Tal Rimah Range Rehabilitation – Recreating a Valuable Resource

Jordan Component of the Sustainable Development of Drylands Project
Report# 4

New Mexico State University
College of Agriculture
Department of Agricultural Economics and Agricultural Business

and

The Badia Reseaerch and Development Center

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Executive Summary

Badia rangelands provide a significant portion of the domestically produced forage that sustains the range livestock industry. Sale of livestock and livestock products support an important sector of the economy and enable many rural communities to maintain a valued and traditional way of life. This report describes the results of a range improvement project that included several alternative water harvest techniques that concentrate rain-fed runoff water into a smaller area to allow forage shrub establishment and growth in the low rainfall Tal Rimah area of Jordan. In addition the project focused on appropriate grazing management for sustaining increased grazing.

Tal Rimah is situated northwest of Safawi and about 70 km east of Al-Mafraq. The demonstration site chosen for the Tal Rimah range project encompasses about 50 hectares northeast of the village of Tal Rimah.

A critical element in the selection of this particular site was the willingness of the herders in the Tal Rimah area to cooperate with BRDC and its partners in setting this area aside for an indefinite period as a demonstration. The local community was involved in the project from the starting point of problem definition, possible solutions, site selection of plant species suitable to the area and the intended use by livestock owners.

The 50-hectare demonstration site was prepared to demonstrate a variety of water harvesting configurations for shrub planting including; contour furrows, micro-catchments, and low rock walls.

Information developed indicates that water harvesting techniques used along with proper grazing management practices may have the potential for increasing the range carrying capacity from 100 to 250 sheep grazing days per hector annually in areas with at least 200 mm rainfall per year, an increase from three to six fold as compared to non improved range under present management practices. Increases in grazing capacity are expected to be similar in lower rainfall regions, those averaging from 100 to 150 mm per year, but the range carrying capacity is expected to be lower, requiring from 3.5 to 7.0 hectors to support a sheep year-long compared to 1.5 to 3.5 hectors for ranges averaging 200 mm rainfall per year.

The test plot used relatively high cost construction alternatives for building the water catchments and planted comparatively expensive shrubs. Even under these conditions the concept appears to be feasible with investment payback period ranging from 4 to 17 years depending up assumptions of the sustainable level of grazing and average rainfall. Community based construction using lower cost construction techniques and lower cost direct seeding may offer a more cost effective approach to increasing the grazing capacity of selected area in the Badia.

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Introduction

Approximately 90 percent[1] of the Hashemite Kingdom of Jordan is arid rangeland, generally referred to as the Badia[2]. This region has an average annual rainfall of less than 200 mm (Abu Zanat 1995), but despite its aridity, Jordan's Badia makes two vital contributions to the life and economy of the Kingdom (Al-Tabini 2001):

- Badia rangelands provide a significant portion of the domestically produced forage that sustains the range livestock industry. Sale of livestock and livestock products support an important sector of the economy and enable many rural communities to maintain a valued and traditional way of life.
- Rangelands are also the watersheds that receive rainfall, yield surface water and replenish ground water throughout the region east and south of the western Jordan highlands.
- Badia watersheds are considered an essential part of Jordan's national water conservation strategy.

Although periods of severe drought can be cited as part of the reason for deterioration of rangeland health, the main causes of range degradation are:

- Increased stocking around boreholes and other sources of water,
- grazing at the wrong time of the year for range conditions,

[1] The area of rangeland in Jordan varies from about 85 percent to 97 percent of the total area of the country depending upon how it is defined. Assessment can be made either on the basis of land use; (rangeland is the land that is actually being used for extensive grazing); or, alternatively on average rainfall.
[2] The root of the word Badia is the same as that of Bedouin and generally translates as desert (or, in the case of committed douin, people of the desert).

- destruction of vegetation cover by plowing the land for dryland cultivation, particularly in depressions which are considered the main area for growth of fodder shrubs and perennial plants that provide a source of seeds for forage species, and
- unwise and unsustainable crop farming on range areas ill-suited to tillage, (IFAD 1999; Al-Tabini 2001).

Whatever the cause for deterioration of the range resource, the responsibility to reverse the unsustainable downward trend on the Badia falls to responsible range users. Incorporating the combined advice and assistance of trained specialists from the Badia Research and Development Centre (BRDC)[3], the Hashemite Fund for Badia Development, the U.S. Forest Service, the Jordanian Ministry of Agriculture, Jordanian agricultural universities, New Mexico State University, and other organizations, responsible range stewards can apply sound range management methods that fit the needs of the resource as well as those of range users.

In Jordan, sheep and goats are the most important livestock resource in the production of red meat followed by cattle and camels (Siam 1985). The main constraint on livestock production is the shortage of feed from native rangelands. The only local breed of sheep is the Awasii. It is a milk sheep which is well adapted to harsh desert conditions. Its fat tail provides a reserve of nutrients for periods of feed shortage. They graze in the Badia from late autumn until late spring, with supplemental feeding. Then they migrate to the rain-fed and irrigated areas, feeding on crop residues (from cereals and summer vegetables) before returning again to the Badia. Sheep and goat numbers are probably in decline at present. Feed subsidies were removed on August 1, 1996 and the response of some owners was to sell some of their animals to buy feed. The reduction in the number of animals between 1996 and 2000 was about 25%., which is at least partially related to the decrease in animal prices. Some range users, mainly those that had additional sources of livelihood, disposed their entire flocks.

The project described in this report was conducted at the Tal Rimah cooperative near Mafraq in northeastern Jordan (figure 1). Funded by the U.S. Forest Service, the project was initiated in April 2002 with the primary purpose of re-vegetating rangeland that was decimated by drought and overgrazing. Grazing management studies are still being conducted on the site and will continue at least through 2008.

One of the most effective ways of rehabilitating depleted Mediterranean rangelands is the planting of saltbushes, as shown in many Mediterranean countries over the past 40 to 50 years. But, there is no miracle solution; planting saltbushes in rangelands or farmland is also constrained by species selection, establishment and management (Le Houre'ou 1990).

This project involves establishment of nutritious, drought-tolerant shrubs in what could be called forage shrub reserves to rehabilitate the Badia rangelands. During the experiment phase, the site was protected from grazing and was planted with shrubs from the genera *Atriplex* and *Salsola.* In addition, three water harvesting methods were evaluated. After establishment, these shrubs can be used in various ways, at different times of the year depending on adjacent range conditions and livestock requirements. For example, these forage reserves can be used exclusively during periods of normal seasonal deficits in range forage, or during drought periods; or they can be grazed for a limited time, intermittently, on a daily basis, while adjacent ranges are providing some, but not fully adequate, feed for livestock. The project was designed to

[3] The BRDC is a member of the Higher Council for Science and Technology (HCST) and operates a number of producer-committed projects in the Badia of Jordan. The BRDC was established in 1992 at the initiation of His Royal Highness Crown Prince El-Hassan Bin Talal (BRDP 1999).

demonstrate how the establishment and use of forage shrub reserves can work, and to collaborate with livestock owners in a reciprocal relationship of adaptive range management, wherein both the range users and the range advisors share knowledge of the process with one another and adjust their actions based on what will make the best progress toward common goals. A key element of this project is the cooperation between researchers and herders. During the reserve phase of the experiment no livestock were allowed on the range site; although a BRDC guard was housed on the project, most of the policing was actually done by members and leaders of the cooperative.

The broad framework of this project aims to enhance the awareness of the Badia people about the importance of rangeland management to their production of livestock, and at the same time allow BRDC and its supporting associates to work closely with local communities to demonstrate how certain range management practices can be of direct benefit to the people of the Badia and the resources on which they depend. The potential long-term benefits of this effort could be:

- Sustainable, productive use of the range resources.
- Improved socio-economic conditions for livestock owners.
- Enhanced local capacity to manage and preserve a productive ecosystem.
- Increased biodiversity and stability of rangeland ecosystems

Objectives

The objectives of this project were:

- To demonstrate the feasibility of establishing a forage shrub reserve under the soil and climatic conditions of the Tal Rimah area.
- To demonstrate to the livestock owners and range users of the Tal Rimah area the importance and implementation of sustainable rangeland management.
- To analyze the economic profitability of rangeland rehabilitation.

Methods

Tal Rimah Demonstration Sites

Tal Rimah is situated northwest of Safawi[4] and about 70 km east of Al-Mafraq (figure 1). The demonstration site chosen for the Tal Rimah range project encompasses about 50 hectares northeast of the village of Tal Rimah. The site was selected to demonstrate water harvesting techniques and forage shrub establishment and was referred to as Tal Rimah Shrub Reserve.

A critical element in the selection of this particular site was the willingness of the herders in the Tal Rimah area to cooperate with BRDC and its partners in setting this area aside for an indefinite period as a demonstration. The local community was involved in the project from the starting point of problem definition, possible solutions, site selection of plant species suitable to the area and the intended use by livestock owners. This step was carried out by public meetings

[4] Badia area: N32^{o}17’211”, E36^{o}53’91.6”

with landowners, livestock owners and key personnel in the area. The project team consulted with the local community.

The general topography of the Tal Rimah area is gently undulating with scattered hills. Typical of the rest of the Badia, the climate in the Tal Rimah area is arid. Annual rainfall normally varies between 100 and 200 mm (figure 2). Significant rainfall is not expected to occur outside the period from late October to late March, and its timing and intensity can vary widely from event to event and year to year. Most of the rainfall occurs during January and February. Snowfall is not unknown, but is not expected every year and does not produce heavy amounts. Mean maximum and minimum air temperatures during January are 13 ^{0}C and 3 ^{0}C. Parallel temperatures are 33 ^{0}C and 17 ^{0}C for August, the hottest month in the area (BRDP 2001).

Soils in the Tal Rimah area are essentially calcareous, with textures ranging from silts to silty clays. Vegetation cover is very sparse, with large areas of bare soil. Native herbaceous plant species common to the area include: *Lolium.multiflorum, L.rigidum, Phalris canarienses, Medicago scutellata, Lathyrus sativus ,and Hordeum glucum.*

Figure 1. Tal Rimah range restoration project: northeast Jordan.

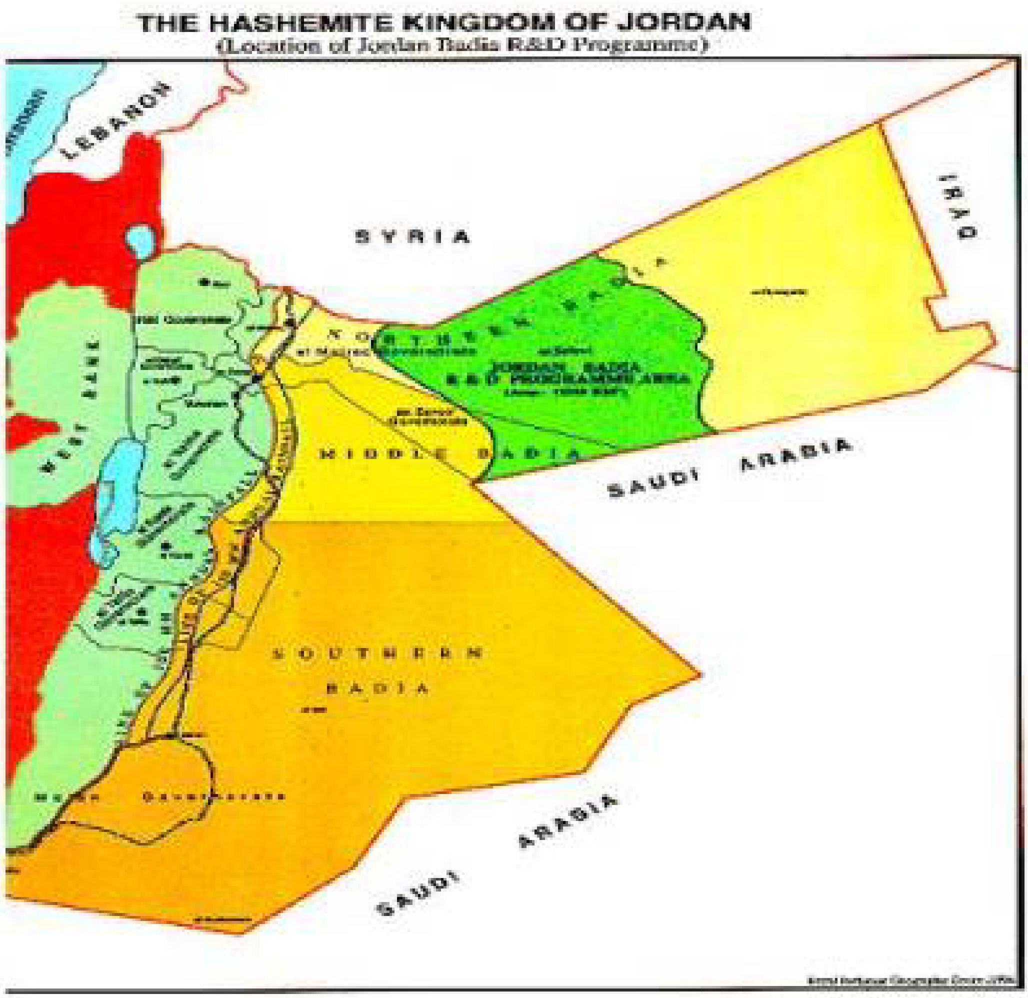
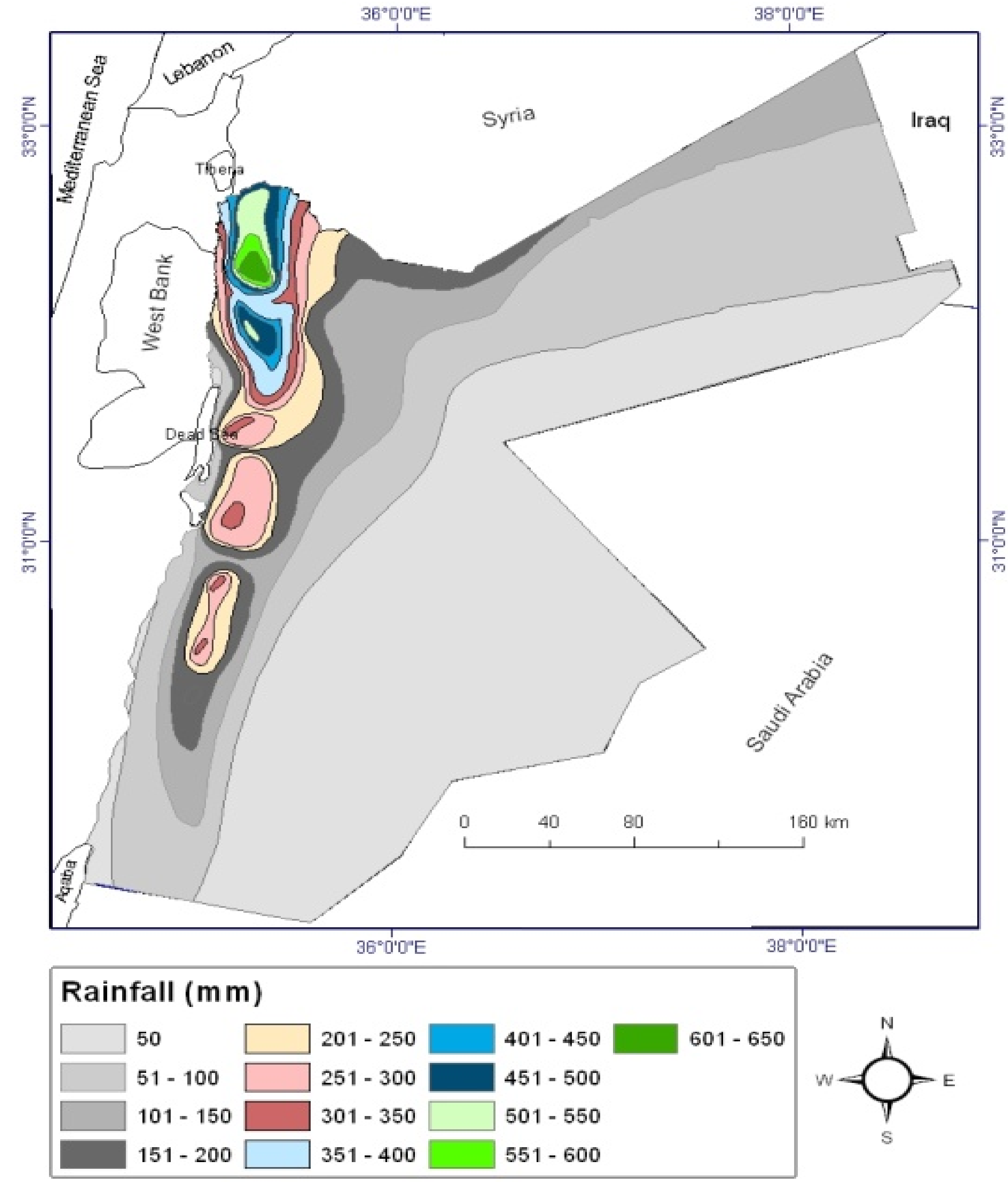


Figure 2. Average rainfall amounts in Jordan.



Community Participation

The Badia is home to about 180,000 people, or 25,000 families, of which about 18,000 households are below the poverty line (Department of Statistics 2001). Since about 98 percent of the families own at least some sheep, this means that there are about 24,500 small businesses involved in animal husbandry. These family businesses are not fully accounted for in agricultural sales or employment statistics, however, because:

- most of the animal care, shepherding, shearing, milking, and management of livestock products such as milk and wool are done by family members – mainly women and children – who do not draw wages or appear in employment statistics but are, nevertheless, employed because their work contributes to the family income, and
- a substantial portion of the products (33 percent of the wool and 44 percent of the milk and yogurt) are consumed in the home and do not enter the commercial market, but also reduce the family's need to purchase wool and milk products.

For those families, employment depends on having healthy pastures for their livestock. During the 1990s, when the average flock size declined by about half, women and young people became unemployed because the family business could no longer support them. They became a burden on government and charitable institutions, while the reduced family income caused malaise in the economic health of the communities.

There is broad consensus in development circles that only active community participation and the feeling of community ownership in project activities will lead to the continuation of intended project activities beyond the project termination date, and the final achievement of project objectives, which in many cases goes far beyond the point where a project may provide outside support. Therefore a set of activities was initiated promoting community participation, with the aim of ensuring greater sustainability of the main project outputs, related to range management and rehabilitation. Training in applying participatory methodology, and the elaboration of participatory communication/extension strategies, and the joint planning by project and land owners of small activities and their implementation were chosen as the main vehicles for introducing and making community participation operational.

Local Community Knowledge

Understanding local knowledge is a fundamental step towards generating a dialogue between local communities and scientists. It is a key reference point that local communities use to make decisions and to communicate among themselves. Scientists need to elicit, analyze and understand community knowledge if they want to contribute to the community by providing new information to them, by developing appropriate technologies with them, or communicating effectively with them.

For our purposes, local community perceptions about alternative technologies are very important, particularly the characteristics they identify to assess whether technologies are appropriate for them and whether they will adopt and maintain the infrastructure after the scientists have moved on. Not necessarily an absolute yes or no answer, assessment of technology appropriateness consists of a ranking of technologies. Knowing how to elicit these perceptions, translate them into criteria for evaluating a technology, and use them to rank alternative technologies is important for helping local communities develop and assess agricultural technologies.

Furthermore, local community knowledge may be inadequate in the presence of extremely rapid technical change, since farmers and livestock owners may not have enough experience with a technology to understand all its dimensions. Even further along the continuum, the farmer or livestock owner and scientist jointly design, manage, and analyze the experiment.

Land Preparation

The 50-hectare demonstration site was prepared to demonstrate a variety of water harvesting configurations for shrub planting. Three basic types of land treatments, or structures, were demonstrated (with approximate percentages of treated area given for each type): contour furrows (70 percent), micro-catchments (crescent-shaped or chevrons) (20 percent), and low rock walls (on lower portions) (10 percent). The contour furrow is a simple water harvesting technique which is very suitable for rangeland rehabilitation, and can be easily done with an ordinary moldboard plow. Contour furrows can be implemented on land slopes of 1 percent to 8 percent with variable soil depth (except shallow soils). A contour furrow is particularly efficient in intercepting runoff water and redistributing it with a relatively high capacity. Micro-catchments are suitable for slopes up to 8percent and are not sensitive to slope changes in direction due to their shapes which concentrate the runoff water where the crop is to be planted. Both types are highly efficient as water harvesting structures and are particularly suitable for range crops with flexibility to plant more than one seedling in each bund, or ridge. Rock walls will help to slow the runoff velocity, to control accelerated soil erosion in the small gullies (soil conservation structures) and serve as a water harvesting structure.

The design of water harvesting practices was based on several criteria including soil texture, land slope, infiltration rate, average annual rainfall, and water requirements of plants for satisfactory growth.

After several meetings with the community, *Atriplex nummularia, Atriplex halimus, and Salsola vermiculata* were chosen for introduction to the site. During the field tour for site selection, local people were interested in Salsola species because they are native to the area and because they are highly palatable. Therefore, two *Atriplex* species and one Salsola species were introduced for comparison. Rehabilitation of rangelands with appropriate shrubs, forbs or trees can add considerably to feed resources as well as stopping degradation. Among such forages are *Atriplex*, *Acacia*, *Salsola* and *Juncos* species. The *Atriplex* species represent a group of plants well adapted to salinity and drought stress. Several studies have recommended the cultivation of such forages in saline soils as good feed resources (Draz 1987, El Shaer et al. 1990, Ben Salem and Nefazawi 1993, Al-Tabini 2002).

Forage production of each shrub species was estimated during June 2003 using the reference unit method (Bonham 1989, Tadros 1987, Al-Tabini 2001). Vegetation sampling was done inside the treatment area with plots distributed randomly over portions of the area not disturbed by construction of the water harvesting structures. Outside the treatment area the plots were randomly distributed on grazed rangeland with no disturbance from construction activities. Ocular estimates of herbaceous biomass were estimated in meter-square sample plots by species. All above-ground plant biomass in each plot was collected, oven-dried and weighed (Knight 1978).

Water Harvesting

The term water harvesting is given to any work done on land surfaces to reduce rain water runoff, either directly by storing runoff water in the soil profile so that the net runoff volume (and hence soil erosion) is reduced or indirectly by storing the surface runoff in a reservoir to be used later (supplemental irrigation of crops, drinking, or for groundwater recharge). Water harvesting can be simply defined as the collection, storage, and management of rain water and runoff water for useful purposes.

A critical criterion for evaluating water harvesting techniques is the ratio between the runoff area (catchment area) and the runon area (cultivated area or storage area). The runoff area is optimized if it reduces enough runoff (adequate runoff coefficient). The runon area, where water is stored or plants are grown, must have enough storage capacity or adequate water holding capacity to supply the planted crop with water. Thus, the amount of harvested water from a certain area is a function of the amount of runoff that can be produced from that area,

Harvested water = Extra water required

The amount of runoff (for a given duration of time) is calculated by multiplying the amount of rainfall by a runoff coefficient, but since not all runoff is utilized (system efficiency), rainfall amount must also be multiplied by an efficiency factor.

Harvested water = Catchment area * Rainfall (design) * Runoff coefficient * Efficiency factor

Extra water = Cultivated area * [Crop water requirement – Rainfall (design)]

From these two equations, we get the following:

$$\frac{\text{Crop water requirement} - \text{Design rainfall}}{\text{Design rainfall} * \text{Runoff coefficient} * \text{Efficiency factor}} = \frac{\text{Catchment area}}{\text{Cultivated area}}$$

$$MC = RA * \frac{\text{Crop water requirement} - \text{Design rainfall}}{\text{Design rainfall} * \text{Runoff coefficient} * \text{Efficiency}}$$

Design rainfall is the amount of seasonal rainfall at which the water harvesting system was designed to deliver enough runoff water to meet or exceed crop water requirement. However, crop water requirements depend on crop type and climate (a crop will require more water if planted in a hot and dry climate). The design rainfall is set depending on a certain rainfall probability (occurrence and exceedence) level. The selection of a design rainfall is critical because it could lead to either crop failure or destruction of the system by flooding. In summary, five factors must be considered when designing water harvesting techniques:

1. Rainfall distribution during the season.
2. Rainfall intensity.
3. Soil infiltration rate and land surface characteristics.
4. Soil water holding capacity (soil depth and texture).

5. Type of crop to be planted (water requirements).

Tal Rimah Rainfall

During the 2002-03 rainy season, from late November to the end of March, Tal Rimah received 163 mm of rainfall, less than 10 percent above its long-term average. The rainfall was well spread out over that four-month period, with 11 measurable rainfall events yielding an average of 15 mm per event. This beneficial distribution of precipitation, in what was essentially an average year in terms of total amount, created favorable conditions for plant establishment and growth in the Tal Rimah area during the 2002-03 rainy season (Table 1).

Since the 2002-03 rainy season, the area has been in a drought. The 2005-06 season rainfall was 50 percent below average. This has negative impact on natural vegetation cover. The typical rainy season occurs between November and March each year. However, the higher amounts of rain occur in December and February when the rain is more than 50 percent of annual average.

Table 1. Annual rainfall expressed in millimeters (mm) at Tal Rimah Rangeland Rehabilitation Site. This rain gauge is maintained and monitored by the Tal Rimah project.

Month	2002-03	2003-04	2004-05	2005-06
November	20	3	17	0
December	63	52	13	8
January	12	19	24	15
February	23	19.5	52	35
March	45	11	3	4
Total	163	104.5	109	62

Construction of Water Harvesting Structures

Contour furrows were installed with a tractor-drawn implement. The micro-catchments (or micros) were constructed manually with large hoes. Water harvesting structures at Tal Rimah were installed in September 2002. After eight months of settling and stabilizing, the average height of the bunds, or ridges, above the original land surface was about 30 cm along the contour furrows and 20 to 25 cm for the micros. The resulting depth of water holding depressions averaged 40 cm for the contour furrows and 30 cm for the micros. Micro-catchments were 3.5 to 4.0 m wide between ends of bunds. Each wing of the chevron micros was about 2.5 m long. The gaps between adjoining micros averaged 1 to 2 m. Contour furrows covered 90 percent of the water harvesting treatment area and micros covered 10 percent. A total of 13,925 m of contour furrows and a total of 0.6 hectares of crescent and chevron micro-catchments were installed at Tal Rimah. Total area covered by contour furrows and micros was about 35 hectares. Total area under grazing protection was 40 hectares, which also includes about 1.5 hectares occupied by rock wall structures, with the balance as an untreated control area.

Results and Discussion

Stability of Structures

Contour Furrows. Based on field observations made immediately following heavy rains in December 2002, and during the entire winter rainy season, contour furrows performed better than micros in terms of resistance to breaching by heavy accumulations of runoff. What slight breaching of the ridges that did occur was usually at points where water flow was concentrated above the furrows in small gullies, putting additional erosion pressure on the relatively loose ridge soil below the furrows. Nothing was observed which would significantly modify either the design or continued use of contour furrows as applied in this demonstration. Given that the 2002-03 rainy season resulted in near average rainfall and five of the 11 rainfall events at Tal Rimah exceeded 15 mm, and that contour furrow ridges had not fully settled or sealed between construction and start of the runoff, the stability performance of the contour furrows was put to a moderately severe test. Performance of these structures was excellent, which is a result of a good engineering and a basically sound design.

Micro-catchments. The crescent-shaped and chevron-shaped microcatchments performed well after initial breaching was repaired in about 40 percent of the structures. More breaching was observed in the chevron micros than in the crescent micros, apparently because of the greater runoff concentration at the apex of the V-shaped catchments than in the curved structures. Location of the micros on, or close to, any existing rills or small gullies increased the tendency for breaching failure of these structures, and should be carefully avoided in any future use of micros. Degree of slope could also be a critical factor in successful location of micros, with placement on lower slopes with slower runoff offering a better chance of reliable performance. As with the contour furrows, performance of the micros was well tested by the significant amounts of runoff, which impacted these structures prior to their ridges becoming compacted. After they were repaired following initial runoff events, micros detained water as designed.

Rock Walls. Both the low rock walls intended for sediment and soil water catchment and the high rock wall diversion structure showed no weaknesses in stability. The locations were suited to their purposes.

Vegetation

Planting Period and Soil Moisture Conditions. Shrub seedlings were planted between 20 November and 20 December 2002, without any supplemental irrigation. Significant rains started at Tal Rimah by 25 November, providing adequate runoff and soil moisture for the newly planted seedlings. In fact, during the last two weeks of planting, many of the empty planting holes were full of water as a result of 60 mm of rainfall between 18 and 22 December and the effectiveness of the water harvesting treatments. This required occasional halting of planting operations due to the presence of water in the structures. In the future, if a treatment site has dry soil conditions during the planting period, some irrigation for the new seedlings may be necessary until rainfall and water harvesting provide enough soil moisture to get the seedlings established. This was not the case at Tal Rimah in 2002. No irrigation was applied to the seedlings at Tal Rimah from the period of planting through the time of this report, and no irrigation is planned or currently needed at this site.

Despite the years of drought after the beginning of the project, the shrubs survived and grown. In 2005, the rainy season was the driest year of the study, and shrubs shed their leaves in response to the drought. In general, the plant have adapted to drought either by evading drought or by resisting its effects (Pratt and Gwynne 1977).

Survival of Planted Shrubs

Seedling Survival. The most important, and least predictable, result of the Tal Rimah demonstration project was survival of shrub seedlings after transplantation to this ecologically hostile site. To start with, the seedlings were already older and larger than optimum for this purpose, and were becoming root bound in their plastic tubes. Pruning back excess foliage and careful planting at the best time of the year may have increased seedling survival. Fortunately, rains came were well distributed throughout the rainy season, as discussed above. Survival of all shrub species planted and success of water harvesting structures met or exceeded expectations. At six months from planting, the average survival rate for all three shrub species was 91 percent (Table 2). Four years from planting, average survival rate for all three shrub species was 88 percent, which is classified as an excellent result. Shrubs were adapted to the area, and the water harvesting techniques worked well. In similar past projects in Jordan, survival rates did not exceed 60 percent.

Table 2. Survival of shrub seedlings at Tal Rimah, 2002 plantings.

Shrub Species	Number planted 2002	Survival Rate June 2003	Survival Rate June 2004	Survival Rate June 2005	Survival Rate June 2006
Atriplex nummularia	3,456	88	92	90	88
Atriplex halimus	3,040	85	92	89	87
Salsola vermuclatea	3,660	86	88	90	90
Mean	10,156	86	91	90	88

Forage Production of Planted Shrubs

Biomass estimates for *Atriplex nummularia*, *A. halimus*, and *Salsola vermiculata* for different water spreading structures are given in Table 3.

Table 3. Estimated biomass of shrubs planted in different water harvesting structures from 2003 to 2006. Values are express in kilograms of dry matter (DM) per hectare (kg DM / ha).

Plant Species	Harvesting Method	2003	2004	2005	2006
Atriplex halimus	Contour furrows	23	196	345	395
Atriplex halimus	Crescent micro	15	186	279	260
Atriplex halimus	V-Shaped micro	15	133	258	332
Mean		18	172	294	329
Atriplex nummularia	Contour furrows	24	245	370	452
Atriplex nummularia	Crescent micro	21	209	314	341
Atriplex nummularia	V-Shaped micro	24	151	306	319
Mean		23	202	330	371
Salsola vermuclatea	Contour furrows	6	22	45	77
Salsola vermuclatea	Crescent micro	5	20	61	60
Salsola vermuclatea	V-Shaped micro	5	14	34	49
Mean		5	19	47	62

Statistical analysis indicated a significant production micro catchment type difference between *Atriplex nummularia* and A. *halimus*, but not for these two species when planted in contour furrows (table 3). There was no significant production catchment difference for Salsola *vermiculata* (table 3). Combined *Atriplex nummularia* and *A. halimus* biomass data structures showed a significant difference between production in contour furrows and chevron micros, but not between contour furrows and crescent micros (table 3). When biomass data were combined for all structures there was a significant difference between *Salsola vermiculata* and either *Atriplex nummularia* or A. *halimus*, but not between the latter two species (table 3). These estimates considered along with other observations from Tal Rimah suggest that contour furrows might be more efficient than micros in supporting shrub forage production.

Figure 6 shows that the biomass production increased every year. Biomass production occurred mainly during the second and third years, which constitute 80 percent of total production. This conclusion is in line with other results which stated that it is important to avoid grazing for 3 to 5 years to allow for depleted rangeland to allow shrubs to become established. Grazing studies were begun in 2007 to provide livestock forage and to avoid shrubs from growing too tall for sheep to forage on.

Natural Vegetation Inside and Outside the Treatment Area

Vegetation biomass within each water-harvesting treatment area (protected from grazing after September 2002) averaged about 950 kg/ha, oven dry basis. Adjacent rangeland outside the protected treatment area yielded 130 kg/ha. Zones close to the upslope side of the low rock walls produced 650 kg/ha, while sites midway between the rock walls yielded only 370 kg/ha. Species composition varied considerably among the samples collected for these estimates, both inside the treated area and outside. The major differences between the two zones were: (1) the total absence of the grass *Poa bulbosa* in the grazed area and (2) the greater biodiversity in the protected zone. The plant community outside the protected area is dominated by *Siedlitizia florida*, a succulent forb that is relatively unpalatable when green, but grazed readily when mature and dry.

Herbaceous forage production in the project area during the 2004 survey was 75 kg/ha inside the reserve compared to 30 kg / ha outside the reserve. Differences between inside and outside the shrub reserve show that grazing can impact rangelands and suggests a potential for greater range forage production under better grazing management. However, in the following years, herbaceous vegetation productivity declined to 27 and 16 kg / ha inside the project area, theamount for the 2005 and 2006 surveys. These differences between years are likely related to the amount and distribution of precipitation. For example, total rainfall in 2003-04 was 104mm, compared to 109 mm during the 2004-05 season; however forage production declined in 2005. During the 2003-04 season there was 55mm of rain during December 2003 (table 1), while in the 2004-05 and the 2005-06 seasons there was little early rain. Early rainfall during December is essential for rapid growth of shrubs and seed germination in arid dry areas. Similarily, the total number of the plants in 2004 is significantly greater than for 2005 or 2006. This explanation originated from the local community, and these results support the explanation. They said that early rainfall is very important for rangeland plants. If rain comes late, the season will be bad for the animals but good for the shrubs.

In the first botanical survey, which was carried out before starting the project (2002-03), there were only 22 plant species belonging to 12 different families. However after four years of protection, the number of plant species and families found in the project area was higher. Fifty one plant species, belonging to 18 families were recorded in the 2005-06 survey. In 2006, a new observation of two plant species, Crocus moabiticus and Iris aucheri, in the family of Iridaceae were recorded. This illustrates the importance of managing grazing and the potential for water harvesting techniques to increase soil moisture. This means that the soil is rich in seeds of different plant species including herbaceous and perennial plants. It is believed that the availability of moisture and protection caused the annual plants to germinate and grow. Abundant species in the 2004 through 2006 surveys are indicated in table 4.

Table 4. Most abundant species identified.

2004	**2005**	**2006**
Schismus arabicus	*Siedlitizia florida*	*Carx stenphylla*
Sisymbrium spectulu	*Bromus damthonea*	*Bromus tecorum*
Aaronsohnia factorovskyi	*Schismus arabicus*	*Schismus arabicus*
Poa bulbosa	*Poa bulbosa*	*Hordeum glaucum steujel*
Bromus damthonea	*Hordeum glaucum steujel*	*Siedlitizia florida*

Only two species present in the samples from the grazed area had a frequency greater than 25 percent, the forbs *Siedlitizia florida* (100 percent) and *Anchusa milleri* (45 percent). These two species contributed an average of 82 percent of the biomass in the plots sampled.

By contrast, natural vegetation in the ungrazed zone included six herbaceous species with frequencies greater than 25 percent and contributed an average of 20 percent each to the biomass sampled. The dominant species in terms of biomass was *Poa bulbosa*. However, the species with the highest frequency was the grass *Romeria hybrida*, which occurred in 86 percent of the samples.

These data support the hypothesis that heavy and continuous grazing results in reduction in biodiversity. Rangelands which are completely and permanently excluded from grazing by livestock could be considered unnatural from an economic viewpoint, and perhaps even from an ecological perspective. However, the goal of improving the biodiversity of range vegetation through better grazing practices and possibly the use of new forage production technologies is valid and potentially valuable.

Contour furrows (CF) constitute 80 percent of the treated area; therefore stocking rates in this case were calculated using forage production in the CF zones. Estimated average annual forage production of *Atriplex nummularia* and *A. halimus* combined was 424 kg dry matter (DM) per hectare. Estimated annual forage production for Salsola vermiculata was 77 kg DM per hectare (ha).

Thus, for purposes of estimating sheep carrying capacity of the site:

Total shrub forage production = Total DM of Atriplex species + Total DM of

Salsola vermiculata

Total DM of *Atriplex* species	=	424 kg / ha * 30 ha = 12,720 kg
Total DM of *Salsola vermulcatea*	=	77 kg / ha * 30 ha = 2,310 kg
Total shrub forage production on site	=	15,030 kg

Atriplex Palatability

In general, sheep consume 1.5 percent, 2.0 percent, or 2.5 percent of their body weight in dry matter when grazing low, average, or high digestibility forages respectively. Otsynia et al. (1982) reported that the digestibility of browse (shoots) decreased from 84 to 36 percent from April to August. Digestibility of *Atriplex* species averaged 59 percent in the spring and 49 percent in the summer (El-Aich 1992).

Sheep utilization of chenopod shrubs, as a percentage of their diet, is moderate to low when grasses are available and increases as the grasses become less available (Wilson 1966a). Most *Atriplex* species provide a reasonably high nutritive value for sheep and goats, and are useful as a feed supplement (Rizk 1986). The highest forage values for this genus are found during the wet season of the year when plants are green and actively growing (Chatterton et al. 1971; Kandil and El-Shaer 1988 and 1990).

It has been suggested that in desert regions, such as the Badia of Jordan, where the average annual rainfall ranges between 100 to 250mm, use by sheep and goats of Atriplex shrubs should be as a supplementary feed rather than as the sole feed source (ACSAD 1987). When sheep or goats browse *Atriplex nummularia* or *A. halumius* as a sole feed source, they usually are not able to fully satisfy their energy requirements. As a result they tend to lose weight (Kandil and El-Shaer 1990). Consequently, animal feed intake was estimated as 2.5 percent of body weight. The average body weight of Awassi ewes is 60 kg; therefore, and the daily feed intake was estimated to be 1.5 kg DM (2.5 percent x 60 kg).

Utilization of Atriplex shrubs should not exceed 60 percent to insure regeneration of shrubs in following years (Zaroug 1985). Estimated grazing capacity was estimated as follows.

Total available shrub forage on site	=	15,030 kg DM
Proper utilization	=	60 percent
Forage available to be grazed	=	15,103 x 60 percent = 9,018 kg DM
Estimated grazing capacity	=	9,018 kg / 1.5 kg = 6,012 sheep days

Economic Analysis

To be economically sustainable in the long run, sheep grazing must be managed to insure that the range grass and shrub re-growth during the rest period is balanced with animal needs and with long-run production of palatable leaves rather than woody stems. If the correct balance can be found and maintained in heavy and in light rainfall years, native grasses and planted shrubs should continue to produce palatable forage sustainably in the very long run, maybe as long as 25 to 40 years or more.

The increased forage production due to resting the range and planting shrubs is clearly the primary economic benefit, but that benefit must be judged relative to the cost of installing water harvesting structures[5], the opportunity loss of grazing an unimproved site during the reserve period, and the time value of money. Additional benefits, however, are substantial although not quantifiable at this stage. Higher lamb crops, less abortion and lower infant lamb mortality will follow enhanced nutrition of breeding stock due to sustainable grazing. In addition, the ecological diversity from increased plant and animal species due to habitat redevelopment will have strong long-term economic benefit as well. Although grazing trials have not yet begun, we know enough about the grazing system and the forage production to be able to begin to develop an economic analysis of the range rehabilitation scheme implemented at Tal Rimah.

Installation and Production Costs and Assumptions

Construction costs were extracted from BRDC accounting records for the development of the Tal Rimah rangeland rehabilitation project; costs of the engineer and scientists assigned to the project were not charged to this analysis in order to simulate the costs of establishing this site on a commercial basis with appropriate support from public sources (BRDC, University of Jordan, and Ministry of Agriculture (MoA)). Seedlings were provided to the BRDC by the MoA

[5] The economics of downstream impacts of water harvesting techniques such as those installed at Tal Rimah are negligible. Virtually all runoff evaporates prior to any recoverable downstream flow.

without cost, but seedlings were charged for in this analysis, again, to simulate commercial conditions. Based on three independent estimates of the grazing rental rate, we estimated the additional forage produced on the rangeland rehabilitation site to be worth 0.15JD per sheep per day. Furthermore, we used 60% forage utilization and 1.5 kg per head per day, as mentioned before, as our norm production parameters.

Building on local grazing rental practices and alternative forage sources in the area, a cost and return estimate (table 6) for sheep production was developed in consultation with BRDC, University of Jordan, and NMSU researchers, and NMSU cost and return processes (Libbin and Hawkes 2008). Because of the success of the furrows relative to the micro-catchments, we modeled a furrow-only approach.

Net Present Value

Net present value of grazing benefits was computed under several scenarios. These scenarios and results are presented in table 5. Net present value (NPV) is the best approach to compare mutually-exclusive, independent investment alternatives as it theoretically correctly accounts for the time value of money and the timing of payments and receipts. Any project with

Table 5. Installation and planting costs and parameters used in present value analysis.

		Year 0	Year 1	Year 2	Year 3
Installation and Planting Costs, JD per hectare					
Construction		84.16	3.92	3.13	1.10
Seedlings		10.58	0.75	0.37	0.07
Digging / planting		13.05			
Present value of construction & planting costs		107.79	4.36	3.06	0.96
Installation and Planting Costs, JD per hectare -- Furrows only					
Construction		81.16	1.51	2.01	1.01
Seedlings		10.58	0.75	0.37	0.07
Digging / planting		13.05			
Present value of construction & planting costs		104.78	2.11	2.08	0.88
Parameters used					
Real discount rate	7.0%				
Proper forage utilization	60.0%				
Daily feed intake (kg per head)	1.5000				
Grazing value (JD per sheep day)	0.1500				
JD / US$ exchange rate	0.705				

a positive NPV will yield a Benefit-Cost ratio in excess of 1. NPV represents the discounted value (recognizing that money received a year from today is worth less – and thus must be discounted to present value – than an equal amount of money received today).

If rainfall continues in all future years at the same pace as for 2006, there will not be enough additional new forage to justify investment in a commercial project, in fact the NPV for that scenario is just -52.41JD per hectare for the 100-hectare site. It seems contradictory to indicate that the payback period for this scenario is 19 years, especially when NPV is negative. However, the undiscounted payback period investment criterion ignores the time value of money, a central component of NPV analysis. If rainfall through Year 25 (the assumed life of the furrows) was to return to Year 2 levels (Scenario 2), NPV turns positive to 60.03JD with a payback period of 9 years. However, a reasonable assumption is that rainfall will soon return to long-term average levels (Scenario 3). With long-run average rainfall, the rangeland rehabilitation project truly proves its worth, generating a NPV of 140.87 JD per hectare and a payback period of just four years. In our experience of working with Western U.S. rangeland improvements, that is a substantial positive net return, indicating just how difficult range conditions are in the Jordan Badia currently.

NPV results were computed with a 7.0% real discount rate, a fairly low opportunity interest rate, but results at other interest rate levels were not particularly sensitive to the discount rate. Not until a 15.2% real discount rate is reached would NPV be driven to zero (i.e., the internal rate of return of the project was 15.2%).

There is some question about the sustainability of the 60% forage removal level. If a 50% forage removal level is assumed, NPV values are -60.58JD for Scenario 1 (drought level), 34.80JD for Scenario 2 (drier than normal), and 108.94JD for Scenario 3 (normal rainfall). If a 40% forage removal level is assumed, NPV values are -68.76JD (Scenario 1), 9.58JD (Scenario 2) and 77.01JD (Scenario 3). Breakeven levels are reached at 124.1% forage harvest levels for Scenario 1, 36.2% for Scenario 2, and 15.9% for Scenario 3.

One of the most critical economic values is the value of sheep grazing. While 0.15JD per sheep day is usual, values can change between individuals, over time, and regionally. Breakeven levels for sheep grazing rates are 0.273JD per sheep day for Scenario 1, 0.99JD for Scenario 2, and 0.068JD for Scenario 3.

Additional Value

While not measured specifically in this analysis, we can safely conclude that there will be a positive value placed on improved, healthier breeding livestock and resultant heavier, healthier offspring. We did not attempt to quantify that amount, but will after grazing trials have commenced. Furthermore, increased species diversity and the return of native flowering plants due to the rangeland rest are very important. They are significant enough, however, to cause us to begin to think of ways of protecting certain areas of the rehabilitation site to produce native dryland herbs in their natural habitat. The furrows constructed at the Tal Rimah rehabilitation project were surveyed and constructed with rented farm tractors. On a smaller scale, there are less-expensive means of surveying in the furrows, on a larger scale, economies from renting machinery and building structures could be significant. Supplemental irrigation of both *Atriplex* and *Salsola* species might be necessary in the year of planting, depending on rainfall conditions, but the benefits to the Jordan Badia rangeland are sufficient enough to cover substantial cost increases over the excellent establishment year encountered in this research project.

Conclusions and Recommendations

Shrub species selected and water harvesting structures were well suited to the objectives and performed well. From a production viewpoint, it might be tempting to conclude that furrows are the most successful water harvesting structure. However, performance differences between contour furrows and micro-catchments, though observable, were not sufficient to eliminate micro-catchments for future evaluations. Further observations of shrub growth and production responses to these water harvesting methods are needed to better evaluate relative differences.

Micro-catchments offer a useful option to individual landowners who wish to establish forage shrubs with a water harvesting system, but lack the mechanized power usually associated with installation of contour furrows. Small-scale shrub reserves can be established by installation of micro-catchments by hand, with simple tools that are readily available. Site selection criteria and practical guides for use of micro-catchments should be developed as part of this project. Shrub species selected for this project are well adapted to the site and performed very well in the first phase of the demonstration. Shrub survival was excellent, even recognizing that the 2002-03 rainy season was favorable for plant growth.

Survival and production performance of the three species was similar enough at the time of this evaluation to preclude any definitive ranking for future use. Grazing management studies now underway should shed light on that choice soon.

Timing of planting should be scheduled prior to the anticipated start of the rainy season. Pre-plant irrigation of seedlings, if required to maintain viability until rains begin, would be preferable to waiting for the rains to begin before planting. Wet conditions in 2002 interfered with late planting and probably reduced the growth of some seedlings.

Keeping native shrub species in any selection of species to be used under these ecological conditions should be an accepted practice for plantation projects of this kind in the Badia. This will become especially important when the technologies tested and developed in this program are disseminated to the general public under the extension phases of this project. It is not a certainty in the case of these three shrub species, because the introduced shrub performs so well, but the native species probably will tolerate a lower level of management and still survive. Further observations and additional shrub species plantings are underway within this project to help support or refute this assumption. Also, additional sites are being surveyed for further testing and demonstration in other regions of the Jordan Badia.

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