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Effect of Micro-catchment Water Harvesting on Soil-water Storage and Shrub Establishment in the Arid Environment

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ABSTRACT

Potential of micro-catchment water harvesting (MCWH) to conserve soil-water and establish shrubs on a degraded land in an arid environment was studied. A research site was developed on 100 ha in Syrian rangelands having an average annual rainfall 117 mm. Contour ridges with 6 and 12 m spacing were built by using mechanized implements and 10,000 shrubs were planted with direct seeding and seedling methods. Rainfall, soil-water and shrub survival and growth parameters were measured. Results revealed that water at shrub location site was 1.2-4 times higher than the soil-water in micro-catchment area. Soil-water remained below wilting point during dry spells and increased after each runoff generating rainfall event. After 24-36 hours of rainfall, the soil-water was high in layers between 15 and 45 cm and low below 60 cm depth. Shrub survival rate was highest for *Atriplex halimus* (71%) followed by *Salsola vermiculata* (56%) and *Atriplex leucuclada* (31%). Efforts to raise shrubs by direct seeding method were not successful as only a few seeds germinated and none of them survived. Very low rainfall during second year (44 mm) contributed to low survival rate. In general, the shrub growth was slow but it was highest for *A. halimus* and lowest for *S. vermiculata*. The study showed that *A. halimus* due to its high survival and growth rate, is suitable for this environment.

Key Words: Arid environment; Micro-catchment water harvesting; Soil-water; Shrub survival

INTRODUCTION

Arid environment constitutes a large part of the globe and suffers from various degrees of land degradation. Dry hydro-climate; where water is a limiting factor for biomass production, combined together with fragile and inherently low fertile soils, implies higher degree of vulnerability (Falkenmark, *et al.*, 1990). Degradation of rangelands; a main source of livelihood in arid environments, is generally linked to poor management of water resources and exploitation of vegetation cover. Eastern Mediterranean countries consist of vast rangelands, which are largely degraded. Syria alone has about 8.3 million hectares rangeland, which is 55% of the total area of the country (Syrian Ministry of Environment and UNDP, 1997). The average annual rainfall varies between 50 and 200 mm and its unproductive losses are high. The vegetation cover is sparse and its grazing capacity is reduced to less than one-fourth. Development of surface crust discourages *in-situ* infiltration and encourages a large part of rainfall to runaway with little benefits to local environment.

Micro-catchment water harvesting (MCWH) can be used to capture rainwater to improve soil-moisture and vegetation. After transplantation, rainwater harvesting can be used to speed up tree establishment and deep root development, and to reduce the mortality rate (Boers, 1994). According to Gatot (1999), water harvesting could increase crop productivity and diversity, decrease soil erosion and rehabilitate degraded lands. A higher runoff efficiency of micro-catchments can capture a large proportion of the rainfall as run-on and concentrate this additional water for shrub establishment. Stern (1979) inferred that under same hydrological conditions, a runoff equal to 50% of incident rainfall may be expected from small area as compared with river basin where it hardly reaches to 5% of the rainfall. Nevertheless, degree of success of MCWH in shrub establishment can vary with the environment depending on the rainfall, soils and shrub species. Bunch (2000) emphasized on research need for MCWH conducive to specific agroclimatic and socioeconomic environment. The objective of this study was to evaluate effectiveness of the MCWH to improve soil-water storage and establish fodder shrubs in the Syrian rangelands.

MATERIALS AND METHODS

A research site was selected (34°-08'N & 37°-09'E; altitude, 894 m) in Syrian rangeland near Qaryatein town at about 120 km in northeast of Damascus. Arid climate with an average annual rainfall of 117 mm prevails in the region (Table I). Depth-integrated soil samples at 20 cm incremental depth and their analysis determined important properties of the soil. The soil depth varied between 30 and 80 cm and described as sandy-clay-loam. The samples were tagged, processed and divided by using Riffle type sample splitter in ICARDA Soil Laboratory. Mechanical analysis of the soil was carried out by using hydrometer with Bouyoucos scale (Bouyoucos, 1962). Chemical analysis was carried out by extraction method for organic matter (Walkley, 1947; FAO, 1974), total and mineral nitrogen (Bremner & Mulvaney, 1982), and electrical conductivity (Richard, 1954). A 100 ha of land with slope 2-5% was developed with continuous and intermittent contour ridges by using Vallerani and Pakistani implements. The spacing between the ridges were fixed 6 and 12 m. The treatments included Vi-12, Vi-6, Vc-12, Vc-6, P-12 and P-6, where Vi, Vc and P denote Vallerani intermittent, Vallerani continuous and Pakistani and 6 and 12 represent spacing between the contour ridges. Around 10000 plants of three shrubs species *Atriplex halimus*, *S. vermiculata* and *A. leucuclada* were planted by direct seeding and seedling transplantation, during December 2004 and January 2005. Shrub to shrub distance was kept at 4 m, which created micro-catchments of 24 and 48 m^2 area. Each treatment was replicated three times in three blocks. Somme *et al.* (2004) in another study in the same environment, showed a shrub survival rate of 2-5% in control conditions. Due to very low probability of survival, the shrubs in control treatment were not planted. Soil-water was measured by gravimetric means in the top 15 cm soil layer and by Neutron probe for each incremental layer of 15 cm to a depth of 90 cm at 99 access tube locations in catchment and planted areas. An automatic weather station and two rain gauges were installed at site to measure the rainfall and climatic parameters. Soil-water was measured periodically and after 24-36 hours of each rainfall event. Shrub survival rate was estimated by counting total number of shrubs survived at the end of each growing season. Shrub growth was measured by volume as cutting and weighing was not feasible in dormant period during first two years. Shrub canopy was measured through shortest diameter (d_1), longest diameter (d_2) and canopy height (h). A total of 927 shrubs were measured from all the treatments. Change in soil-water for each incremental soil layer was estimated by using:

$$SWS = \left(\theta_{v2} - \theta_{v1}\right)\frac{D}{100}$$

Where,

SWS, is soil-moisture storage (mm), θ_{v1} and θ_{v2} are volumetric water contents (%) before and after rainfall, and *D* is the thickness of soil layer. Summation of *SWS* estimated the soil-water change in soil profile. Difference of soil-water change in catchment and target area was used as an indicator of water harvesting.

RESULTS AND DISCUSSION

Soils. Soils of study site consisted of sand (50%), silt (18%) and clay (32%). Clay contents slightly increase and sand decreases with depth. Field capacity (25-34%) and wilting points (11-13%) depict plant available soil-moisture 14-21%. Organic matter (0.8-1.2%) was deficient. Total

Fig. 1. Distribution of water contents in soil profile after 36 hours of rainfall on 24 Oct, 2006

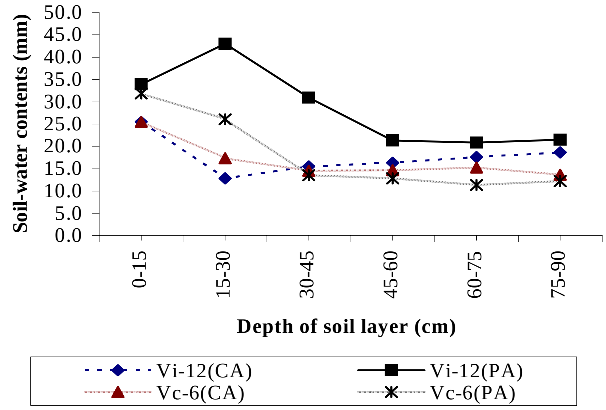
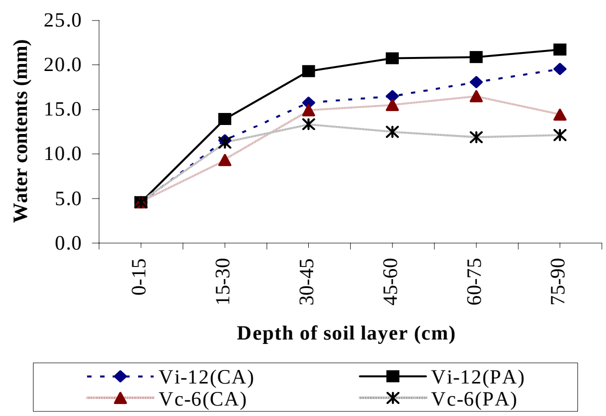


Fig. 2. Distribution of water contents in soil profile during rainless period (28 August 2006)



nitrogen (419-658 ppm) was almost half the critical value (0.11% or 1100 ppm; Sobulo & Adepetu, 1987). Available nitrogen (Min-N) varied between 15 and 34 ppm. Plant available Phosphorous (Olsen-P) varied between 4 and 9 ppm and decreases with depth (P less than 6 ppm is considered as critical). Electrical conductivity (0.8-18 dS m^{-1}) increased with depth. Landon (1984) showed that soil is saline if EC value exceeds 4 dS m^{-1} (0-2 salt free, 2-4 slightly saline, 8-15 moderately saline and >15 strongly saline). These soils are common in arid regions. Exchangeable potassium (K = 2.5-9.5 meq L^{-1}) was higher than the critical value (0.2 meq 100gm^{-1} or 2 meq L^{-1}). Overall the soils were deficient in nutrients.

Rainfall. Long-time annual rainfall data at Qaryatein near study site (1958-93) showed average annual rainfall 117±38.09 mm and coefficient of variation 35%. The standard deviation was high as compared to temperate climates where it varied between 10-20% (Thames, 1989). The annual minimum rainfall was 26% of the annual maximum and about 50% of the average annual rainfall. Annual rainfall varied between 45 and 160% of the average

Table I. Mean-monthly climatic parameters at Qaryatein (1958-93)

Climatic parameters	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Annual
[1]Mean rainfall (mm)	13.6	14.6	23.7	13.7	17.4	0.1	0.0	0.0	0.2	8.7	12.6	12.6	117.2
Mean temp. °C	6.4	6.5	8.84	13.8	21.3	23.7	26.6	25.7	22.8	17.7	11.8	7.0	16.0
Mean max. temp °C	10.5	12.3	14.5	22	29.1	32.8	34.3	34.0	30.5	25.2	18.6	12.8	23.0
Mean mini. temp. °C	0.7	-0.2	2.0	6.2	11.7	14.8	17.5	16.3	13.1	8.2	5.9	1.6	8.1
Mean relative humidity (%)	73.9	64	58.2	51.7	34.7	43.9	45.2	48.7	48.2	50.6	61.7	73.1	54.5
[2]Mean wind speed (m/s)	3.4	3.73	3.74	4.05	4.15	4.63	5.9	4.3	3.8	3.2	3.6	4.1	4.0
Ref. evapo-transpiration (ETo) in mm	40	60	87	136	222	222	218	223	194	147	79	43	1671
P/ETo	0.34	0.24	0.27	0.10	0.08	0.00	0.00	0.00	0.00	0.06	0.16	0.29	0.07

[1]Based on data from 1956 to 1993; [2]Based on data from 1967 to 1983; ETo is based on data from 1958 to 1988; Underlines figures represents annual total.

Table II. Change in soil-water in catchment and planted areas for major rainfall events

Date	Event rainfall (mm)	Soil-water contents (mm/90cm) for various treatments: Vi-12		Vc-12		P-12		Vi-6		Vc-6		P-6	
		CA	PA	CA	PA	CA	PA	CA	PA	CA	PA	CA	PA
4/18/05		97.3	109.7	85.5	90.1	61.3	115.0	103.9	84.2	90.4	77.1	102.0	103.5
4/25/05	8.1	110.9	128.3	94.9	105.4	79.2	133.8	122.5	101.9	105.6	95.8	119.5	126.3
Change in water contents		13.6	18.6	9.4	15.4	17.9	18.8	18.6	17.8	15.2	18.7	17.4	22.8
%age increase in water contents		14.0	17.0	11.0	17.1	29.3	16.4	17.9	21.1	16.8	24.3	17.1	22.0
5/2/05		104.7	116.3	91.6	93.9	73.1	119.9	110.7	92.1	98.2	84.9	108.3	109.9
5/5/05	13.1	118.1	142.1	100.1	114.2	84.1	140.2	125.7	109.0	117.5	106.2	121.8	134.2
Change in water contents		13.4	25.8	8.5	20.3	11.1	20.3	15.0	17.0	19.3	21.4	13.5	24.3
%age increase in water contents		12.8	22.2	9.2	21.6	15.2	16.9	13.6	18.5	19.6	25.2	12.5	22.1
1/23/06		89.8	102.8	69.5	81.2	59.5	107.6	98.9	78.2	81.8	71.0	97.3	98.3
1/24/06	5.3	96.3	109.1	71.4	84.3	64.0	111.1	99.4	79.4	86.8	74.6	98.7	100.4
Change in water contents		6.6	6.3	1.9	3.1	4.5	3.5	0.5	1.1	5.0	3.7	1.4	2.1
%age increase in water contents		7.3	6.1	2.7	3.8	7.6	3.3	0.5	1.4	6.1	5.2	1.5	2.1
4/3/06		94.3	106.6	70.7	81.3	63.1	111.6	101.1	79.3	84.6	73.1	97.5	101.5
4/6/06	6.4	100.9	132.6	77.0	106.4	70.3	135.8	107.5	118.4	91.0	97.6	105.0	126.0
Change in water contents		6.6	26.0	6.2	25.1	7.2	24.2	6.4	39.1	6.5	24.5	7.5	24.5
%age increase in water contents		7.0	24.4	8.8	30.9	11.4	21.7	6.3	49.2	7.6	33.5	7.7	24.2
8/28/06		86.0	101.2	56.6	72.8	54.1	102.2	86.8	75.5	75.3	65.7	86.4	92.0
10/26/06	26.2	106.5	171.5	89.3	120.6	79.4	133.0	110.4	158.4	101.0	108.1	109.3	154.2
Change in water contents		20.5	70.4	32.7	47.8	25.3	30.8	23.7	82.9	25.8	42.4	22.9	62.1
%age increase in water contents		23.9	69.6	57.7	65.7	46.7	30.1	27.3	109.9	34.2	64.5	26.5	67.5

CA = catchment area; PA = Planted area

Table III. Shrub survival rate for various MCWH techniques

Year	Rainfall (mm)	Species	Survival rate (%) for MCWH techniques: Vi-12	Vi-6	Vc-12	Vc-6	P-12	P-6	Average
2004-05	127.5	AH	92	80	98	81	91	77	87
May, 2005		SV	86	70	89	73	82	82	87
		AL	73	61	79	54	85	58	68
2005-06	44.1	AH	75	77	71	79	64	62	71
May, 2006		SV	75	68	47	69	59	17	56
		AL	30	32	22	43	30	26	31

AH= Atriplex halimus, SV = Salsola vermiculata and AL = Atriplex leucuclada
Vi-12 = Vallerani intermittent with 12 m spacing, Vi-6, Vallerani intermittent with 6 m spacing, Vc-12 = Vallerani continuous with 12 m spacing , Vc-6 = Vallerani continuous with 6 m spacing and P-12 and P-6 stand for Pakistani implement with 12 and 6 m spacing respectively

annual rainfall. Based on FAO (1981) criteria the dry, average and wet conditions occurred in the study area for about 30, 59 and 11% of time respectively. The annual rainfall was just 8% of the reference evapo-transpiration. Monthly rainfall-evapo-transpiration ratio (Table I) from May to October was soil-moisture stress period. UNESCO (1977) climatic zoning, on the basis of rainfall-evaporation ratio, places the research site environment closer to the margin of arid to hyper-arid zone. This environment poses limitation to plant survival and growth without additional water.

Soil water. Analysis of the total soil profile showed that the soil-water increased from 17 to 70% in planted area with water harvesting as compared to 9 to 58% in catchment area for different rainfalls (Table II). For 26 mm rainfall, the increase in soil-water storage in planted area was 1.5-4 times higher than the catchment area for various treatments. It was 1.2-3 times higher for 13 mm and 1.2-1.5 times higher for 8 mm rainfall. During dry spells, the soil-water was below wilting point in catchment area, when it

Fig. 3. Growth rate of Atriplex halimus (AH), Atriplex leucuclada (AL) and Salsola vermiculata (SV) for Vi-12 treatment.

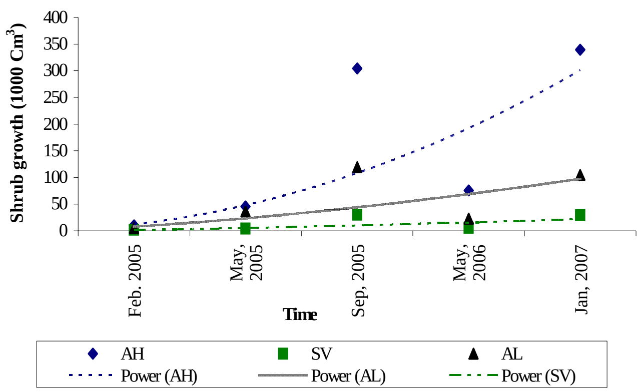
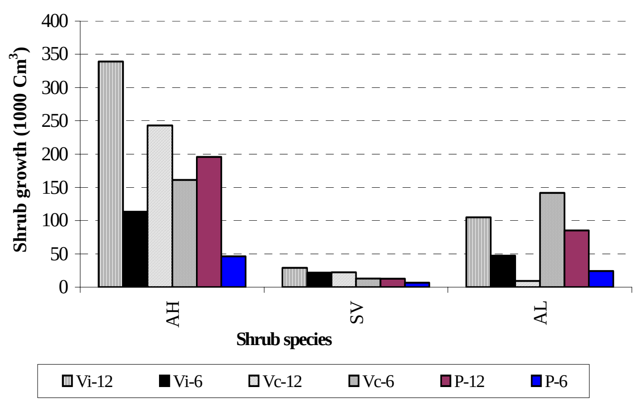


Fig. 4. Shrub growth in relation to shrub species



remained above wilting point for most of the time in planted area. Soil-water below wilting point in micro-catchments minimized the chances of survival of shrubs under control conditions. The high soil-water contents in planted area showed the strength of water harvesting by the micro-catchments. Fig. 1 shows a typical case of soil-water distribution in different soil layers as a result of rainfall event on 24 October 2006. The soil-water after 36 hours of rainfall was maximum in layer 15-30 cm layer followed by 30-45 cm layer. The soil-water reduced to minimum below 60 cm depth. In rainless period (June to August, 2006), the soil-water was between 10 and 20 mm in 15-30 and 30-45 cm soil layers (Fig. 2), which is a dominant rhizosphere. The soil-water during rainless period was below wilting point (13%) for most of the treatments.

Shrubs survival and growth. The survival rate of shrub planted by seedling method was 87% for *A. halimus* and *S. vermiculata* and 68% for *A. leucuclada* by the end of first rainfall season and dropped to 71%, 56% and 31% for *A. halimus*, *S. vermiculata* and *A. leucuclada* respectively in second year (Table III). The shrub survival across MCWH techniques did not differ significantly. Low rainfall in 2005-06 (44 mm) could be one reason for this insignificant difference. No seed germinated; therefore, shrub rising with direct seeding method was not successful. Shrub growth with time (Fig. 3) showed flat trends, which is an indication of a slow growth rate. Shrub growth in relation to shrub species showed that *A. halimus* performed better followed by *A. leucuclada* and *S. vermiculata* (Fig. 4). Comparing the performance of techniques, Vi-12 performed relatively better, followed by Vc-12 and P-12. Overall, on the basis of better survival and growth rates shrub *A. halimus* can be regarded as better performing species.

CONCLUSIONS

In arid environments such as Syrian rangeland, where rainfall is very low, MCWH can increase the soil-water at shrub location and help in shrub establishment. A micro-catchment area with 12-m slope length performed relatively better in this study; however, it cannot be generalized as other factors such as land slope, soil type and rainfall intensities also play important role. Shrub survival rate was low for *A. leucuclada* and high for *A. halimus*. Growth of *A. halimus* was also better, followed by *A. leucuclada* and *S. vermiculata.* Based on better shrub survival and growth, *A. halimus* was found the most suitable for the study environment.

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