

Techniques	Soil loss (t/ha/y)	Annualized income (JD/ha/y) Financial	Annualized income (JD/ha/y) Economic
Shrubs with WH	50.9	18.5	13.9
Traditional pits	51.1	10.8	6.5
Barley with WH	50.9	7.3	4.2
Barley farmers' practice	53.0	4.9	3.5

Note: * discount rate 10% and age of techniques 15 years. Source: results of BCA of different WH techniques.

planting shrubs with mechanized WH was 7.67 JD/ha/y. The cost of soil erosion for barley cultivation with WH techniques and traditional barley cultivation were 11.2 and 13.54 JD/ha/y, respectively (Table 8.10). Total cost of soil erosion was around 115.05 JD/ha for planting shrubs the traditional way. The approximate cost for barley cultivation with WH was 168 JD/ha, and approximately 203.1 JD/ha for barley cultivation using farmers' practice.

8.4 Potential adoption of different WH techniques

8.4.1 The number of farmers who adopted WH techniques for cultivated areas through the project

The project worked with 36 farmers from the Mharib community to implement project activities. The total number of households in the community is 55, including two farmers who implemented the WH techniques in their fields of an area of 0.35 ha without the help of the project. (Table 8.11) shows areas depending on the type of implementing WH techniques. The total area of the implemented techniques was about 218.1 ha and the total potential area for plantations in the whole watershed was 3000 ha.

The adoption rate of planting barley and range shrubs with WH techniques was estimated from project data available on the implemented areas and was predicted for the period 2006–2017 using regression analysis (logistic pattern). The adoption rate (adoption ceiling) of plant shrubs with the WH was estimated at 10% to be reached by 2013; the expected adoption rate of planting barley with WH was less and estimated at 5% by 2013 (Figure 8.2).

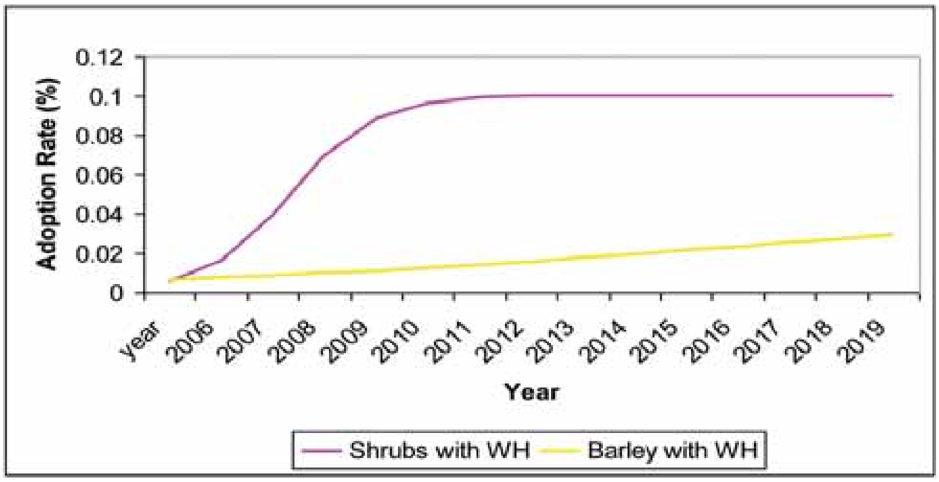

Figure 8.2. Adoption rate (%) for planting shrubs and barley with WH techniques.

Table 8.11: Areas (ha) with various WH techniques implemented during project work.

Year	Area (ha)		Total area (ha)
	Planting barley with WH	Planting shrubs with WH (mechanized)	
2005/06	86.7	36.6	246.6
2006/07	4.8	90	189.6
Total	91.5	126.6	436.2

Source: BBM, 2007.

These estimated adoption rates are considered reasonable in the light of environmental and climatic constraints and financial investment opportunities in the Jordanian Badia.

8.5 Conclusions

The economic analysis showed that the EIRR of planting barley with WH gave the highest value to 17%, compared to other types of WH techniques; and EIRR was estimated at 7.8% for planting barley the traditional way. The plantation of shrubs with WH was more feasible than planting shrubs in the traditional way, with EIRR estimated at 13 and 7.4%, respectively.
In the case of planting shrubs using WH techniques, the contribution of environmental benefits in the calculations of return on investment for WH techniques increased FIRR to 36% and EIRR to 17%, compared to 13 and 17%, respectively, calculated from economic benefits only. The valuation and assessment of environmental benefits associated with implementing WH techniques is very important to justify public investment for these techniques in dry areas of Jordan. Environmental benefits were not previously taken into account when implementing this type of agricultural project, and the direct economic benefits for the project based on individual economic analysis did not justify the investment in such projects in the arid areas of Jordan.

8.6 References

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Annex 1

Annex 1.1 Watershed sites and their soil physical and chemical characteristics.

Loc.	slope (CLASS)	slope %	surface crust (CLASS)	soil depth (CLASS)	soil depth (cm)	stone cover (CLASS)	Gravel %	Stone %	Boulders %
MH1CRS	C	7	2	m	47+	0	10	5	1
MH3CRSa	C	7	1	d	60+	0	10	2	0
MH3CRSb	D	9	2	m	50	0	15	10	2
MH3CRSc	E	14	2	sm	45	s1	20	15	5
MH4CRSa	D	12	2	sm	45	s2	20	10	2
MH4CRSb	C	3	2	m	80+	s1	5	2	0
MH6CRSa	C	6	2	m	60+	g1	15	10	0
MH6CRSb	B	5	2	d	40+	0	15	10	0
MH7CRS	D	10	3	m	42+	0	15	5	2
MH8CRS	E	10	3	m	50+	0	15	15	5
MH9CRS	C	14	2	m	60+	0	15	10	2
MH10CRS	B	9	2	m	65+	0	5	5	0
MH12VSa	C	7	2	m	45	0	15	5	2
MH12VSb	A	3	2	d	60+	0	5	10	0
MH13VS	D	12	2	m	40+	0	25	10	5
MH14VS	D	6	2	m	35+	0	15	20	0
MH17VSa	E	11	2	m	50	0	40	5	0
MH17VSb	D	14	3	m	60+	s1	25	15	10
MH17VSc	B	5	3	d	55	0	35	10	0
MH17VSd	C	7	2	d	50	0	25	5	2
MH18CRS	B	9	1	d	45	0	15	5	2
MH19VSa	A	5	1	d	50	0	5	10	0
MH19VSb	C	8	1	m	45	0	15	20	0
MH20CRS	D	11	2	m	55+	0	15	10	0
MH21CRSa	B	5	2	d	60+	0	5	10	0
MH21CRSb	B	6	2	m	50	g1	30	5	0
MH22VSa	C	5	2	m	50	g1	5	30	5
MH22VSb	C	3	2	d	60+	0	5	10	0

Annex 1.1 (Continued).

rock outcrop %	bulk density(gm/cm³)	pH	EC (ds/m)	O.M %	P (ppm)	K (ppm)	$CaCo_3$ %	Soil Texture class
0-10	1.35	8.1	0.92	0.33	13.2	412.87	18.6	SC
0-10	1.38	7.8	0.95	0.66	20	702.98	19.3	SCL
0-10	1.38	7.8	0.95	0.66	20	702.98	19.3	SCL
0-10	1.38	8	0.76	3.28	42.4	967.87	13	SCL
0-10	1.28	8	0.76	3.28	42.4	967.87	13	SCL
0-10	1.31	7.9	1.05	1.51	23.4	740.82	18.6	SCL
0-10	1.26	7.8	2.72	1.64	20.4	614.69	13	SCL
0-10	1.26	7.8	2.72	1.64	20.4	614.69	13	SCL
0-10	1.34	7.7	2.43	0.33	23	652.53	13	SCL
0-10	1.1	8	1.4	1.44	20.6	539.01	14.9	SCL
0-10	1.44	7.9	0.72	1.97	26	652.53	14.9	SCL
0-10	1.23	7.8	9.3	3.34	27	715.6	16.7	SCL
0-10	1.35	7.8	16.69	1.83	26.4	1018.32	14.9	SL
0-10	1.35	7.8	16.69	1.83	26.4	1018.32	14.9	SL
0-10	1.25	8	0.74	0.98	15.2	551.62	17.8	SL
0-10	1.25	8	0.74	0.98	15.2	551.62	17.8	SL
0-10	1.33	8	1.36	2.82	41	614.69	18.6	SCL
0-10	1.23	8	1.36	2.82	41	614.69	18.6	SL
0-10	1.38	8	0.86	2.29	68.8	829.12	19.3	SCL
0-10	1.38	7.7	32.6	1.31	22.4	665.14	19.3	SCL
0-10	1.26	8.1	0.59	1.31	13.8	526.39	20.4	SCL
0-10	1.26	8.1	0.59	1.31	13.8	526.39	20.4	SCL
0-10	1.31	8.1	0.59	1.31	13.8	526.39	20.4	SCL
0-10	1.33	8	0.66	0.33	25	753.44	14.9	SCL
0-10	1.31	8	0.66	0.33	25	753.44	14.9	SCL
0-10	1.31	8	0.66	0.33	25	753.44	14.9	SCL
0-10	1.3	8	0.66	0.33	25	753.44	14.9	SCL
0-10	1.38	7.9	0.83	0.33	21.4	766.05	14.9	SCL

Notes: Slope class: a= almost flat 0-5%; b= Gentle sloping 5-10%; c= Sloping 10-15%; d= moderate sloping 15-25%; e= steep sloping 25-35%; f= very steep sloping > 35%; u= undulating slope 2-10%
Depth: d= deep soil > 1 meter; m= medium soil depth 50-100cm; sm= shallow to medium soil depth 30-100cm; 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. Boulders: (% of surface cover)
Rockinesss: 0= 0-10%; 1= 10-25%; 2= 25-50%; 3= > 50%. Stoniness: 0= 0-10%; 1= 10-25%; 2= 25-50%; 3 = >50%

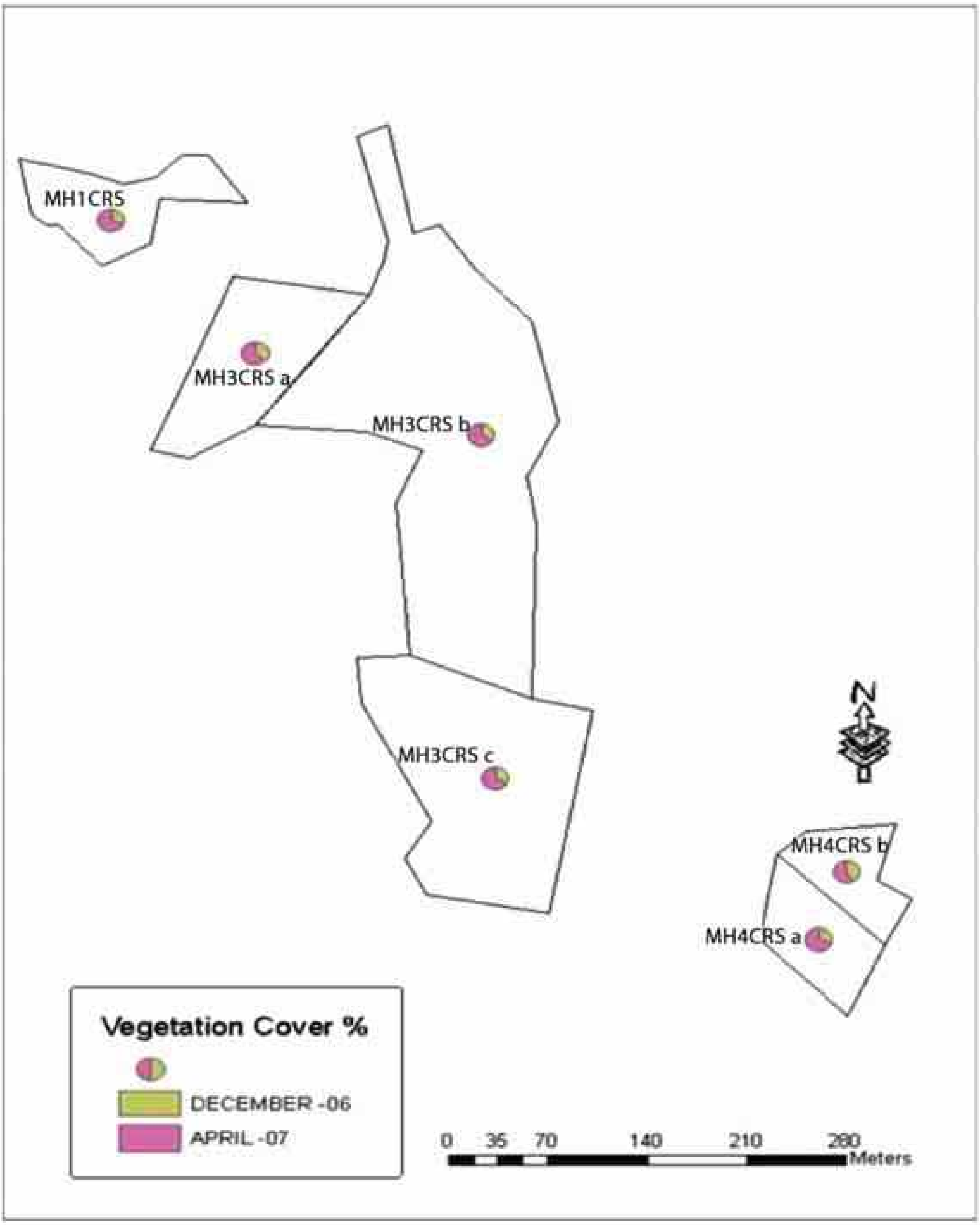
Annex 1.2 ICARDA Passport Data for the Studied Sub-Watersheds.

DATE---Dec., 2006 --------	COLL. ORG ---- NCARE ------------------ COLLECORS ------------------		
COUNTRY ----- Jordan ----------------	PROVINCE ----- Amman ----------------- Nisreen al-Shawahneh		
VILLAGE, LOCATION----------Mharib--			
SITE NUMBER MH1CRS	LONGITUDE :E/W -------------------	LATITUDE: N/S --------------------	
ALTITUDE ----------- --------	RAINFALL -------------------------		
SITE HABITAT	AC = AGRICULTURAL CROP	PARENT	BA = BASALT
	TP = THRESHING PLACE	ROCK	AL = ALLUVIAL
	FS = FARM STORE		LI = LIMESTONE
	BY = BACK YARD		SA = SANDSTONE
	LM = LOCAL MARKET		OTHERS = ----------------
	CM = COMMERCIAL MARKET		
	IN = INSTITUTION		
	SP = SOWN PASTURE	TEXTURE	ST = STONES, ROCKY
	FA = FALLOW		GR = GRAVEL
	GR = GRASSLAND		SA = SAND
	FO = FOREST		SL = SANDY LOAM
	WL = WOODLAND OR MARGINAL FOREST		LO = LOAM
	RS = ROAD SIDE		CL = CLAY LOAM
	PE = PROTECTED OR ENCLOSED		CY = CLAY
	DI = DISTRIBUTED		SI = SILT
	OTHERS = --- rangeland-----------------		HO = HIGHLY ORGANIC
	1 =1 SPOT < $1M^2$		CA = CALCAREOUS

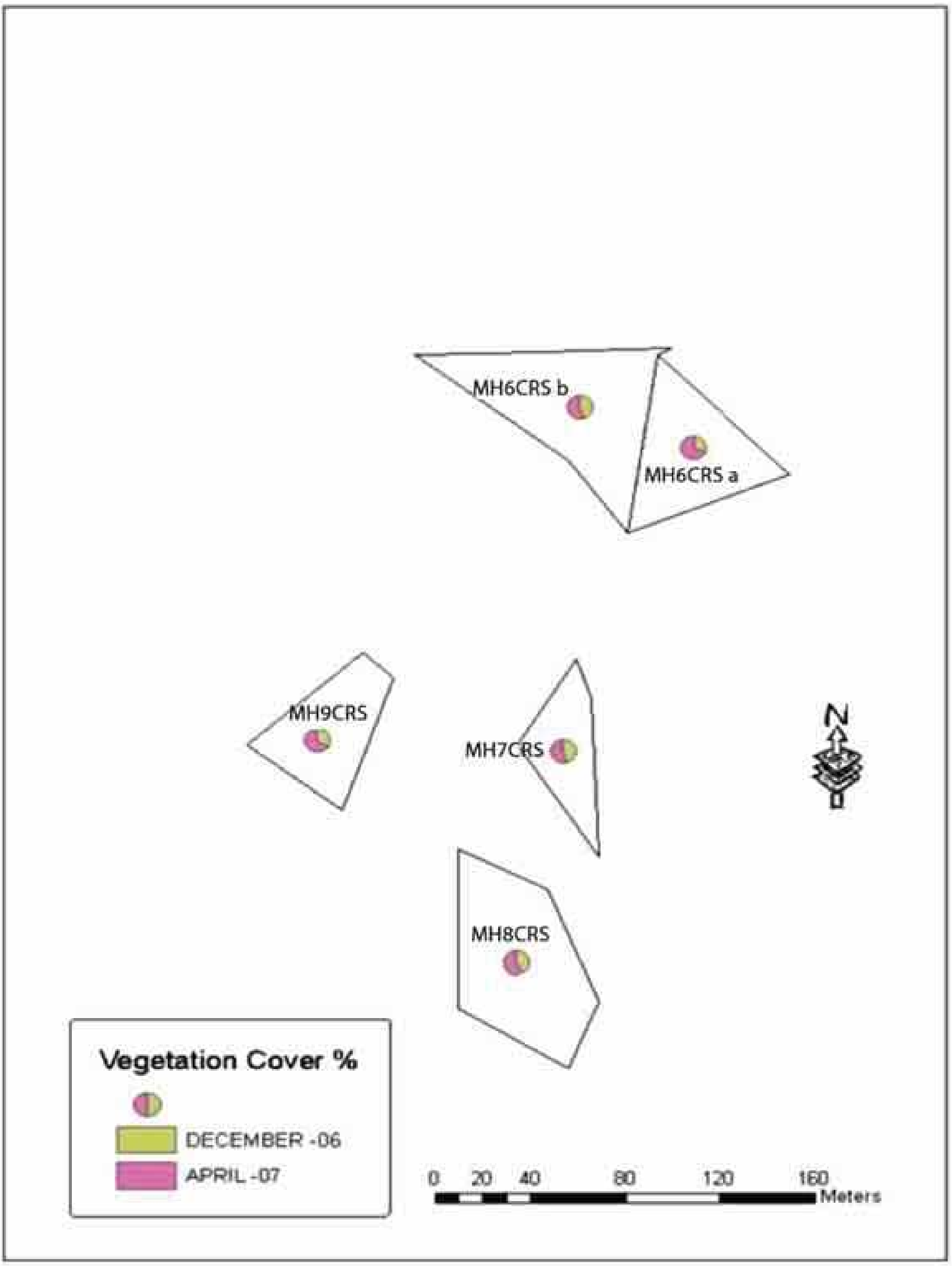
Annex 1.2 (Continued).

SIZE OF AREA			OTHERS ---- silty clay -----
	2 =1-10 M^2	ASPECT	F =FLAT
	3 =10-100 M^2		N = NORTH
	4 = 100 M^2 - 0.1HA		E = EAST
	5 =0.1-1 HA		S = SOUTH
	6 = >1 H		W = WEST
SLOPE 7%	1 = SWAMP & FLOOD PLAIN	SALINITY	1 = NONE
	2 = LEVEL (0-3%)		2 = LOW
	3 = UNDULATING (3-8%)	EC =	3 = MEDIUM
	4 = GENTLY ROLLING (8-18%)	).92ds/m	4 = HIGH
	5 = SLOPING (16-30%)		5 = PRESENT
	6 = STEEP (>30%)		
	7 = STEEPLY DISSECTED		
	8 = MOUNTAINOUS		
BCL - REACTION	1 = NONE	WATER RELATION	FD = FREELY-DRAINED
	2 = SLIGHT		FR = FREELY-NOT DRAINED
	3 = STRONG		WT = WATERTABLE
			SW =SWAMP
PH	1 = VERY LOW (4.0)	DEPTH	--- 47+ --- CM
	2 = LOW (4.0-5.5)		
	3 = MEDIUM (5.5-7.5)		
	4 = HIGH (7.5-9.0)		
	5 = VERY HIGH (>9.0)		
DOMINANT SPECIES: Anabasis syriaca, Bromus madritensis sub sp. delile, Hammada egii, Poa bulbosa, Torularia			CHARACTERISTIC SPECIES: Anabasis syriaca Poa bulbosa
Transect: 1B Poa bulbosa, Torularia 1 W Allium orientale, Anabasis syriaca, Bromus madritensis sub sp. delilei, Hammada egii, Poa bulbosa, Torularia			

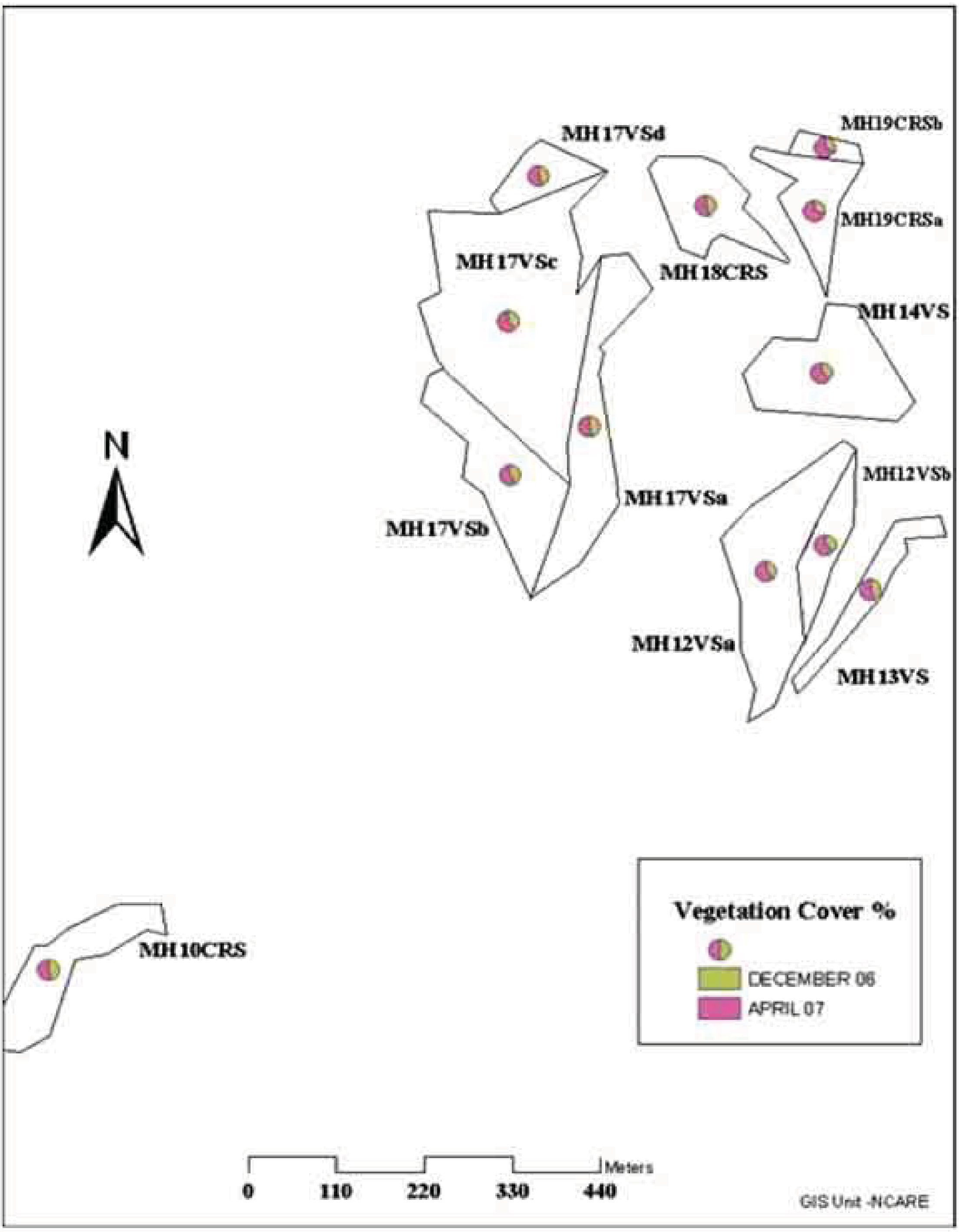
Annex 1.3 Vegetation cover percentages for microcatchment watersheds in the Mharib area during the survey on December 2006 and April 2007 for sites MH1CRS, MH3CRSa, MH3CRSb, MH3CRSc, MH4CRSa, and MH4CRSb.



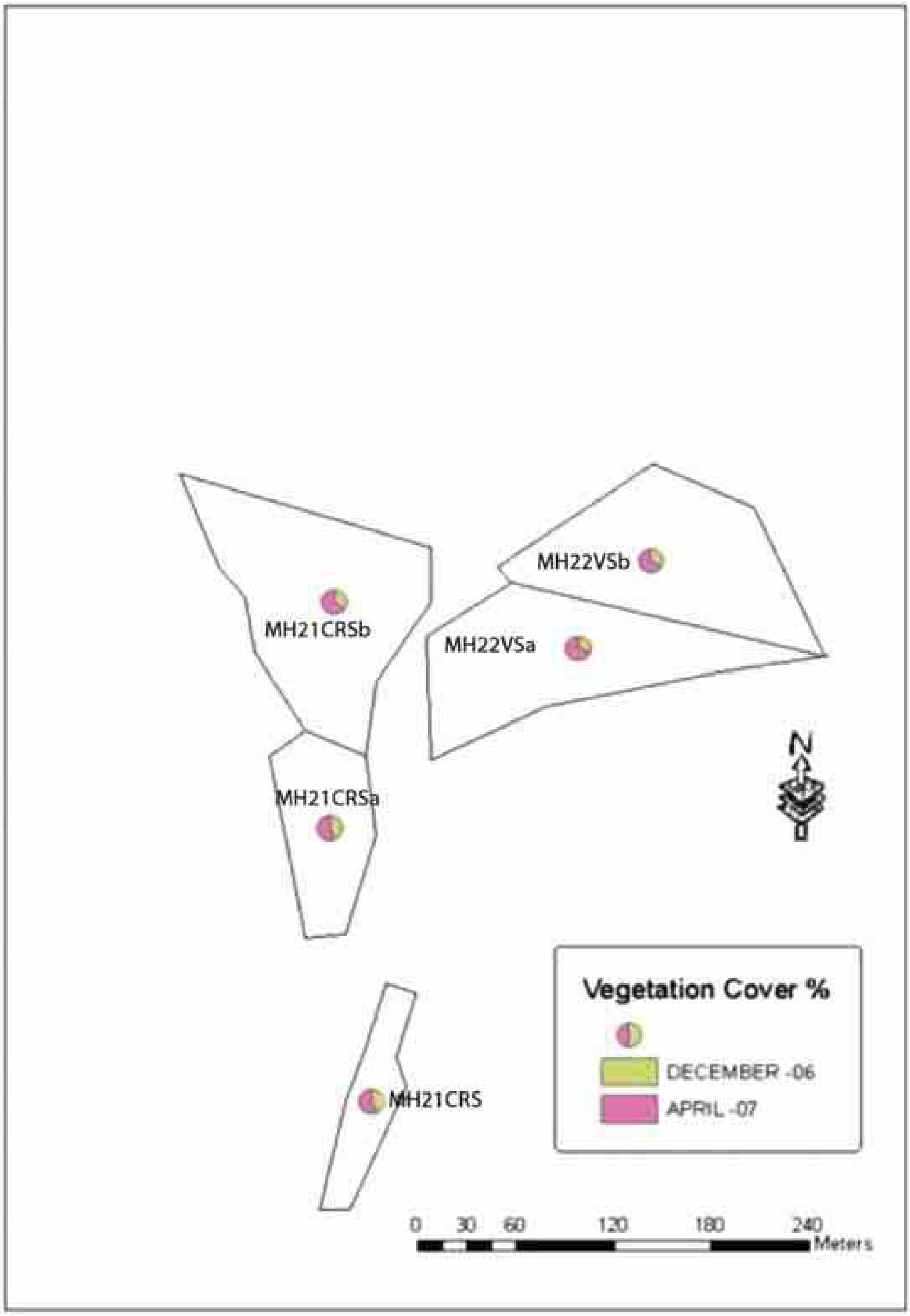
Annex 1.4 Vegetation cover percentages for microcatchment watersheds in the Mharib area during the survey on December 2006 and April 2007 for sites MH6CRSa, MH6CRSb, MH7CRS, MH8CRS, and MH9CRS.



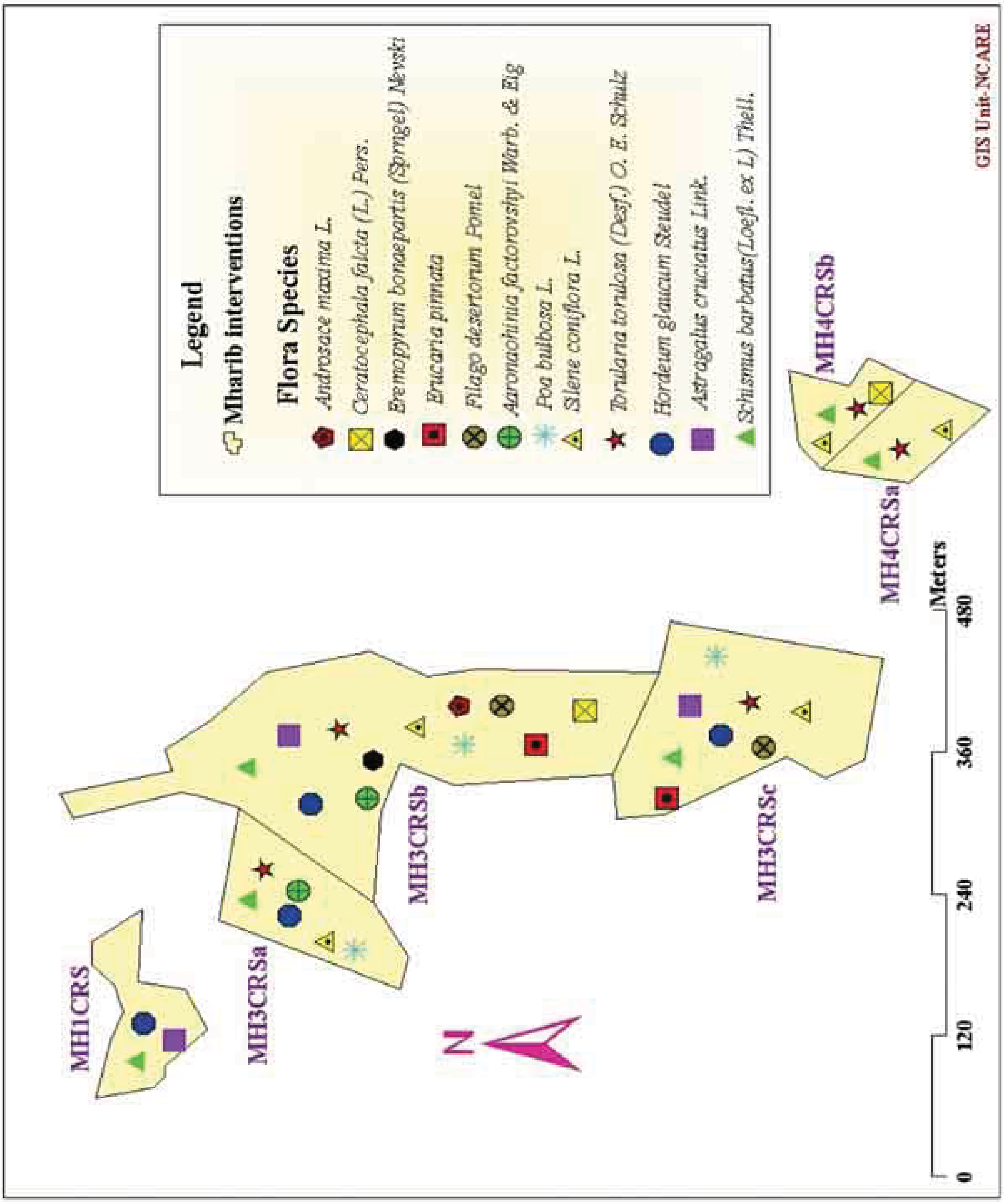
Annex 1.5 Vegetation cover percentages for microcatchment watersheds in the Mharib area as in the survey during December 2006 and April 2007 for sites MH10CRS, MH12VSa, MH12VSb, MH13VS, MH14VS, MH17VSa, MH17VSb, MH17VSc, MH17VSd, MH18CRS, MH19CRSa, and MH19CRSb.



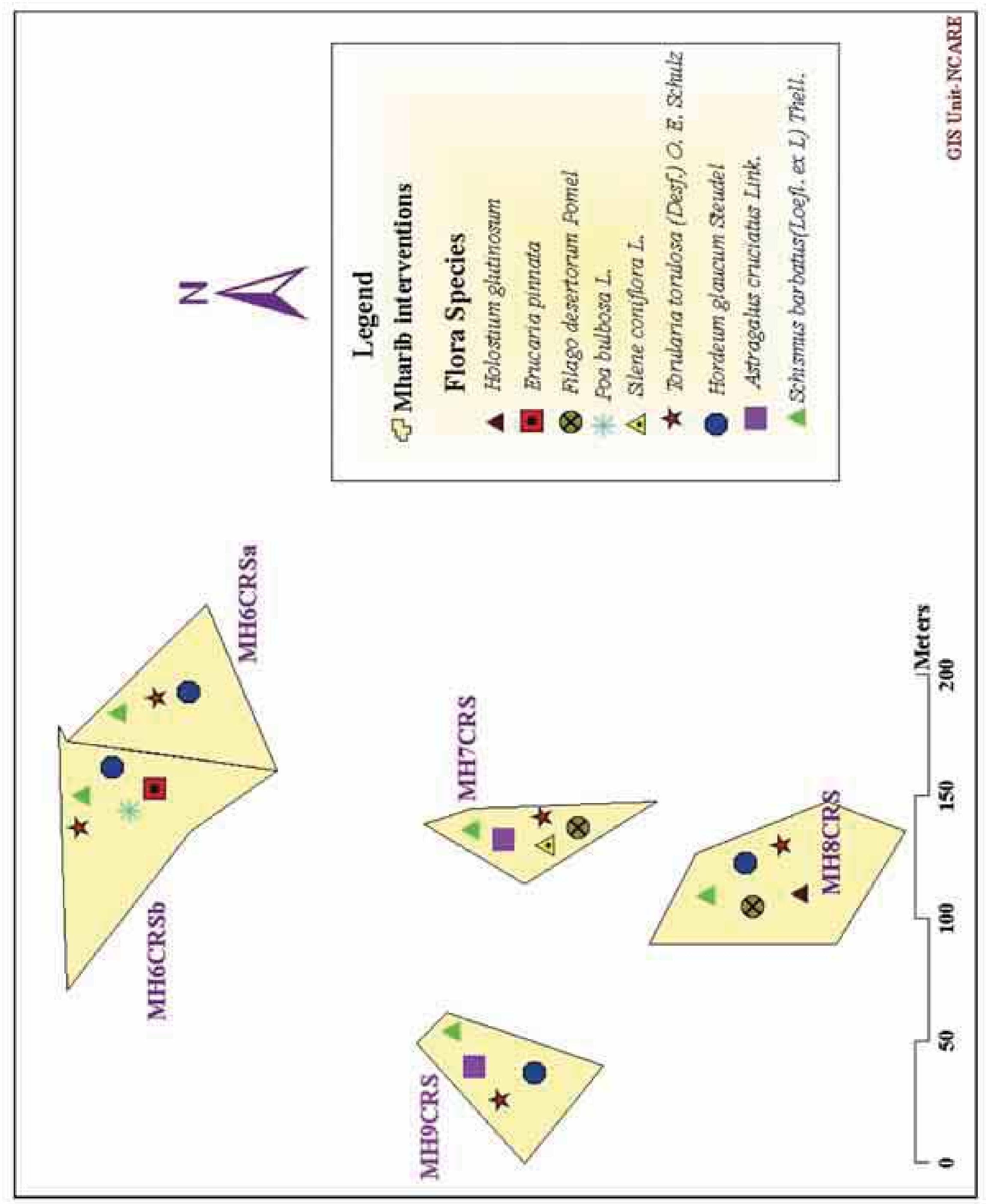
Annex 1.6 Vegetation cover percentages for microcatchment watersheds in the Mharib area as in the survey during December 2006 and April 2007 for sites MH20CRS, MH21CRSa, MH21CRSb, MH22VSa, and MH22VSb.



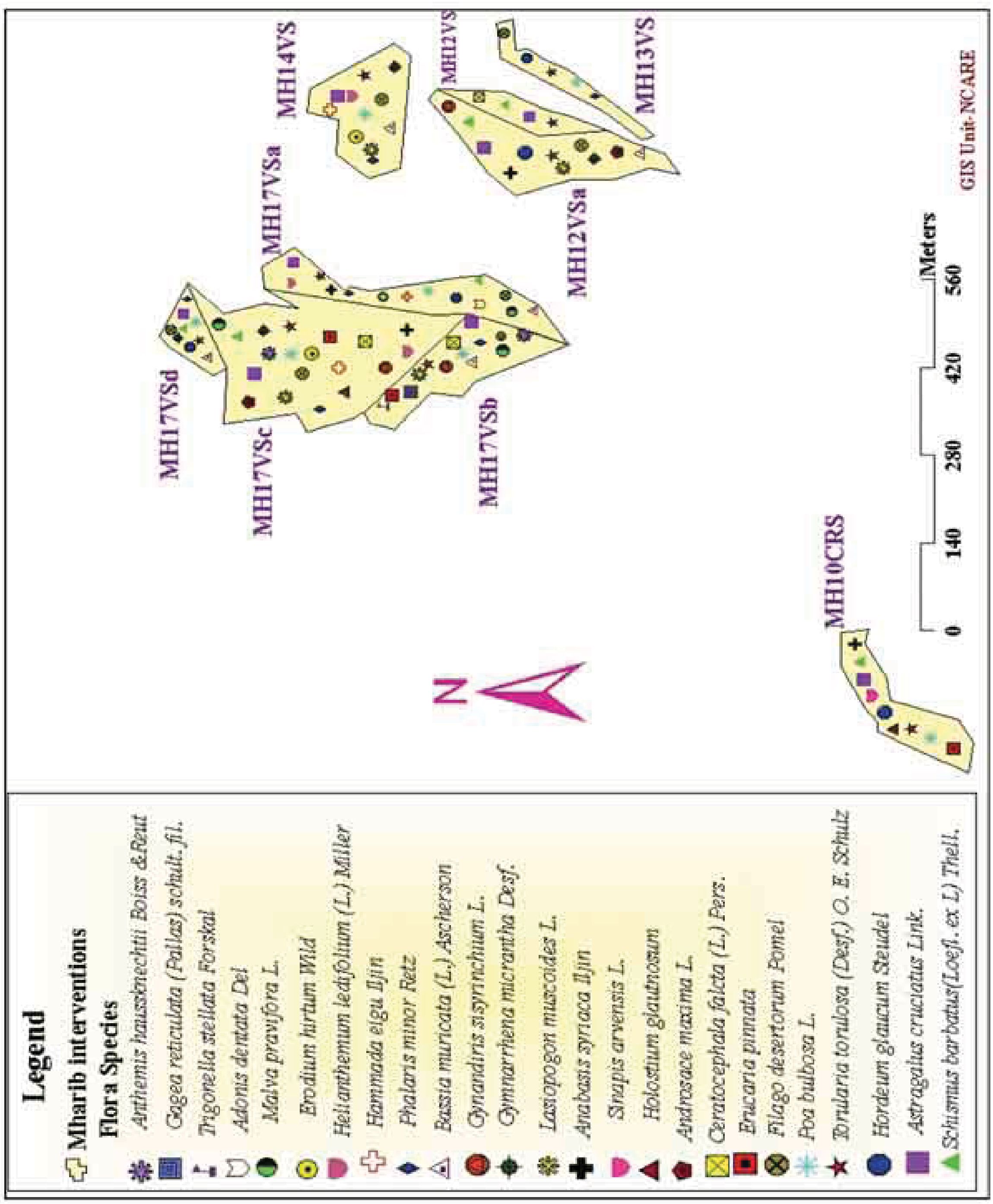
Annex 1.7 Flora map for microcatchment watersheds in the Mharib area as in the survey during December 2006 and April 2007 for sites MH1CRS, MH3CRSa, MH3CRSb, MH3CRSc, MH4CRSa, and MH4CRSb.



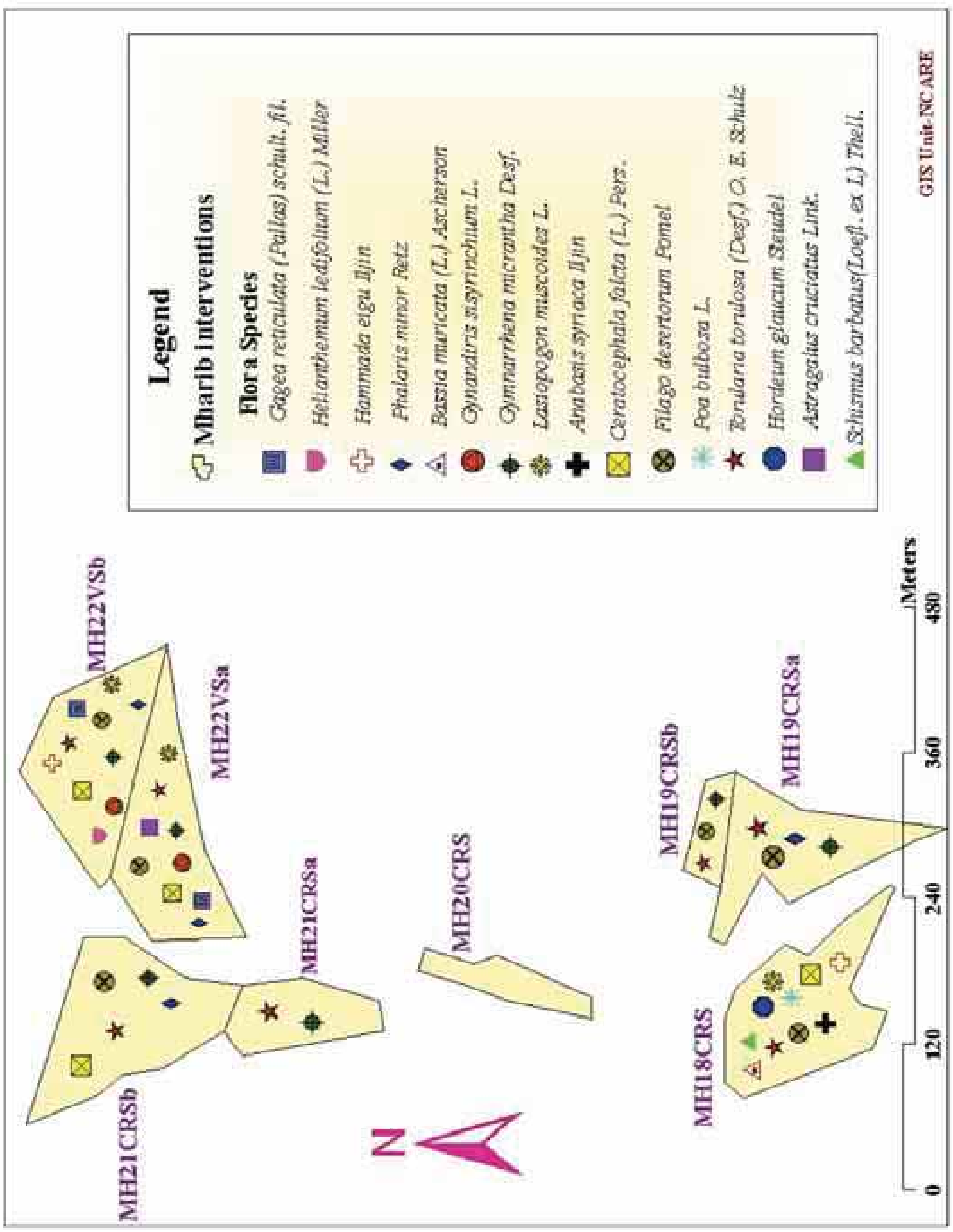
Annex 1.8 Flora map for microcatchment watersheds in the Mharib area as in the survey during December 2006 and April 2007 for sites MH6CRSa, MH6CRSb, MH7CRS, MH8CRS, and MH9CRS.



Annex 1.9 Flora map for microcatchment watersheds in the Mharib area as in the survey during December 2006 and April 2007 for sites MH10CRS, MH12VSa, MH12VSb, MH13VS, MH14VS, MH17VSa, MH17VSb, MH17VSc, MH17VSd, MH18CRS, MH19CRSa, and MH19CRSb.



Annex 1.10 Flora map for microcatchment watersheds in the Mharib area as in the survey during December 2006 and April 2007 for sites MH20CRS, MH21CRSa, MH21CRSb, MH22VSa, and MH22VSb.



Annex 1.11 The effect of slope, intervention treatments (trt), sampling dates, and their interaction on seed number extracted from soil.

Type 3 Analysis of Variance		
Source	**DF**	**Mean Square seed number (no/m^3)**
slope	1	7040105*
trt	8	470913652***
slope×trt	8	19642555**
rep(slope×trt)	36	8374390**
date	1	32155858**
slope×date	1	2408399*
trt×date	8	14850505***
slope×trt×date	8	11756391**
Residual	1548	5053090

Notes: *$P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Annex 1.12 Effect of slope, intervention treatments (trt), sampling dates, and their interaction on mean plant numbers (plant/m^2).

Type 3 Analysis of Variance		
Source	**DF**	**Mean Square seed number (no/m^3)**
slope	1	31973**
trt	7	330744***
slope×trt	7	11782*
rep(slope×trt)	32	9202***
date	2	166111***
slope×date	2	5678*
trt×date	14	27368***
slope×trt×date	14	4998**
Residual	640	3273

Notes: *$P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Annex 1.13 The effect of slope, intervention treatments (trt), sampling dates, and their interaction on mean plant height (cm).

Type 3 Analysis of Variance		
Source	**DF**	**Mean Square seed number (no/m^3)**
slope	1	590**
trt	7	578**
slope×trt	7	63
rep(slope×trt)	32	119***
date	2	1046***
slope×date	2	23 *
trt×date	14	89***
slope×trt×date	14	38**
Residual	640	17

Notes: *P < 0.05, ** P < 0.01, *** P < 0.001

Annex 1.14 Species richness and species evenness for the experiment site on December 2006.

Species	Species Richness (SR)	Species Evenness	Species	Species Richness (SR)	Species Evenness
Allium desertorum Forssk	16	0.592593	Hammada eigü Iljin	136	0.057749
Anabasis syriaca Iljin	87	0.583893	Helianthemum ledifolium (L.) Miller	66	0.20625
Androsace maxima	87	0.386667	Herniaria hirsuta L.	125	0.082237
Anthemis haussknechtii Boiss. & Reut.	6	0.75	Hirschfeldia incana (L.) Lagrèze-Fossat	2	0.4
Astragalus cruciatus	11	0.611111	Hordeum glaucum Steudel	46	0.373984
Astragalus gutatus	8	0.421053	Lasiopogon muscoides L.	70	0.082938
Atriplex halimus L.	15	0.384615	Lappula spinocarpos	3	0.75
Bassia muricata (L.) Ascherson	17	0.708333	Leopoldia comosa	4	0.5
Biarum anguotifol	2	1	Malva sylvestris	1	0.333333
Bromus madritensis sub sp. delilei	5	0.333333	Poa bulbosa	172	0.063259
Capcella bursa pastoris	5	1	Rhagadiolus stellatus (L.) Gaertner	8	0.888889
Cardaria draba	3	1	Roemeria hubrida	14	0.333333
Catapodium rigidum (L.) C.E. Hubbard ex Dony	3	0.2	Rostraria berythea	7	0.538462
Ceratocephala falcata	143	0.128366	Scismus barbatus	73	0.089681
Colchicum tunicatum	21	0.636364	Scorzonera schweinfurthii (Boiss) Thiébaut	7	0.875
Dipoltaxis erucoides (L.) DC.	2	0.4	Silene conoides L.	7	1
Erodium hirtum Willd	90	0.604027	Sinapis arvensis L.	7	0.538462
Eruca sativa Miller	36	0.62069	Sisymbrium irio L.	3	0.5
Eruca sativa	3	1	Torularia torulosa (Desf.) O. E. Schulz	224	0.089708
Eremopyrum bonaepartis (Sprengel) Nevski	3	0.333333	Trigonella	3	1

Annex 1.14 (Continued).

Species	Species Richness (SR)	Species Evenness	Species	Species Richness (SR)	Species Evenness
Evax contracta Boiss.	3	0.6	Vaccaria pyramidata	19	0.333333
Filago desertorum Pomel	131	0.055768	Simpson's Index = D	0.106736	
Gagea chlorantha	46	0.190083	Simpson's Index of Diversity (1–D)	0.893264	
Gagea reticulate	64	0.277056	Shannon–Wiener Diversity Index (SDI)	2.51108	
Gymnarrhena micrantha Desf.	199	0.056906	Shannon's equitability (EH)	0.652204	
Gynandiris sisyrinchium	86	0.30605			

Annex 1.15 Species richness and species evenness for the experiment site on April 2007.

Species	Species Richness (SR)	Species Evenness	Species	Species Richness (SR)	Species Evenness
Aaronsohinia factorovshyi Warb. & Eig	14	0.269231	Herniaria hirsuta L.	156	0.072897
Adonis dentate	19	0.413043			
Allium desertorum Forssk	25	0.462963	Hirschfeldia incana (L.) Lagrèze-Fossat	18	0.382979
Alyssum damascenum Boiss. Et Gaill	19	0.358491	Hordeum glaucum Steudel	59	0.18612
Anabasis syriaca Iljin	95	0.539773	Lasiopogon muscoides L.	77	0.070064
Androsace maxima	89	0.259475	Lappula spinocarpos	4	0.571429
Anthemis haussknechtii Boiss. & Reut.	15	0.46875	Leopoldia comosa	28	0.5
Astragalus cruciatus	18	0.45	Lopochloa pumila	20	0.133333
Astragalus gutatus	11	0.25	Malva sylvestris	1	0.333333
Atriplex halimus L.	25	0.301205	Malcolmia conringiodes Boiss.	11	0.333333

Annex 1.15 (Continued).

Species	Species Richness (SR)	Species Evenness	Species	Species Richness (SR)	Species Evenness
Bassia muricata (L.) Ascherson	21	0.617647	Plantago	2	0.4
Biarum anguotifol	3	0.75	Poa bulbosa	189	0.047921
Bromus madritensis sub sp. delilei	22	0.116402	Raphanus aucheri	6	0.75
Capcella bursa pastoris	6	0.6	Rhagadiolus stellatus (L.) Gaertner	16	0.533333
Cardaria draba	4	1	Roemeria hubrida	33	0.289474
Catapodium rigidum (L.) C.E. Hubbard ex Dony	22	0.104265	Rostraria berythea	20	0.289855
Ceratocephala falcate	160	0.099502	Salsola vermiculata L.	4	0.666667
Colchicum tunicatum	21	0.636364	Scismus barbatus	98	0.054749
Dipoltaxis erucoides (L.) DC.	15	0.357143	Scorzonera schweinfurthii (Boiss) Thiébaut	19	0.575758
Erodium hirtum Willd	123	0.411371	Silene conoides L.	19	0.527778
Eruca sativa Miller	41	0.554054	Sinapis arvensis L.	15	0.535714
Eruca sativa	12	0.48	Sisymbrium irio L.	14	0.538462
Eremopyrum bonaepartis (Sprengel) Nevski	20	0.097561	Spergularia	8	0.444444
Evax contracta Boiss.	12	0.428571	Stipa	6	0.428571
Filago desertorum Pomel	151	0.048584	*Torularia torulosa* (Desf.) O. E. Schulz	232	0.035556
Gagea chlorantha	62	0.186186	Trigonella	6	0.75
Gagea reticulata	87	0.261261	Vaccaria pyramidata	19	0.333333

Annex 1.16 Species richness and species evenness for the experiment site on April 2008.

Species	Species Richness (SR)	Species Evenness	Species	Species Richness (SR)	Species Evenness
Aaronsohinia factorovshyi Warb. & Eig	16	0.202532	Hordeum glaucum Steudel	65	0.030777
Adonis dentate	13	0.464286	Lasiopogon muscoides L.	2	0.5
Allium desertorum Forssk	35	0.614035	Leopoldia comosa	32	0.653061
Alyssum damascenum Boiss. Et Gaill	12	0.571429	Lopochloa pumila	35	0.147059
Anabasis syriaca Iljin	52	0.234234	Malcolmia conringiodes Boiss.	13	0.371429
Androsace maxima	30	0.141509	Plantago	1	0.125
Anthemis haussknechtii Boiss. & Reut.	7	0.5	Poa bulbosa	129	0.040797
Astragalus cruciatus	9	0.75	Raphanus aucheri	2	0.5
Astragalus gutatus	29	0.763158	Rhagadiolus stellatus (L.) Gaertner	6	0.333333
Atriplex halimus L.	18	0.352941	Roemeria hubrida	28	0.41791
Bromus madritensis sub sp. delilei	26	0.164557	Rostraria berythea	2	0.666667
Catapodium rigidum (L.) C.E. Hubbard ex Dony	17	0.097701	Salsola vermiculata L.	6	0.75
Ceratocephala falcata	34	0.377778	Scismus barbatus	65	0.116279
Colchicum tunicatum	5	1	Scorzonera schweinfurthii (Boiss) Thiébaut	3	0.75
Dipoltaxis erucoides (L.) DC.	19	0.422222	Silene conoides L.	8	0.5
Erodium hirtum Willd	10	0.666667	Sinapis arvensis L.	7	0.636364
Eremopyrum bonaepartis (Sprengel) Nevski	31	0.081152	Sisymbrium irio L.	3	0.230769
Filago desertorum Pomel	40	0.327869	Spergularia	11	0.261905
Gagea chlorantha	6	0.352941	Stipa	2	0.5
Gagea reticulate	35	0.208333	*Torularia torulosa* (Desf.) O. E. Schulz	182	0.028788

Annex 1.16 (Continued).

Species	Species Richness (SR)	Species Evenness	Species	Species Richness (SR)	Species Evenness
Gymnarrhena micrantha Desf.	167	0.023386	Trigonella	4	0.666667
Gynandiris sisyrinchium	16	0.615385	Simpson's Index = D	0.214428	0.538462
Helianthemum ledifolium (L.) Miller	31	0.137778	Simpson's Index of Diversity (1–D)	0.785572	0.444444
Herniaria hirsute	34	0.178947	Shannon–Wiener Diversity Index (SDI)	1.996315	0.428571
Hirschfeldia incana (L.) Lagrèze-Fossat	39	0.47561	Shannon's equitability *(EH)*	0.521416	0.333333

Annex 1.17 Analysis of variance of the effect of the two slopes, different intervention treatments, and two experiment dates on the parameters studied in the direct seeding rehabilitation strategy.

Type 3 Analysis of Variance								
		Mean Squares						
		1st	2nd		3rd		4th	
Source	DF	Seed emergence	Seedling length (cm)	survival rate	Seedling length (cm)	survival rate	Seedling length (cm)	survival rate
Date	1	14968***	30.9***	1031.7***	142.9***	7693.5***	2629.2***	8361.8***
S	1	57.3*	5.2**	36.8***	10.6*	32.2**	16.7**	27.2**
D×S	1	35.7*	0.1	1.0	0.1	19.3*	6.0*	27.2**
TRT	7	2770.8***	50.5***	1654.3***	97.1***	911.1***	108.5***	808.3***
D×TRT	7	1238.9***	1.8*	118.8**	4.86*	619.4	41.51***	706.1***
S×TRT	7	29.5*	0.6	16.0*	0.9	12.1*	4.6*	10.2*
D×S×TRT	7	23.8*	0.5	3.4	2.0	5.9	4.2*	8.8
R(S×TRT)	32	22.0	1.7*	14.1	2.5	9.5	2.5	8.0
R×D(S×TRT)		23.1	0.9	20.8	2.6	8.5	3.1	8.2
Residual	32	52.0	1.6	25.7	3.6	16.6	6.5	15.7

Notes: *$P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

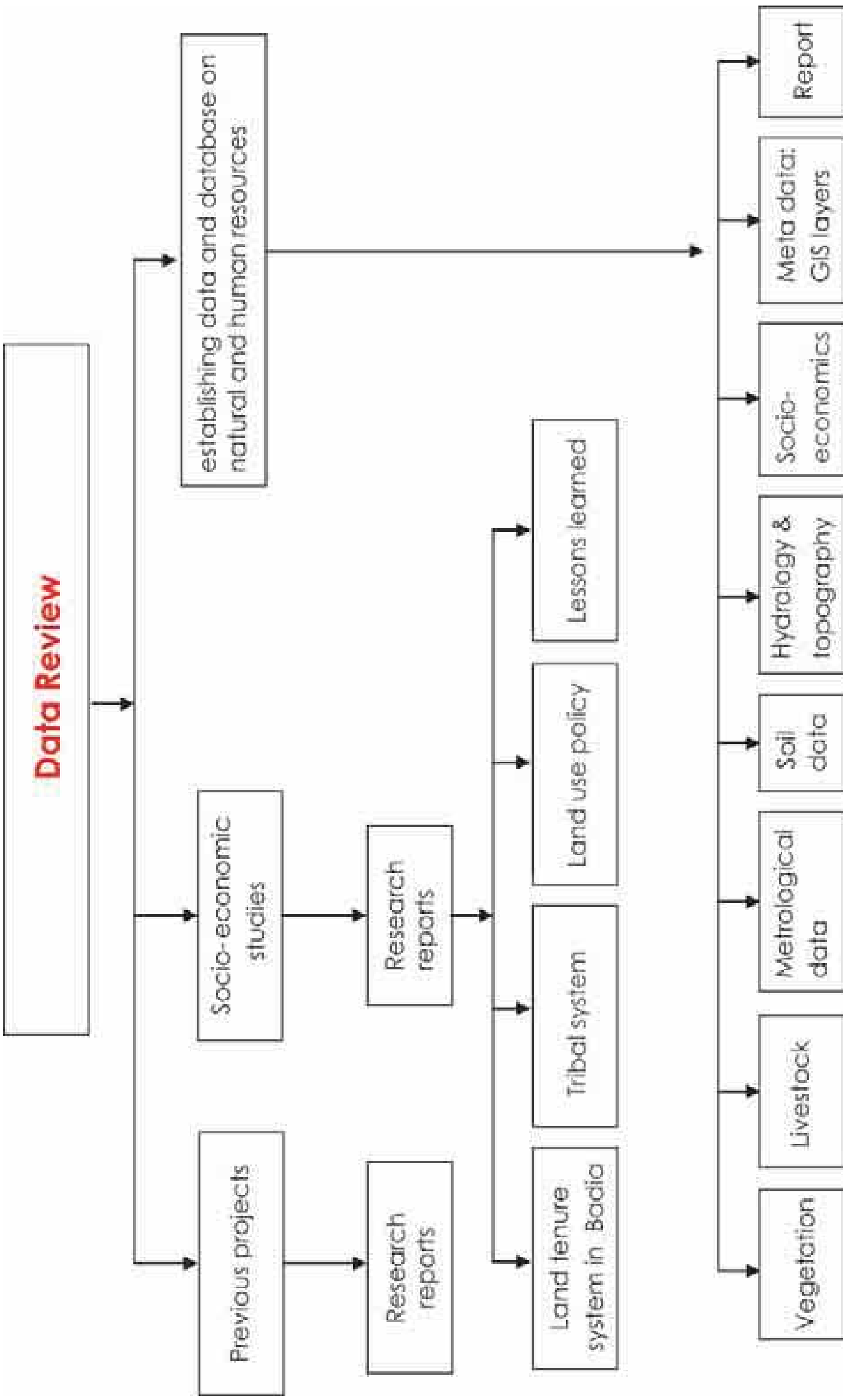
Annex 1.18 Analysis of variance of the effect of the two slopes, different intervention treatments, and two experiment dates on the transplanting rehabilitation strategy.

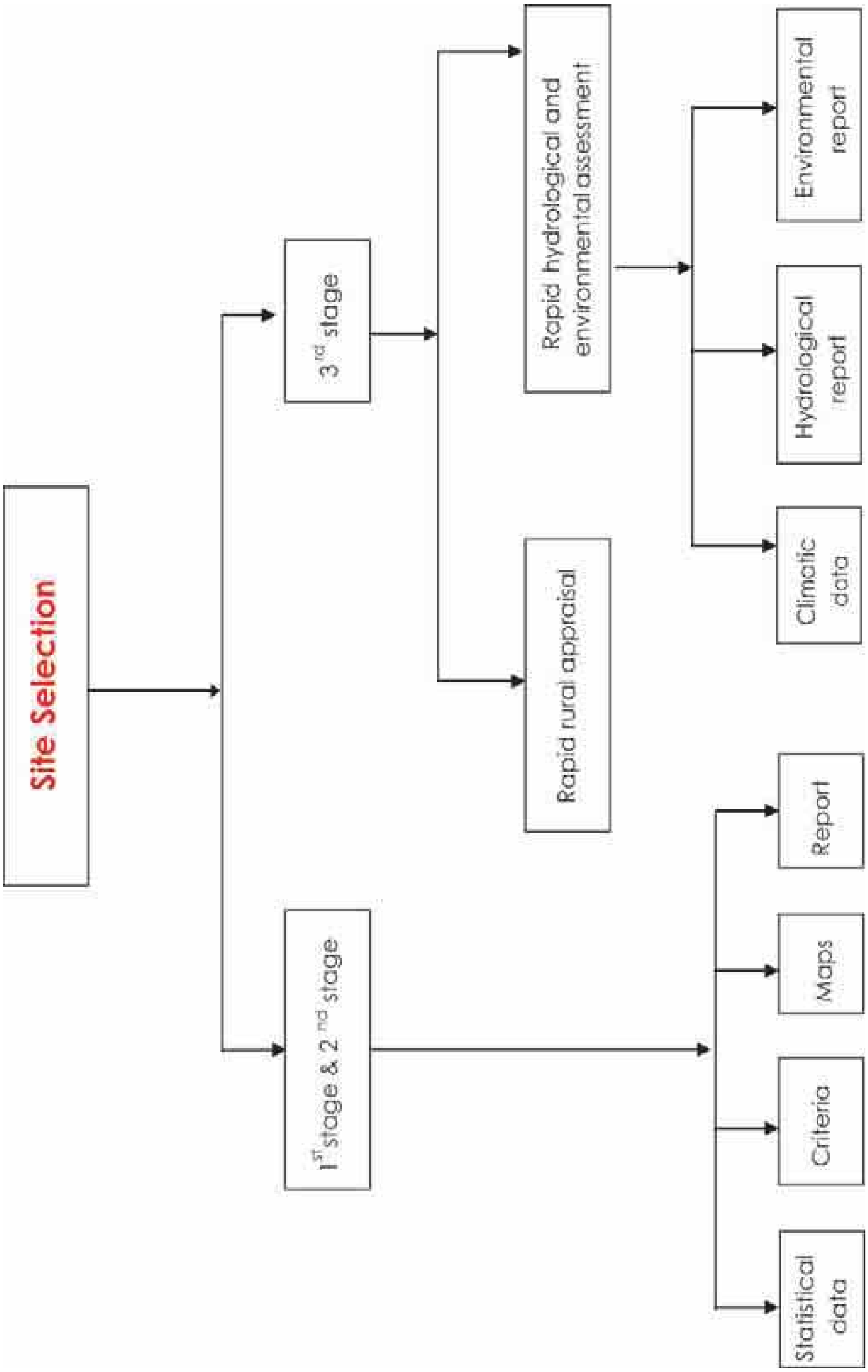
Type 3 Analysis of Variance

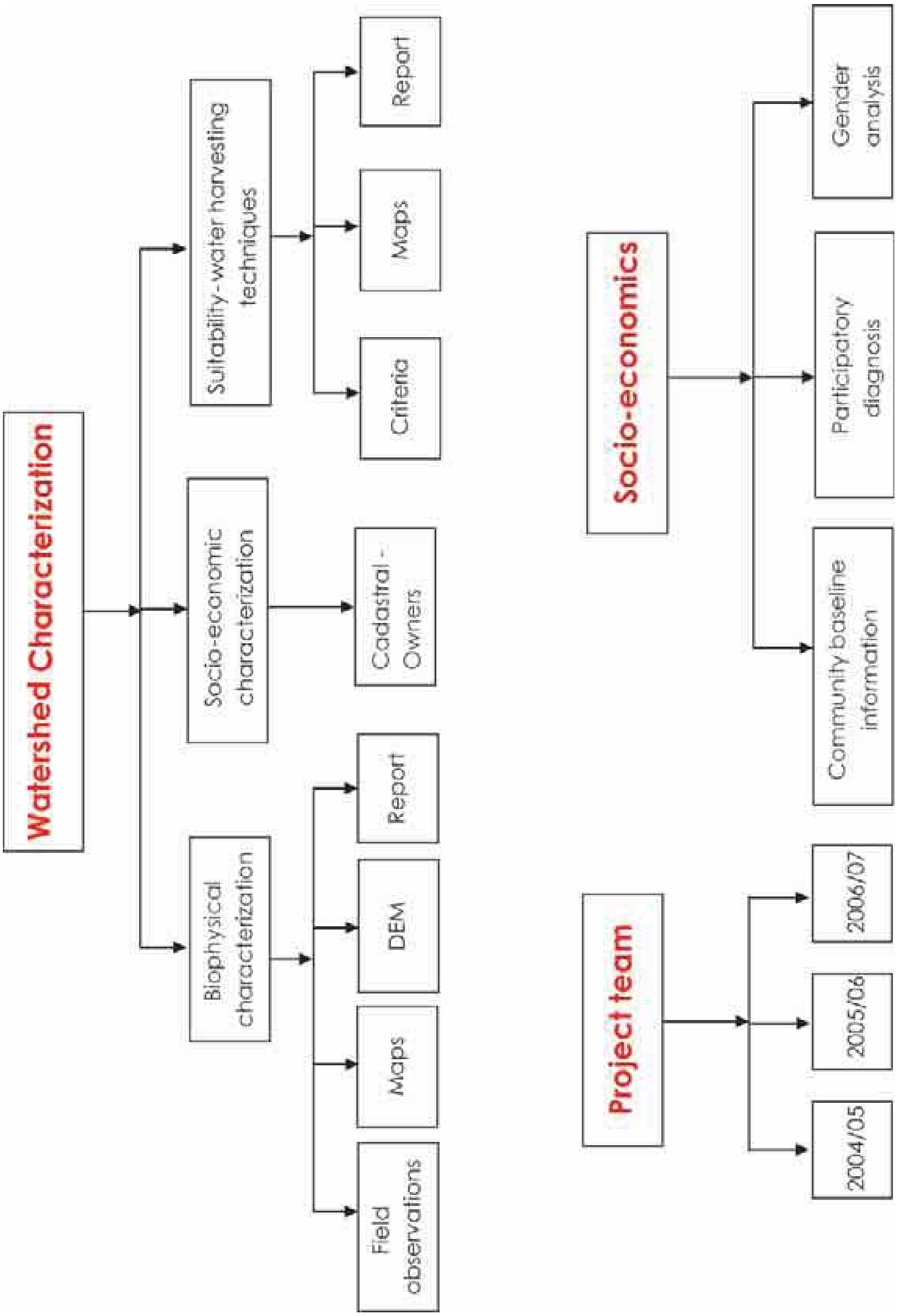
Source	DF	Initial seedling length	Mean Squares					
			1st		2nd		3rd	
			survival rate	Seedling length (cm)	survival rate	Seedling length (cm)	survival rate	survival rate
Date	1	3.510857	353423***	1536.885073 ***	909587***	6873.264054 ***	1212385***	8361.8 ***
S		4.061167	844.333929*	0.048751	675.133929 *	183.216095*	478.933929 *	27.2**
D×S	1	6.865929	389.572024*	8.925001	520.372024 *	65.293714	724.172024 *	27.2**
TRT	1	22.667755	256.151616	22.869901	158.598554	208.909571*	253.840731	808.3***
D×TRT	1	22.449388	1747.648214**	34.357665*	901.115561 **	147.726101	488.874745 *	706.1***
S×TRT	7	21.234949	1221.818282	38.541581	624.459099	136.512054	375.801956	10.2*
D×S×TRT	7	20.355357	358.212840	17.501641	294.186990	207.934707*	354.373384*	8.8
R(S×TRT)	7	28.217847	1380.973214 **	46.340363*	739.710714 **	209.672162*	472.058333 *	8.0
R×D(S×TRT)	7	33.081835 **	786.330357	32.522268*	337.329762 **	204.135496 ***	340.213095 ***	8.2
Residual	32	17.617929	824.826910	26.829386	305.446354	80.712613	79.261632	15.7

Notes: *$P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

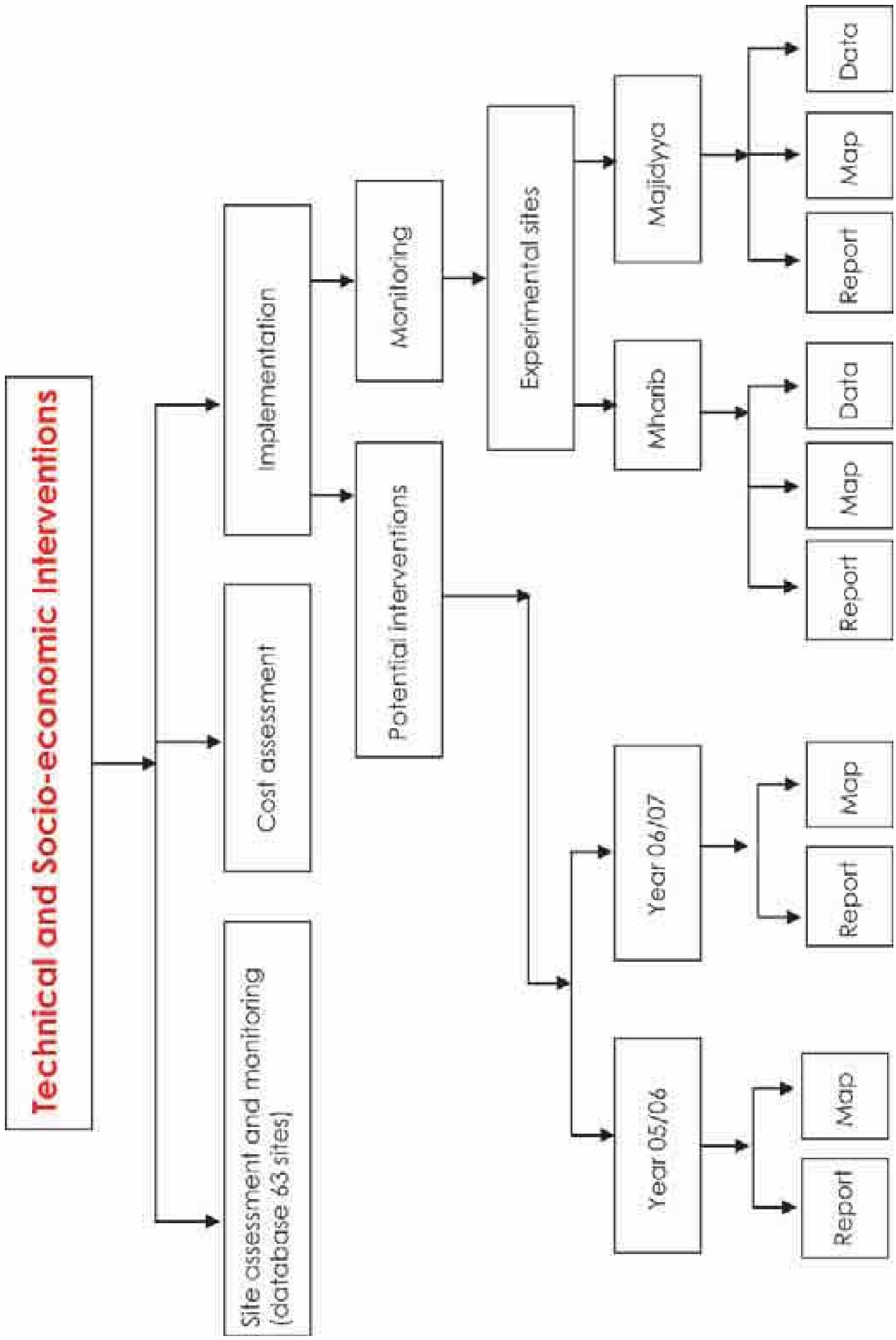
Annex 2 Details of content and hierarchy for each of the database components in Figure 7.8




Site Selection
1st stage & 2nd stage
3rd stage
Rapid rural appraisal
Rapid hydrological and environmental assessment
Statistical data
Criteria
Maps
Report
Climatic data
Hydrological report
Environmental report



Watershed Characterization
Biophysical characterization
Socio-economic characterization
Suitability-water harvesting techniques
Field observations
Maps
DEM
Report
Cadastral - Owners
Criteria
Maps
Report
Project team
2004/05
2005/06
2006/07
Socio-economics
Community baseline information
Participatory diagnosis
Gender analysis



Technical and Socio-economic Interventions
Site assessment and monitoring (database 63 sites)
Cost assessment
Implementation
Potential interventions
Monitoring
Experimental sites
Year 05/06
Year 06/07
Mharib
Majidyya
Report
Map
Report
Map
Report
Map
Data
Report
Map
Data

Meetings
Tech. committee meetings
Team meetings
Field meetings
General meetings
Steering committee meetings
Regional
Local
Photos
Regional
Local
Capacity Building
Workshops
Training
Public awareness program
Regional
Local
Regional
Local
Brochures
Media
Reports
Field visits
Calendar
TV
Press
Regional
Local

Annex 3

Annex 3.1 Project dissemination and potential uptake

The Jordan Badia is representative of the vast drier environments in WANA. Drought and the ensuing water shortages over the last decade have prompted the people and decision-makers to explore the potential use of these marginal dry areas. The focus on developing the Badia in Jordan, Syria, Egypt, Tunisia, and other countries in WANA is increasing and ICARDA has been approached to assist in developing options for managing the resources in these areas for improved production and to combat desertification.

Interventions adopted by the project address the sustainable and integrated resource management (IRM) of the Badia by implementing, with community participation, WH interventions and fodder shrub plantations that conserve the soil, increase fodder production, rehabilitate natural vegetation, and improve farmers' incomes. These include microcatchments (planted to *Atriplex* and *Salsola*), check-dams and ponds.

3.1.1 Objectives, outputs, and stakeholders

The objective is widespread integration and adoption by people in the Badia, of suitable WH techniques, to capture and efficiently utilize rainwater runoff in more productive and sustainable systems.

Expected outputs

Improved methodologies for the identification of WH sites and methods with high potential for various conditions.
Techniques for providing sustainable supplies of water from rainfall runoff for economic production from rangeland, field crops, fruit trees, and methodologies for designing and implementing such techniques at the field and watershed levels.
Methodologies for the characterization of catchments' potential and optimal use of harvested water in these catchments.
Analysis of potential economic and institutional constraints and recommended policy measures to support the integration of WH in agricultural systems

Stakeholders

The main stakeholder groups follow:
At the community level: Beneficiaries, farmers, land users, livestock owners, women, and community associations.
Other relevant projects: Mashreq/Maghreb (M&M) Project, Yarmouk Basin Development Project, Agricultural Resource Management Project (ARMP II), and Sabha/Subhieh Development Project.

Governmental and nongovernmental organizations: Ministry of Agriculture, Jordan Cooperative Corporation, Ministry of Water and Irrigation, Ministry of Interior, Ministry of Planning, Badia Research and Development Center, Department of Land and Surveying, Royal Jordanian Geographic Center, National Center for Agricultural Research and Technology Transfer, Hashemite Fund for Badia Development, Royal Society for Conservation of Nature, Queen Alia Fund, Noor Al-Hussein Foundation, civil societies, and universities.
Donors: IFAD, AFSED, and OPEC

3.1.2 Dissemination venues

The community and participatory approach

The project followed a community participatory-based approach. This approach emphasizes the involvement of local communities in planning, programming, monitoring, and evaluation of project activities. This approach has a built-in dissemination mechanism to other community members whether they are involved directly or indirectly in project activities. The participatory approach is the main feature of the project, where stakeholders participated in the different activities and were consulted during the planning and implementations of these activities.

Linkages with development projects and other research projects
Linkages and cooperation were established with other research and development projects and institutions working in the Badia such as the Badia Research and Development Center, Mashreq/Maghreb project, Subha/subheih development project, and Muwagar Station for Badia Development (University of Jordan). Moreover, NCARE technical staff, who are involved in the project implementation, extended the project methodology to Yarmouk Basin Development Project through the technical backstopping provided by NCARE to this project.

Communication and linkage with policy-makers
From it is inception, the project involved policy-makers at different levels with its activities.

Badia Deputies in the parliament attended and actively participated in the project meetings with the communities and in field days organized by the project.
The Secretary General of the Ministry of Agriculture is the Chairman of the National Steering Committee.

Policy-makers attended the project initiation workshop and participated in key project activities.

Sherefa Zien Bent Naser, Head of Hashemite Fund for Badia Development, attended a field day at the Mharib site with participation of the Secretary General of Ministry of Agriculture and other high-level officials.
A national steering committee meeting of the project was chaired by H.E. Minister of Agriculture, who expressed the Government's support for the project and its commitment to the sustainable development of the Badia.

Workshops and meetings
The project organized several workshops and meetings with the stakeholders, including meeting with the target communities. A project launching workshop was organized with the participation of more than 100 participants representing around 25 institutions, NGOs, private sector companies, and other projects working in the Badia. Several meetings were held with community members to discuss and negotiate project activities and develop community action plans. The project technical committee holds several meetings annually to monitor progress and to discuss and approve the annual workplan and budget. The national steering committee meets twice annually to discuss project strategies, monitor project performance, and endorse the annual workplan and budget.

Field days: Two to three field days were organized annually for farmers from the communities where the project was implemented, and farmers from the neighboring villages, to show them the performance of the introduced interventions. Farmers participating in the field activities, with support from project technical staff, explained to their colleagues what had been done in their fields and their involvement in the different implementation stages. Participating farmers' opinions were assessed through informal discussion to determine their attitudes toward the introduced technologies.
As a result of these activities and other dissemination-related activities, the number of interventions and the area covered by these interventions, and number of farmers who participated in project activities has tripled since the inception of the project.

Regional visits
- Farmers and researchers from Jordan visited Syria

A Jordanian team composed of six farmers and four researchers from NCARE visited the WH sites and Vallerani sites in Syria in early May 2007, to observe the experience of the Syrian partners in rangeland rehabilitation and protection and related issues. The visit covered the following sites:
Al Mhassa Center (Syrian Research Authority) in the Al Qaryatin region in the Syrian Badia area, where the Syrian partners

explained their experiences with WH techniques and the plant species they were planning to transplant to the rangeland.
The Vallerani site in the Al Qaryatin region: a meeting with the local community was arranged to discuss the importance of projects in the Badia region and impacts on Badia rehabilitation and protection.
The Vallerani site in Al-Selmya region in the Hama Directorate: the team was impressed with the sites, the healthy rangeland shrubs planted there, and the rich natural vegetation that had recovered due to the use of the Vallerani machine for WH. The team met with the local community and discussed their experiences and the possibility of adopting their work in other regions.

Khanaser Reserve: tour inside the reserve.
ICARDA, Aleppo: the team met the Benchmark and Vallerani teams at ICARDA, and discussed WH and Vallerani techniques with them.

- Farmers and researchers from Syria visited Jordan

A team of three Syrian researchers and seven farmers visited Jordan in mid-May 2007, the visit covered:
The Badia Benchmark and Vallerani sites at Mharib and Al Majidiyya: they observed the project activities and were impressed with the WH techniques implemented and the measurements taken. A meeting with the local community was arranged, where they discussed the Jordanian and Syrian experience in Badia development following a community participatory approach.

Al Kanasri Station (NCARE) and the JUST-Site: they observed the activities implemented in the two locations, especially the use of WH techniques for fruit tree production.
Al Shoubak in south Jordan: they visited orchards that use WH techniques and also investment farms for fruit tree production under irrigation.

Dissemination of the Vallerani system
One hundre hectars were implemented in the north Badia in Deir Alkahf and Rawdet Al Ameer Ali and Medwer Elken using the Vallerani machine.

Publications
Review documents addressing the major Badia-related issues were produced by the end of the first year of the project. The review documents cover the following topics: policy and institutions in the Badia, biophysical and socioeconomic characterization, tribal systems, land tenure systems, and ongoing and previous projects conducted in the Badia. Brochures, annual reports, and workplans were produced on a regular basis. Newspapers articles about the project and its achievements were published in the major daily newspapers. Radio and TV interviews were broadcast from the national stations. The project can be accessed at the ICARDA and NCARE web sites.

Documentary film
A documentary film was produced in 2007 and broadcast by the national TV station, which described the project objectives and activities, and showed the progress made by the project in improving rainwater storage capacity, increasing vegetation cover, reducing soil erosion, and increasing feed resources by planting fodder shrubs using WH techniques. The community leaders from Mharib and Al Majidiyya were interviewed in the film and expressed their satisfaction with project achievements, and considered it a successful approach in Badia development. They called on government authorities to scale-out project findings to new areas in the Badia.

Database
An electronic database was established at NCARE to document and for easy retrieval of the collected information. The database covered: (i) establishing a GIS database for the intervention sites, which defined each site in terms of its geographic location and extent; (ii) establishing dynamic links to all available data and information (using html-based applications); and (iii) preparation of data-forms for data collection.

Capacity building
Farmer training: Training farmers on project interventions was achieved through field days and on-site training on WH structure establishment, shrub plantations, and maintenance. For the first time in the Badia, Bedouins (men and women) participated in implementing project interventions by planting fodder shrubs in WH structures along contour lines and following the technical staff instructions.

Staff training: Several training courses and workshops were organized during in 2005-2007 to train technical staff on project techniques, such as WH techniques, GIS and remote sensing, data measurements and analysis, and scientific writing. Moreover, since the beginning of the project, two scientists from NCARE were trained on 'Community Approaches' organized by ICARDA in 2004 and a training course on 'Application of GIS and Remote Sensing' was organized in 2005 for the Jordanian scientists involved in the project.

In 2007, two participants were trained on 'Modeling Water Productivity' and a training workshop on 'Monitoring and Evaluation (M&E)' was conducted in Amman, where 11 trainees from NCARE participated. The training focused on M&E subjects: Defining the M&E system and its goals; monitoring process; impact assessment; organization; communication and reporting; M&E system structure; and the impact pathway of the Badia Benchmark Project. The theoretical part included lectures on concepts of M&E and its estimation and measurements. The practical training was conducting by preparing a LOGFRAME Matrix for the Badia Benchmark Project, an impact pathway analysis matrix for the Badia Benchmark Project, and training on reporting procedures.

A Vallerani machine for the construction of WH structures was purchased through ICARDA to support NCARE and the Government of Jordan in scaling-out the successful results to the Badia area.

3.1.3 Uptake of the project early outputs

Uptake of the project approaches
Extending the project approach to other projects: NCARE, the implementing institution in Jordan extended the project approach in executing new projects in north Jordan supported by Gesellschaft Internationale Zusammenarbeit Startseite GTZ and implemented in cooperation with Arab Center for the Study of Arid Zones and Drylands (ACSAD). Moreover, NCARE technical staff, who are involved in the project implementation, extended the project methodology to Yarmouk Basin Development project through the technical backstopping provided by NCARE to this project. Arrangements are being made with Badia Research and Development Center to lodge an expression of interest in adopting the project approach and technical interventions for the northern and southern Badia where the center is working.

National collaboration: The project was pioneering in bringing national institutions and scientists together in planning and implementing project activities. Around 14 institutions, led by NCARE and representing universities, Ministry of Agriculture, NGOs, and other ministries and departments participated in the project implementation. The project steering committee has representatives from different organizations. It is expected that the involved institutions will take up the project approaches and successful interventions and apply it in similar activities implemented by their institutions.
Regional collaboration: Saudi Arabia, a satellite site of the Badia Benchmark Project, established a close collaboration with the project. Scientists from the satellite site attended the technical meetings, visited the fields, and became acquainted with the approach and methodology in addressing the fragile ecosystem in the Badia. The approaches will be followed in the site in Saudi Arabia.

Adoption of technologies
Interventions adopted by the project addressed the sustainable and integrated resource management of Badia by implementing, with community participation, WH interventions, fodder shrub plantations, and drought-tolerant fruit trees that conserve soil, increase fodder production, rehabilitate natural vegetation, and improve farmers' incomes. These include microcatchments (planted with *Atriplex* spp Salsola spp or fruit trees), check-dams, and ponds. The willingness of the farmers in the area to adopt and implement these technologies and interventions in their lands has increased threefold since the project started. It is expected that the adoption rate and intensity will significantly increase when proper policy and institutional options are applied to the Badia area.

An innovative approach was developed in selecting the proper area for project implementation. The selection criteria considered the watershed as a basic unit for Badia development, and for the technical and socioeconomic interventions. The approach utilized the GIS and remote sensing techniques in integrating biophysical and socioeconomic factors in selecting appropriate watersheds, and sites within watersheds, for project intervention. The selection approach is being adopted by NCARE in executing other projects in the Badia and in development of new proposals for projects addressing these areas.
The project, in cooperation with the Swiss-supported Vallerani project, introduced the Vallerani machine for the construction of WH structures. The machine provides the opportunity to rapidly construct WH structures for larger areas and make such interventions economically viable. The mechanized system provides the planted fodder shrubs with a better environment thus improving survival, controlling soil erosion, and enhancing natural vegetative cover. The Government of Jordan purchased a high power tractor (which was not available in Jordan) to operate the machine, showing the government commitment in expanding and out-scaling this approach in the development of the Badia. The system is now being used and will be used in implementing other projects in Jordan.

Influence of government investment in the new initiatives
Expanding at the national level: NCARE, following the benchmark project approach, developed a US$4 million national project to disseminate project results and achievements to other areas in the Badia. The proposal is being considered by the Ministry of Environment under the Desertification Combating Program within the Jordan National Action Plan (NAP).

Farmers traveling workshops
Exchange of experiences among farmers and technical staff: Farmers and technical staff visited Syria and became acquainted with the work in the Syrian Badia; similarly, farmers from Syria visited the site in Jordan and observed the progress made by the project. These visits provided the opportunities for interaction of farmers and technical staff and exchange of experiences. Likewise, in-country visits to the project site were conducted by farmers from other areas in Jordan.

3.1.4 Potential uptake

The areas in the Badia of Jordan that have potential for agricultural development account for around 1 000 000 ha. These areas suffer from land degradation and vegetation cover deterioration, and some are facing desertification. Previous efforts in Badia development through several projects have failed to achieve sustainable development, being based on addressing the biophysical aspects of the problem. However, the present project introduced a new approach to sustainable development of the Badia, taking into consideration the communities that use the resources, socioeconomic factors, and the policies and institutions involved in Badia management.

The project emphasizes community participation as an important mechanism in the development process, and involves the community in planning, executing, monitoring, and evaluation of the activities. Before the end of the project, the policy and institutional options that will support the adoption of technology will be developed and tested by the communities in their areas. Therefore, involving policy-makers at different levels was considered from the project inception.

It is expected that the Government of Jordan will apply the project approach to extend the success of the project to new areas and new communities. The policy-makers indicated, during project-organized meetings with communities, the Government's commitment to the sustainable development of the Badia and that they were impressed at the success realized by the project. Therefore, it is expected that the project approach and methodology, and its technical interventions, will be adopted by the national system. This adoption is expected to be at two levels: institutionalization of the project approach within NCARE and Ministry of Agriculture systems, and extension of the success of the project into new areas in the Badia of Jordan. This is will be supported by technical staff from the national institutions, who have been trained by the project. Moreover, the models that the project is developing will be a good technical tool to extend the success to similar areas in Jordan and the region.

Annex 3.2 Satellite Site of Saudi Arabia

3.2.1. Introduction

The Wadi Hossaida project is located in the West Hossaida Valley, west of Al-Quarayat District, at the right side of the highway leading to the Saudi–Jordan border. Since October 2004 some activities have been undertaken for site selection and characterization of the project area. The purpose of this progress report is to report these activities. Two essential tasks were undertaken during the last year. The first task was site selection, based on community needs in the area, and was made by both soil and water specialist Dr. Al-Sharari and range specialist Dr. Al-Hajouj. The second task of site characterization was with regard to water harvesting (soil erosion, geography, and topography), vegetative cover data, and status.

The Saudi Arabia-partner participated only in the beginning of the project. Two surveys were conducted, one by Dr. Al-Sharari to collect soil and climate data, and the other by Dr. Al-Hajouj to collect data on vegetation and livestock in the area. In 2007, representatives from the Saudi satellite site visited Jordan to observe the activities and achievements of the Badia benchmark site.

3.2.2. Activities conducted and achievements

Site selection

A preliminary visit was made early in the year by Dr. Al-Sharari to Bayer and Hossaida Valleys through the General Director's Bureau of Agriculture in Al-Qurayat. The aim was to select one site, from the two sites, to be studied.

Owing to the small annual budget allocated for the satellite site, the study's other visit was made by Drs. Al-Hajouj and Al-Sharari to make a final decision on the selection of one of the two sites. During this visit, the Hossaida Valley was found to be geographically more suitable for microcatchment works as it was heavily used by nomads, and it had fair rangeland conditions. There were more plant species in the valley as compared to Bayer Valley. Thus the team selected the West Hossaida Valley downstream from the Hossaida concreted dam for the proposed study. The study area is located 300 m east of the dam. It is 3 km in length along the valley, 500 m wide, and has an area of 150 ha.

Data collection and evaluation

Soil data, climate data, and vegetative cover data of the site were collected through survey works.

Soil and climate data collection
The soil and water science specialists used two representative soil profiles to characterize the soil of the site. Due to the soil uniformity observed, two representative soil profiles were dug to a depth of 1 m and the recognized horizons were sampled. One soil profile represented the bottom of the valley and the other one represented the east bank of the valley. Soil samples were prepared and sent for laboratory analysis. Soil texture was determined by feel method and found to be loamy to sandy loam in the bottom of the valley, and very gravelly sandy loam on the east bank. Detailed results of the analysis will be reported in the next annual progress report. Climate data regarding temperature and rainfall for the past 20 years were procured and will be analyzed and reported later.

Vegetative data collection
Range management specialists surveyed the area and found that the wadi beds support trees and shrubs, which grow in the valley. The plant cover in the wadi beds was about 30% and the main species Tamarix sp. However, plant cover is < 1% outside the valley.
Due to the soil structure in the valley (where soil is deeper, more gravelly, and sandy), the proportions of trees and shrubs in the wadi are presented in (table Annex 1).

The area appears degraded and the signs of degradation are evident on both soil and plant components. The good perennial palatable species are either extinct or on the brink of extinction and appear in a highly degraded condition outside the valley, where plant cover is close to zero.
The palatable species found, e.g. *Atriplex halimus* and Traganum nudatum, are at the brink of extinction. The area could, however, support some very good palatable species such as Salsola villosa through re-vegetation by re-seeding.

Livestock data
During survey works, camels were seen grazing in the valley. More than three flocks of camels were seen, making a total of 300 heads. Sheep flocks and goats were also seen grazing in the valley and the flocks seen accounted to a total of about 1500 heads.

Workshops
A regional training workshop 'Database Management and Web Site Administration' was conducted by the project during 19–23 June 2005 in Aleppo, Syria, with active participation from the project team in Saudi Arabia.

Table annex-1. percentage of species in the wadi

Species	%
Tamrix aucheriana	85.0
Nitraria retusa	9.0
Pulicaria crispa	3.1
Lycium shwaii	1.5
Retama retum	0.5
Alhagi graecorm	0.2
Atriplex halimus	0.2
Traganum nudatum	0.2
Achillea frangrantissima	0.2
Rhyzya stricta	0.1

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