Chapter 8

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

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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 micro-catchments (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 micro-catchment 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/m³)			
	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.

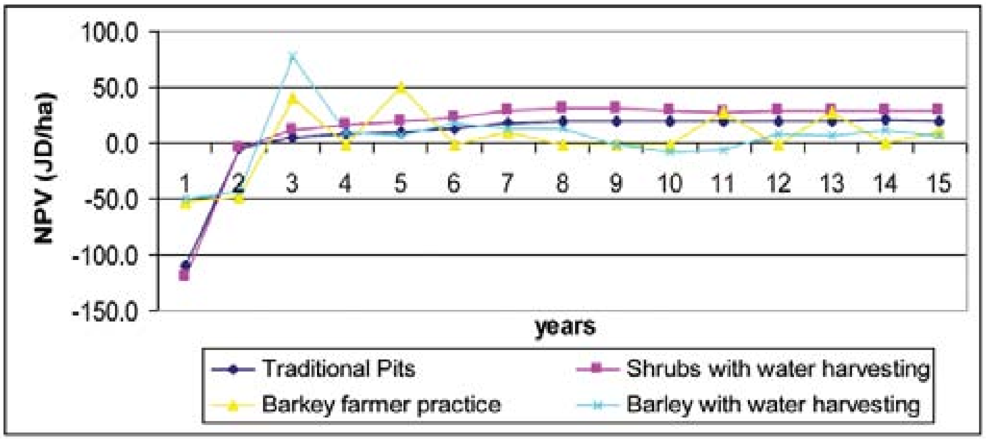

Figure 8.1. Cumulative NPV of different land-use systems and WH techniques (JD/ha).

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).

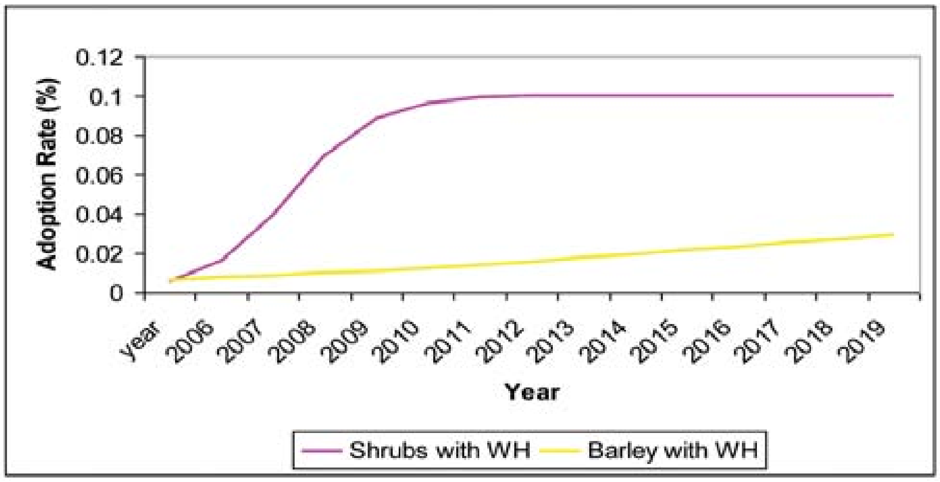

Figure 8.2. Adoption rate (%) for planting shrubs and barley with WH techniques.

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.

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