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Effect of Three Water Harvesting Techniques on Forage Shrub and Natural Vegetation in the Badia of Jordan

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Abstract: The current study aimed to investigate the effect of three water harvesting techniques on the establishment of three forage shrubs and productivity of natural vegetation at Tal Rimah (N32° 17' E36° 53'), North-eastern Badia of Jordan. Three forage shrub species (*Atriplex nummularia*, *Atriplex halimus*, *Salsola vermiculata*) were planted. The effect of three water-harvesting techniques: Contour furrows, crescent-shaped and V-shaped micro-catchments was studied on biomass production and natural vegetation. The results showed that using contour furrows gave higher shrub biomass when compared to the crested and v-shaped techniques. Moreover, both *Atriplex* species produced higher average biomass (350 kg ha^{-1}) than *S. vermiculata* (62 kg ha^{-1}), which was clearly shown in 2006. Protection of the study site for 3-4 years improved shrub production of *A. nummularia* from 23 kg ha^{-1} in 2002 to 37 kg ha^{-1} in 2006. Plant survey of the natural vegetation also indicated an increase in the number of families (18) and species (51) in the protected areas. Concluding that, for rangeland rehabilitation in the Badia of Jordan, it is important to establish reserves with the emphasis on sustainable management such as protection from grazing for 2-3 years and using water-harvesting techniques.

Key words: *Atriplex*, *Salsola*, biomass, micro-catchment, vegetation cover, diversity

INTRODUCTION

More than 80 % of Jordan is arid rangeland, generally referred to as the Badia, with average annual rainfall of less than 200 mm (IFAD, 1996). This area is not suitable for rainfed cropping. Periods of severe drought and improper grazing practices can be cited as major reasons for the deterioration of rangeland. Specifically, this could be attributed to increased grazing pressure and browsing at the wrong time for range conditions. Furthermore, cultivation of rangelands unsuited to tillage aggravates the situation (IFAD, 1999; Al-Tabini, 2001).

Vitally important challenges in the development of Jordan's Badia include combating desertification and controlling the degradation of its natural resources. One of the most effective ways of rehabilitating these depleted rangelands is the planting of saltbushes. *Atriplex* species are by far the most planted native species in the Mediterranean region in general and Jordan and neighbor countries in particular (Al-Tabini *et al*., 2008). Revegetation of degraded rangelands by the use of drought tolerant species was considered an important method (Prider and Facelli, 2004). The method of furnishing supplemental forage involves establishment of nutritious, drought tolerant shrubs in what could be called "forage shrub reserves." The shrubs can be utilized in various ways, at different times of the year depending on what the adjacent range conditions are at any given time and what the livestock requirements are? The problem of planting shrubs is mainly related to the availability of soil moisture. A key constraint to plant growth in the Badia is water shortage. The shortage of water is not caused by low rainfall as normally perceived but, rather by a lack of capacity for sustainable management and use of the available water.

The most critical management challenge is how to deal with the poor erratic distribution of rainwater leading to short periods of heavy precipitation and flooding and long periods of water deficit (Irshad *et al*., 2007). Most rains are of low intensity (1-15 mm h^{-1}), however, because of the nature of the soils and the large drop size, even the least intense rainfall causes mechanical breakdown of the surface soil aggregates and crust formation (Dutton and Shahbaz, 1999). Therefore, to insure success of establishment of forage shrubs water harvesting techniques can be used to collect rain water in areas close to the shrubs. Conservation and development of water resources are important ways to reduce human impact on water resources and environment. Water Harvesting (WH) is a promising method for development of water resources especially in the arid environment where much pressure is exerted on the ground water (Ahmed *et al*., 2007). Among the widely used microcatchment WH techniques are contour ridges, semicircular and

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Fig. 1(a-d): (a) Photograph showing contour furrows, (b) crescent-shaped, (c) V-shaped, (d) micro-catchments established for water harvesting at Tal Rimah experimental site

trapezoidal bunds and small runoff basins (Oweis and Hachum, 2004). Boers (1994) as cited by Ali and Yazar, (2007), mentioned that after transplantation, rainwater harvesting can be used to speed up shrub establishment and deep root development and to reduce the mortality rate.

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* species, *Acacia* species, *Salsola* species and *Juncos* species. *Atriplex* species (salt bushes) known in Arabic as Qataf, are major group of forage shrubs belong to the family Chenopodiaceae. They are persistent perennial shrubs that keep their foliage throughout the year. These shrubs are commonly used for extending the grazing season because of their nutritional value and chemical composition (Ortiz-Dorda *et al*., 2005; Abbad *et al*., 2004; Prider and Facelli, 2004; El-Shatnawi and Turuk, 2002; El-Shatnawi and Mohawesh, 2000). Furthermore, they are well documented for their tolerance to environmental stresses (Ben Hassine *et al*., 2008; Nedjimi *et al*., 2006).

Hence, this study was conducted to measure the effect of three water-harvesting techniques on forage shrub establishment and natural vegetation at Tal Rimah area.

MATERIALS AND METHODS

Experimental site: Tal Rimah area is situated North-west of Safawi (N32° 17' E36° 53') and about 70 km east of Al-Mafraq city. The general topography of the Tal Rimah area is gently undulating with scattered hills. As typical of the rest of the Badia, the climate in the Tal Rimah area is classified as arid. The long term average annual rainfall is about 150 mm. 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 year to year. Most of the rainfall occurs during January and February. Mean maximum and minimum air temperatures during January are 13 and 3°C, respectively. The parallel temperatures are 33 and 17°C for August, the hottest month in this area (Al-Tabini *et al*., 2008).

The soil texture varies from clay loam at the surface to clay for the rest of the soil profile. Vegetation cover is very sparse, with large areas of bare soil. Native herbaceous plant species common to the area include: *Lolium multiflorum, Lolium rigidum, Phalris canarienses, Medicago scutellata, Lathyrus sativus* and *Hordeum glucum.*

A 50-hectare demonstration site was prepared, using a variety of water harvesting configurations and digging holes for shrub planting. Three basic types of water harvesting treatments, or “structures,” were demonstrated: Contour furrows, micro-catchments (crescent-shaped and V-shaped). The contour furrow is a simple water harvesting technique, which is very suitable for rangeland rehabilitation, was easily done with an ordinary moldboard plow. Contour furrows were implemented on land slope of 1-8% with variable soil depth. Crescent-shaped and V-shaped microcatchments are suitable for slope up to 8% 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 (Fig. 1). Both types are highly efficient as water harvesting structures and are particularly suitable for

Table 1: Annual rainfall (mm) distribution at Tal Rimah, from 2002-2006

	Season (year)			
Month	02/03	03/04	04/05	05/06
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

range crops with flexibility to plant more than one seedling in each structure.

Plant materials: One year old seedlings of *Atriplex nummularia*, *Atriplex halimus* and *Salsola vermiculata* were planted November 20, 2002 without any supplemental irrigation. Significant rains started at Tal Rimah by November 25, 2002 which provided adequate runoff and soil moisture for the newly planted seedlings. During the 2002-2003 rainy seasons, from late November to the end of March, Tal Rimah received 163 mM of rainfall (Table 1) which was 10% above the long-term average for this area. The rainfall was well distributed over the four-month period, with 11 measurable rainfall events yielding an average of 15 mM per event. The good distribution of precipitation created favorable conditions for plant establishment and growth. Since the 02/03 rainy season, the area has been in a drought. The 05/06 season rainfall was 50% below the rainfall average (Table 1). This has negative impact on natural vegetation cover. However, the higher amounts of the rain occurred in December and February where the rain is more than 50% of the annual average.

Measurements: Survival rate of shrubs were measured by monitoring seedlings after plantation. Seedlings were counted 4 times at one-year interval starting from June 2003 till June 2006. Based on initial expectations sixty percent survival will be considered the minimum level for "success," either for the overall site or for any subset of the plantation (shrub species, water harvesting method and initial irrigation rate).

Biomass of shrubs was also estimated, during May and June for all the period of the study, using a nondestructive sampling, known as the reference unit technique (Bonham, 1989).

Sampling of natural vegetation was done both inside and outside the study area, during April every year using the transect method. Outside the treatment area, plots were randomly distributed on grazed rangeland with no disturbance from construction activities. The project area was divided into 4 sections, 3 of which were inside and one outside the protected area. These sections were located according to the site topographical map. Eight study points were located within the 3 sections inside the project area and one outside since there was a little vegetation cover. These points were identified and fixed with a long (1 m) metal stick. Also, these points were fixed by GPS. Three transects (30-m each) were taken from each point in three different directions. The first transect was selected towards the north, while the second and third transects were selected at 120° angle. Along each transect 5 quadrates (1 m^2 each) were taken to study the following: plant cover (%), number of different plant species and dry biomass. Ocular estimates of the biomass contribution to the vegetation of the meter-square sample plots for each species present were recorded for each plot. All the above ground plant biomass in each plot was collected, oven-dried and weighed (Knight, 1978).

Table 2: Survival rate for planted shrubs at Tal Rimah, from 2003-2006

	No. of seedlings planted at	Survival rate (%)			
Shrub species	Nov. 2002	June 2003	June 2004*	June 2005	June 2006
Atriplex nummularia	3456	88	81	73	64
Atriplex halimus	3040	85	78	70	61
Salsola vermiculata	3660	86	76	68	61
Average	3385.3	86	78	70	62

*Decrease in "dead" seedlings reported in June is because new foliage growth on some seedlings severely desiccated in January showed they were still alive

Statistical analysis: Repeated measure analysis with years as the repeated effect was used to analyze continuous response variables such as survival rate average biomass production and plant cover percentage using the SAS software, version 9 (SAS Institute, 2002). Number of plant families and species over 5 years was analyzed using Chi square analysis (Kuehl, 2000). Throughout, $p = 0.05$ was used to define statistical significance.

RESULTS AND DISCUSSION

Survival Rate of Planted Shrubs: Survival of seedlings during the first year was an outstanding success for all shrub species planted and for all water harvesting structures used. Four years from planting the average survival rate for all three shrub species was 62% (Table 2). The shrubs were adapted to the area and the water harvesting techniques worked well in producing this result. Abdul-Halim *et al.* (1990) found that survival rate of *Atriplex halimus*, *Atriplex nummularia* and *Salsola rigida* was 36, 19 and 17%, respectively. This rate is much lower than the rate obtained from current study. This could be attributed primarily to the erratic variable seasonal precipitation that dominates most of the Jordanian rangeland areas. On the other hand, Abu-Zanat *et al.* (2004) found that overall survival rate of *Atriplex* seedlings grown in Jordan, after 3 growing seasons averaged 67% under rainfed conditions; while by using water harvesting the survival rate reached 95%. The differences in survival rate value between the current study and other studies could be related to differences in the environmental condition for each case. It seems that the good rainfall received in the beginning of the season was reflected in having no significant effect of the tested water harvesting treatments on survival rate of the three shrub types used in the current study. However, Somme *et al.* (2004) found that survival rate of *Atriplex* seedlings was increased significantly as a result of using water harvesting.

Ali and Yazar (2007) reported that *Atriplex halimus* produced the highest survival rate (71%), followed by *Salsola vermiculata* (56%), *Atriplex leucuclada* (31%). These values were very close to those obtained in this study. Al-Farrajii and Al-Hilli (1994) reported that the *Atriplex* shrubs are drought resistant and can thrive well even under severe conditions. In the current study, the rainy season in 2005, was the driest season among the previous seasons, where the shrubs did not receive enough water. Therefore they shed their leaves. Never the less, the survival rate of the tested shrubs was ranged from 68% in *Salsola vermiculata* up to 73% in *Atriplex nummularia* . In general, the plants have adapted to drought either by evading drought or by resisting its effects (Pratt and Gwynne, 1997).

Forage production of planted shrubs: Statistical analysis indicated that estimated biomass which produced within contour furrows is significantly higher than the production within the crescent and V shape water harvesting techniques (Table 3). This effect was clearly shown in 2005 and 2006, after 2 years of starting the study. On average, biomass production of forage shrubs under contour furrows was 25 and 30% higher than that in the Crescent-shape and V-shape, respectively. The reason for the difference is related to the accumulation of soil moisture under the contour furrows. Ali and Yazar. (2007) said that microcatchment water harvesting is used to capture rainwater to improve soil moisture and vegetation. Another study carried out in the Syrian Badia proved the positive effect of water harvesting, where dry matter production was doubled as a result of using contour ridges (Somme *et al.*, 2004).

Combining all biomass data for all structures indicated significant differences between *S. vermiculata* as compared to both *A. nummularia* or *A. halimus* (Table 4). In 2006, *Atriplex nummularia* produced about 371 kg DM ha^{-1}, compared to only 62 kg DM ha^{-1} from *S. vermiculata*. Abu-Zanat *et al.* (2004) reported that dry matter production from *A. nummularia* reached about 613 kg ha^{-1}, this higher value could be attributed to different factors such as soil and climatic condition and

Table 3: Average biomass production of forage shrubs (kg DM ha^{-1}) as affected by three water harvesting techniques at Tal Rimah

	Water harvesting techniques		
Year	Contour Furrows	Crescent- shape	V-shape
2003	17.7g	13.7g	14.7g
2004	154.3de	138.3ef	99.4f
2005	253.3b	218.0bc	199.3cd
2006	308.0a	220.3bc	233.3bc
Average	196.83	147.58	136.68

Means of the effects of various water harvesting techniques followed with the same letters are not significantly different at $p \leq 0.05$.

Table 4: Biomass production (kg DM ha^{-1}) of 3 forage shrubs grown at Tal Rimah during 2003-2006

	Forage Shrub Species			
Year	*A. halimus*	*A. nummularia*	*S. vermiculata*	Mean
2003	17.7def	23.0def	5.4f	15.37
2004	171.7c	201.7c	18.ef7	130.7
2005	294.0b	330.0b	46.7de	223.57
2006	329.0ab	370.7a	62.0d	253.66
Average	216.6	231.35	33.2	

Means followed with the same letters are not significantly different at $p \leq 0.05$

age of shrubs. These higher value significantly differs between different species were documented by Talhouni (2009). Biomass production of *A. nummularia* was significantly higher than *A. halimus* at June and Decemebr sampling dates. This was reflected by higher leaf dry weight, stem dry weight and root dry weight (Talhouni, 2009). Also, Abdul-Halim *et al.*, (1990) reported that *A. lentiformis* grown at Iraq, produced 17800 kg ha^{-1}, meanwhile *A. halimus* and *A. nummularia* produced 2360 and 2520 kg ha^{-1}, respectively.

Biomass production is sharply increased every year. It is clearly seen that the biomass production was mainly during second and third year, which constitute 80% of the total production. This conclusion is in line with other results, which stated that it is important to leave the depleted rangeland from 3 to 5 years for rehabilitation process. Abdul-Halim *et al.* (1990) found that the growth of forage shrubs in the first year was small, but it increases after that, however there was some fluctuations in the average growth which might be related to the growth period during which the measurements were taken.

Natural vegetation inside and outside the treatment area

Biomass production: Forage production from the natural herbaceous plants found in the project area during 2004 survey was estimated as 75 kg ha^{-1} inside the reserve compared to 30 kg ha^{-1} outside the reserve (Table 5). These differences between inside and outside the shrub reserve show that grazing can have significant negative effect on these rangelands and suggests what the potential can be for range forage production under better grazing management. However, in the following years, productivity inside the project area declined from 75 to 27 and 16 kg ha^{-1}, for both 2005 and 2006,

Table 5: Natural forage biomass from different plant species growing inside and outside the study area

	Natural forage biomass (kg ha^{-1})	
Year	Inside	Outside
2004	75	30
2005	27	3
2006	16	3

Table 6: Plant cover (%) for the natural vegetation at Tal Rimah during 2002-2006

	Plant cover (%)					
Treatment	2002*	2003	2004	2005	2006	Mean**
Protected-No water harvesting	16.5de	53.5ab	47.0ab	40.0bc	17.0de	34.8
Protected-water harvesting	14.5e	58.3a	43.5b	52.0ab	26.3cd	38.9
Not protected-No water harvesting	22.0cde	61.0ab	22.0cde	11.0 de	9.0de	25.0
Average	17.7	57.6	37.5	34.3	17.4	

*Initial % cover before starting the project. **Means followed with the same letters are not significantly different at p = 0.05

respectively (Table 5). This variation between years is related directly to the differences in rainfall amounts and distribution between the seasons of the study. For example, the total amount of rainfall in 2003/2004 and 2004/2005 was 104 and 109 mm, respectively, compared to 62 mm during 2005/2006 season. From rainfall data (Table 1), we can see that in 2003/2004 season there was 52 mm of rain during December 2003, while in 2004/2005 and in 2005/2006 seasons the early rain was significantly low. It appears that early rainfall during December is essential for seed germination and rapid growth of plants in the arid dry areas. For the same reason the total number of the plants at 2004 is significantly greater than 2005 and 2006. This result is in line with the explanation which comes from the local community about the early rainfall. The local community called the early rainfall in Arabic "Harief" and consider it important for the rangeland plants and if the rain comes late, the season will be bad for the annuals but good for the shrubs.

Plant cover: Results of the vegetation survey showed that the highest natural vegetation cover percentage was obtained when the study area was protected (Table 6). This is clearly shown in the years 2003 and 2004 after one and two years of protection. As an average plant cover (%) over years, it was found that under the protection and water harvesting treatments the plant cover was 38.9% compared to 25.0% in the unprotected area and without water harvesting (Table 6). In another part of the Jordanian Badia, Al-Shawahneh (2009) found that plant cover % in the mechanized contour ridges was higher than the untreated area. She explained that this is due to more moisture conserved in the treated area. It was

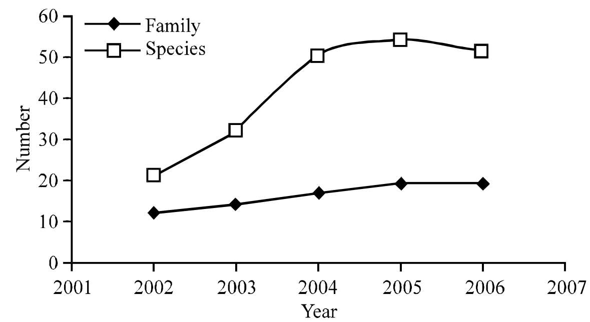

Fig. 2: Number of plant families and species naturally grown at Tal Rimah, during 2002-2006

reported by Allison *et al*. (1998) that after an average to wet winter the low-lying marabs, which are natural water harvesting systems in shallow wadis, will become dense with grasses and flowering plants. Nevertheless, the area is very small and the plants die back when the temperatures rise in late spring.

Natural plant species: The results obtained from the botanical survey showed that in the first survey which was carried out before starting the study (2002/2003), there were only 22 plant species belongs to 12 different families. However, after 4 years of protection, the number of plant species and families found in the project area was higher. Fifty one plant species belongs to 18 families were recorded in the 2005/2006 survey (Fig. 2). In 2006, a new observation of two plant species, *Crocus moabiticus* and *Iris aucheri*, in the family of Iridaceae were recorded. This appears to illustrate the importance of managing the vegetative cover and/or the effectiveness of the 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 regenerate and produce seeds for new growth. These results are in agreement to those reported by Al-Shawahneh (2009).

During 2004 survey, the most abundant plant species were as follows: *Schismus arabicus, Aaronsohnia factorovskyi* and *Poa bulbosa*. However, during 2005 survey the most abundant plant species were: *Siedlitizia florida*, *Poa bulbosa* and *Hippocrepis costricta*. While in the 2006 survey there was: *Hordeum glaucum steuje*l, *Siedlitizia florida* and *Bellevalia desrtorum* (Table 7). In general it is clear that there are certain plant species that can be considered as well adapted to the local climatic and soil conditions. Cope and El-Eisawi (1998) mentioned that most of the Jordan Badia appears without any vegetation cover, however, over 300 plant species have been identified.

Table 7: Most common plant species found at Tal-Rimah as recorded by Parkers loop

Plant species	2004	2005	2006
Schismus arabicus	147	56	70
Poa bulbosa	63	103	23
Gymnarrhena micrantha	20	45	0
Malcolomia conringiojes	31	0	39
Siedlitizia florida	26	228	95
Matthiola aspera	32	0	0
Carx stenophylla	8	35	0
Adonis dentate	8	0	0
Bromus damthonea	18	62	41
Sisymbrium spectulum	10	0	0
Hordeum glaucum steugel	8	58	131
Bellevalia desrtorum	30	12	86
Lasiopagon muscoides	24	0	0
Allium trancatum	0	0	0
Silene vulgaris	20	0	0
Aaronsohnia factorovskyi	83	34	32
Hippocrepis costricta	0	67	5

CONCLUSIONS

From the results of this study we can conclude that contour furrows more efficient than other techniques in supporting shrub forage production. The use of native plant species (*Salsola vermiculata* and *Atriplex halimus*) demonstrated high potential. On the basis of the rainfall patterns, it is recommended that any planting should be late November or early December where the seedlings and the seeds will get enough rain to ensure plants establishment. It is important to leave the depleted rangeland from 3 to 5 years for rehabilitation process. Early rain fall is very important for the rangeland plants and if the rain comes late, the season will be bad for the annuals but good for the shrubs. Appearance of a sensitive plant species (*Crocus moabiticus* and *Iris aucheri*) is strong evidence that the ecosystem habitat is healthy.

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