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Assessing the Potential of Rain-Water Harvesting (*in situ*) for Sustainable Olive (*Olea europaea* L.) Cultivation in Water-Scarce Rain-Fed Areas

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Abstract

The improvement of water productivity in olive cultivation and its production on sustainable basis in areas marked as water deficit. The most essential, natural and cheapest water resource in such water-prone areas of the world is rainfall. The collection and constructive use of rain-water runoff, also known as water harvesting, has the potential to cope with the water scarcity in the semi-arid and dry, sub-humid regions of the world to sustain olive production. Among all the available micro-irrigation techniques, construction of micro catchments can help farmers to produce crops such as olive orchards with minimum water resources. Research experiments were conducted at Barani Agricultural Research Institute (BARI), Pakistan situated in region where the climate is semi-arid subtropical and the annual rainfall varies from 500-1000 mm. To compare water productivity of different micro-catchment methods, three field plots with three different shapes i.e., square, rectangular, and triangular (V shape) were constructed with 3-5% slope. Olive trees, due to their expensive premium quality edible oil and natural adaptability to grow in marginal lands and better drought tolerance, were used as subject crop to evaluate the performance of micro catchments rain water harvesting techniques. Results concluded that micro catchment structures showed significantly better yield (8-9%) as compared to control and are best suitable to sloppy terrene. Only three supplement irrigations were required for sustainable olive plant cultivation through drip/bubbler irrigation system. Average effective rainfall of both years was 594 mm from which 505 mm (85%) was used by olive plants in micro catchments. Conclusively, micro-catchment structure can be utilized as efficient technique to harvest rain water and sustainable cultivation of olive in semi-arid and arid climates.

Keywords: Runoff micro-catchments; Rain-water harvesting; Micro irrigation; Water productivity; Olive (Olea europaea L.)

Introduction

Olive (*Olea europaea* L.) is a drought-tolerant tree which is usually grown in areas with a Mediterranean climate that receive more than 350 mm of annual rainfall. However, olive cultivation has now expanded into drier areas (200-300 mm annual rainfall) where irrigation resources are limited [1]. It can be grown in areas with dry-land conditions with little rain-fall during its critical phonological phases for fruit formation. Olive is among fruit trees known for their high dietetic, economic and social impacts. Due to its international demand for its edible oil and table olives, olive cultivation has now been expanded to many regions of the world with arid and semi-arid climatic conditions that are considered marginal and even unsuitable for other conventional crops.

Rain-fed agriculture provides nearly 60% of global food, which is about 72% of harvested land and delivers livelihood to approximately 70% of the world's poverty where income options outside the agriculture are limited. Water availability is considerable constraint in olive cultivation and the improvement of water productivity in this agriculture sector is a great step towards alleviating the poverty in these water-scarce areas of the world by promoting olive culture on sustainable basis. Conventional irrigation methods are expensive and beyond the reach of remote areas where un-availability of irrigation water is the sole constraint to crop production. Rain-water is the only source of irrigating field crops. Improving management methods for better crop, rain-water resources, maintaining soil moisture, and supplement irrigation are the key factors to improve water productivity and livelihood of these areas [2,3]. The occurrence of surface runoff is common in arid regions where high rainfall intensities, shallow soils, dense surface crusts, and poor vegetative cover often cause the rainfall to exceed the infiltration capacity of the soil. Collection of this runoff water may allow crops, shrubs, and trees to grow in areas where the natural rainfall alone would not be sufficient for their growth.

Conventional irrigation techniques involve utilization of rain water after it has infiltrated into the ground, using underground water, water from rivers and streams. But the techniques used in this study involve collection of rain-water before in enters the soil. Thus the collection of runoff and its use to grow agriculture crops, trees and pastures is called as water harvesting. Rainwater harvesting structures can be very useful for semi-arid and dry, sub-humid regions especially as water scarcity is caused by extreme variability of rainfall rather than the amount of rainfall [4]. Water productivity can be enhanced by either improving the production per unit of water consumed, or by maintaining the same production while reducing water use [5,6]. Micro-catchments can capture this local runoff, reduce transmission losses and concentrate it into the plant basins [7]. Micro-catchments collect surface runoff over a flow distance of usually less than 100 m and store the water in the adjacent root zone of a crop, or of one or several shrubs or trees. Typical examples of micro-catchment systems are small basins, semi-circular bunds, and contour ridges. Advantages of micro-catchments as compared to macro-catchments are that these smaller systems have higher runoff efficiency, absence of requirement of water conveyance or storage facilities, are less susceptible to destruction by heavy storms and can be installed by small farmers using commonly available tools and resources [8].

Therefore, keeping in view the increasing demands of olives, frequently occurring droughts due to abruptly changing climatic conditions, less water availability in these areas and their dependency on rain-water, this research study was organized to optimize sustainable

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irrigation conditions for the olive cultivation in rain-fed areas of the world including Pakistan. In this study, different structures of micro irrigation methods were used to compare their water productivity and water use efficiency to increase the yield of olive trees. This can help the farmers to encourage olive culture in semi-arid and water-scarce areas with minimum water resources where other cash crops are not sustainable.

Methodology

The experiments were conducted at Barani Agricultural Research Institute (BARI) located within 72° longitude, 32° latitude and 575 m altitude in the district Chakwal, Pakistan from 2013 to 2014. The climate of Chakwal is semi-arid subtropical and the annual rainfall varies from 500-1000 mm most of which falls during monsoon (Figure 1) in the form of high intensity showers. The area also receives winter showers of lesser intensity during December to February. Rainfall if not managed, it quickly evaporates or runs as flash floods into saline sinks. The soils of the experimental area are piedmont alluvial. The pH of the soil varies 7.8-8 and field capacity of the experimental area varies from 14-15% by volume and permanent wilting point varies from 4-5% by volume. The soil contained sand (43-55%) followed by silt (49-58%) and clay (8%) and could be classified as sandy loam [9]. Soil characteristics of micro catchment structures are given in Table 1.

Rainfall data for the last 37 years (1979-2014) was collected to investigate the rain water collected and consumed by the olive plants by establishing micro catchment rainwater harvesting structures. Maximum rainfall occurs over a few months (Figure 1) during July to September (Table 2). As a result, the soil saturates and runoff water flows into saline sinks. The uneven distribution also creates a situation of long dry periods.

Three field plots were selected to evaluate the performance of three different shapes; square, rectangular, and triangular or V shape (Figures 2-4)

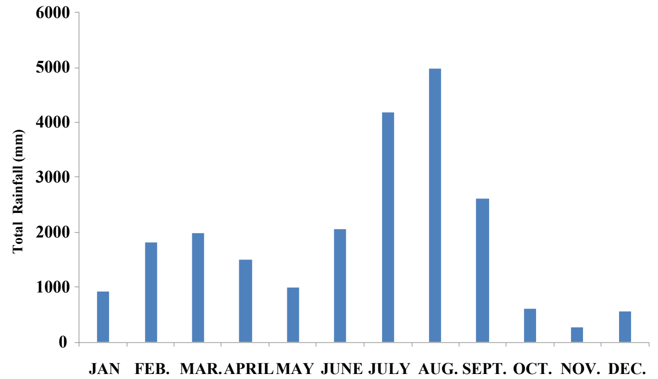

Figure 1: Rainfall pattern of Chakwal District (1979-2014) in Pakistan.

Characteristics	0-0.15 m	0.15-0.3 m
EC (ds/m)	0.3	0.25
Organic matter (%)	0.6	0.33
N (%)	0.8	2
P (ppm)	5	3.4
K (ppm)	138	132
pH	7.68	7.79
Sand (%)	60	
Silt (%)	30	
Clay (%)	10	

Table 1: Soil characteristics of the Micro catchment structures.

Rainfall	Duration	Annual rainfall (%)
Pre Monsoon	March-May	20
Southwest Monsoon	June-September	62
Post Monsoon	October-December	7
Winter or north east monsoon	January-February	11
Total	Annual	100

Source: Met observatory at Soil and Water Conservation Research Institute, Chakwal, Pakistan (1979-2014)

Table 2: Distribution of rainfall by season in Chakwal.

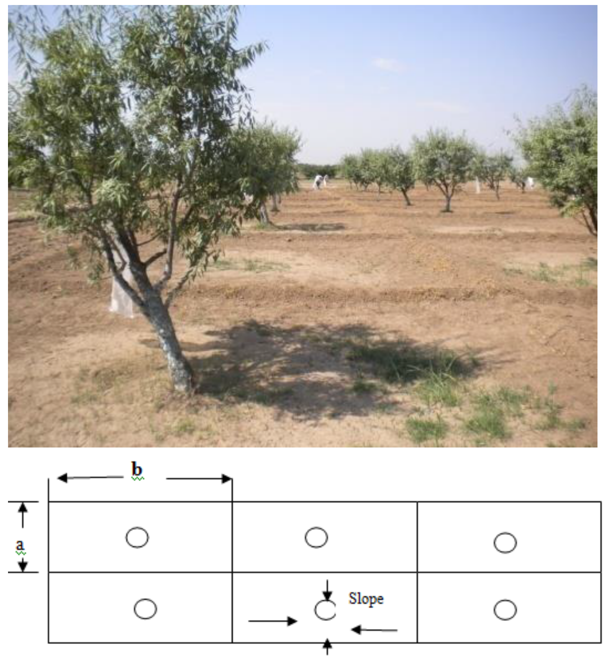

Figure 2: Rectangular micro catchment structure.

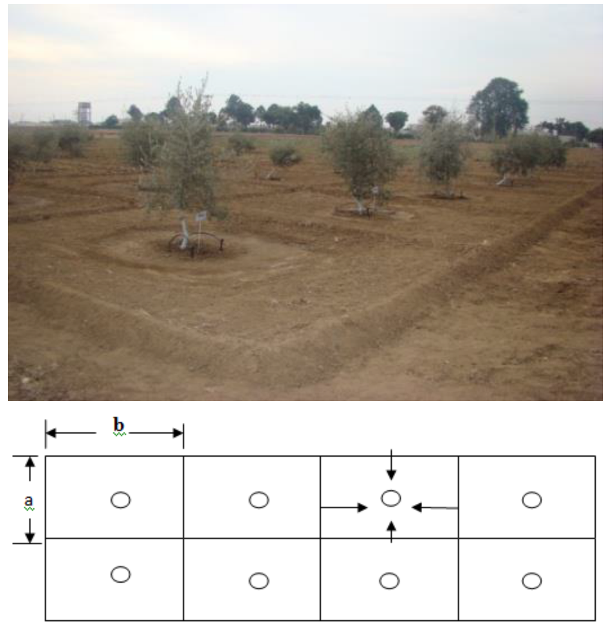

Figure 3: Square shape micro catchment structure.

and sizes were manually constructed with 3-5% slope (Table 3) micro catchment rain water harvesting techniques on olive with 18 ft × 18 ft plant spacing for olive plants at experimental site to harvest rainwater. To design efficient micro-catchment water-harvesting systems, the optimum ratio between catchment and cultivated area was estimated where catchment area (C) which generates runoff, and the cultivated basin (CA) where the runoff was concentrated, stored and productively used by plants. Moreover, C/CA ratio, average plant height, average plant canopy (m) and average slope (%) from each shape of micro catchment structure were also measured (Table 3).

In absence of developed soils and vegetation cover in arid environments, raindrop impact on bare soil, degrades the soil structure, creates surface crust and prohibits infiltration. This phenomenon helps to generate local runoff (or run-on) even from small rainfall amount.

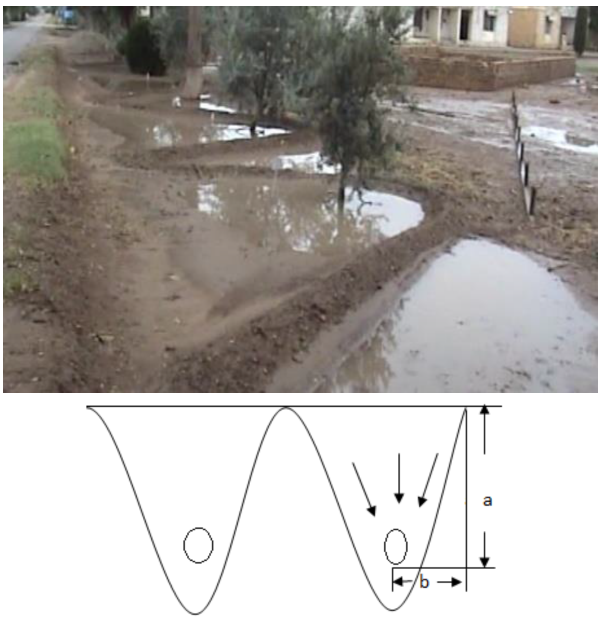

Figure 4: V shape micro catchments.

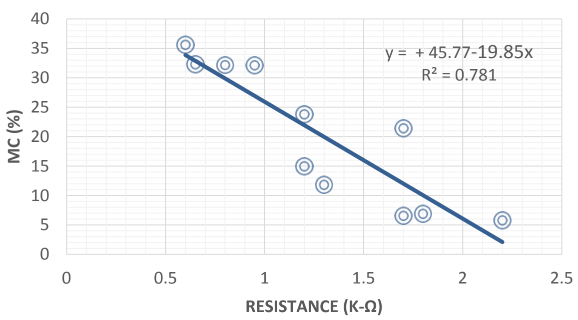

Figure 5: Charts and equation drawn from gypsum block data.

The run-on takes a form of sheet flow until concentrating in clearly defined channels or lost during downstream transmission [10]. A small ridge across the sloping land can capture the sheet flow and develop a micro-catchment basin (Figure 2-4). The micro-catchment concentrates the rainwater into plant basin at the downstream end of the micro-catchment. Harvested water is stored in plant basin.

The soil water balance approach (SWBA) was used to measure changes in soil-water storage in the catchments and the plant basins. These changes were then compared to the incidental rainfall through evapotranspiration (ET_o) and deep percolation (DP). The plant basin area was 4.6 m^2 for all three shapes. Soil moisture in this study was measured from gypsum block devices. Three sets of gypsum blocks were installed at three different depths (0.3 m, 0.6 m, 0.9 m) and monitored the behavior of moisture contents in three shapes of micro catchment structures for two years (2013 and 2014). Before the installation of gypsum blocks in the field, they were first calibrated by soaking them in the soil tray for three days and continuously taking the data of moisture contents along with resistance, and then by using this set of data, charts and equations were drawn (Figure 5), between resistance and moisture contents. And these equations then were used to monitor moisture contents in the micro catchments. The equation developed separately for each gypsum block, Figure 5 is the example of one gypsum block.

Results and Discussions

In 2013 & 2014, 823 & 770 mm rainfall were received respectively (Figure 6) that created a large number of runoff. The success or failure of rainwater harvesting depends to a great extent on the quantity of water that can be harvested from an area under given climatic conditions. The threshold retention of a catchment is the quantity of precipitation required to initiate runoff; it depends on various components such as surface storage, rainfall intensity, and infiltration capacity. For a more efficient and effective system, it was necessary to calculate the ratio between the two if the data related to the area of concern in terms of rainfall, runoff (Table 4) and crop water requirements is available [11].

The calculations depicted in Table 4 showed that triangular (V shape) micro catchment structure produced more runoff and harvested more rainwater in comparison with rectangular and square shape. The soil moisture contents distribution in different shapes (Figures 7-9) for the year 2013 and 2014 showed the trend of soil moisture distribution. Field capacity and permanent wilting point of sandy loam soil ranged 13% and 4% respectively, therefore, available moisture content was 9%. It is reported that more than 70% of olive roots are located in first 60 cm of the soil [12]. Therefore, effective root zone depth of olive was 0.6-0.7 m. Total water requirement of the olive tree was 650 mm/year, calculated using CROPWAT v.8 and was in the range as reported by Cadahia [13]. Management Allowed Depletion (MAD) value for olive was 60% that means if moisture content reached to 62 mm then supplement irrigation through micro (drip/bubbler) irrigation system should apply. Moisture distribution charts (Figures 7-9) showed the moisture status along with rainfall (columns) and arrows in downward direction are the events of supplement irrigations.

Above charts (Figures 7-9) showedthat soil moisture curves in

Shape	Avg. catchment area (m^2)	Avg. cultivated area (m^2)	C/CA	Soil type	Avg. plant height (m)	Avg. Plant canopy (m)	Avg. Slope (%)
Triangular (V shape)	20	4.6	4.3	Sandy loam	4	1.2	3
Square	28	4.6	6.5	Sandy loam	3	1.2	2
Rectangular	23	4.6	5.0	Sandy loam	4	1.2	4

Table 3: Characteristics of different shapes of micro catchment structures.

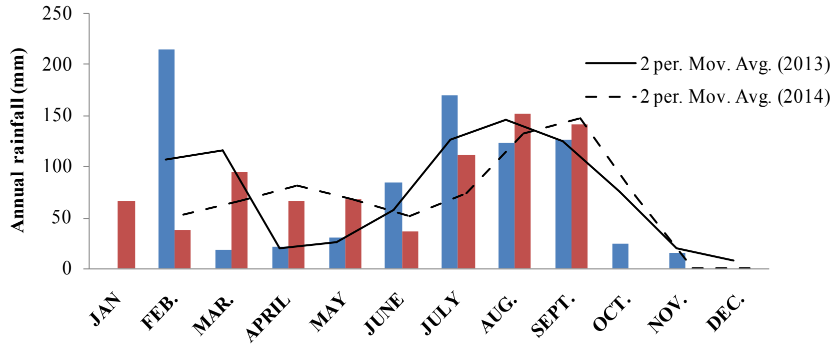

Figure 6: Rainfall distribution pattern in 2013 and 2014.

Shape of Micro catchment	Catchment area (m²)	Vol. of rain water harvested (liter)	Rate of runoff (lph)
Rectangular	23.7	9433	640
Square	24.02	9560	649
V-shape	26.41	10511	713

Table 4: Runoff rate (lph) and volume of rainwater harvested (liter) of different micro catchments.

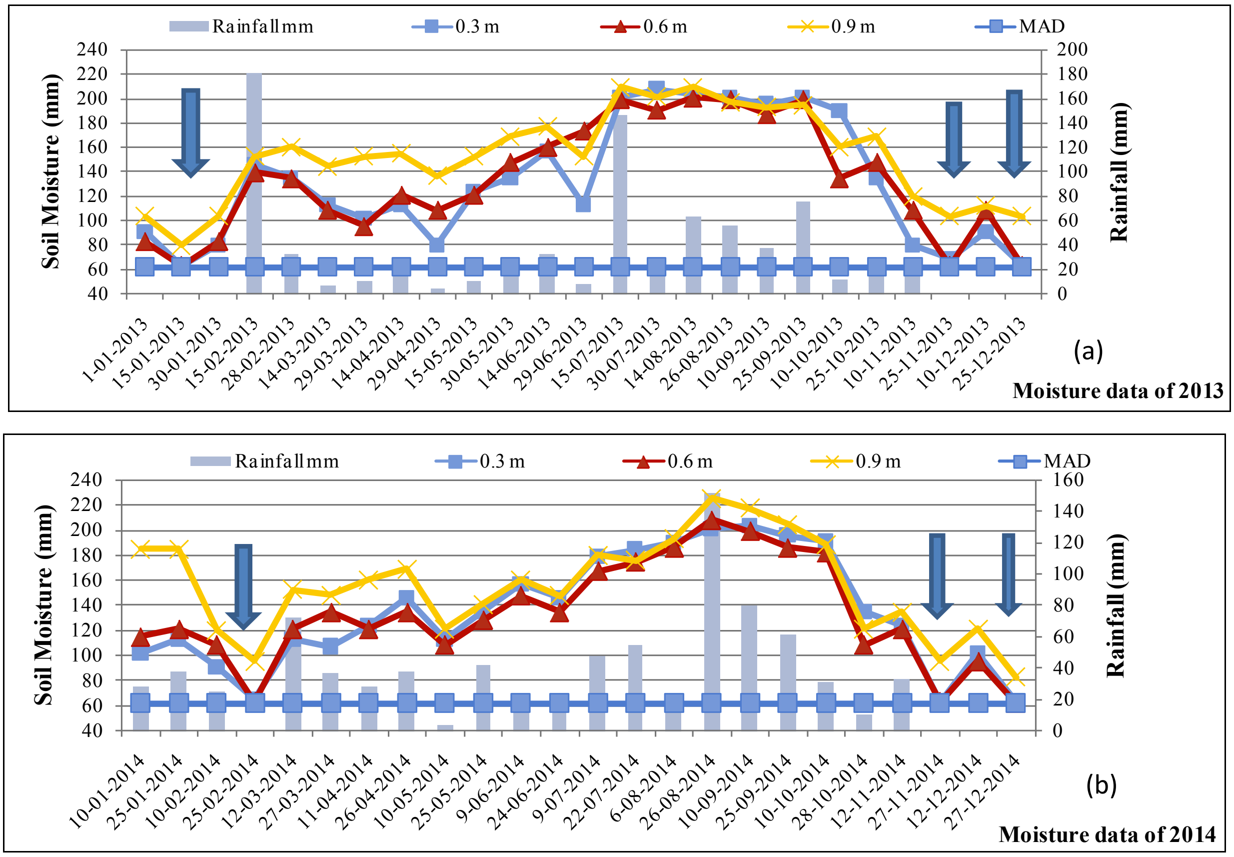

Figure 7: Soil Moisture content distribution in V shape micro catchment (a) for the year 2013 (b) for the year 2014.

case of all the shapes of micro catchment structures touched the MAD line three times in winter owing to less occurance of rainfall in winter season. Therefore, only three supplement irrigations were required to the olive through bubbler irrigation system as compared with control (traditional) structure. Therefore, it may be comcluded that these micro catchment structures are best suitable to this terrain because of their more efficiency inharvesting rain-water. On the other hand, in case of control structure, less rain-water was recored stored in the soil profile and consequntly more irrigations had to be applied for crop establishment and gaining adequate yield.

Constructing micro-catchments among the olive trees utilized 85% rainwater effectively [8] and saved 88% of water through supplement irrigation using bubbler irrigation method (Table 5a and 5b). Control practice could consume only 45% (265 mm) of rainfall while average

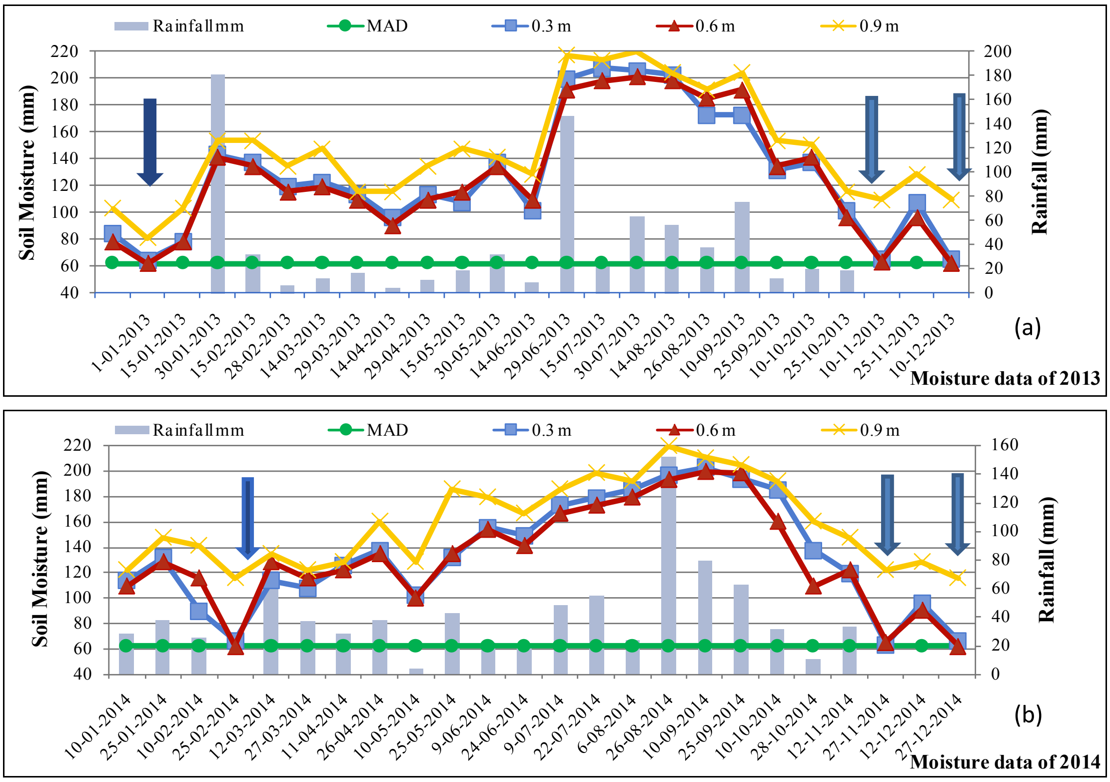

Figure 8: Soil Moisture content distribution in Square shape micro catchment (a) for the year 2013 (b) for the year 2014.

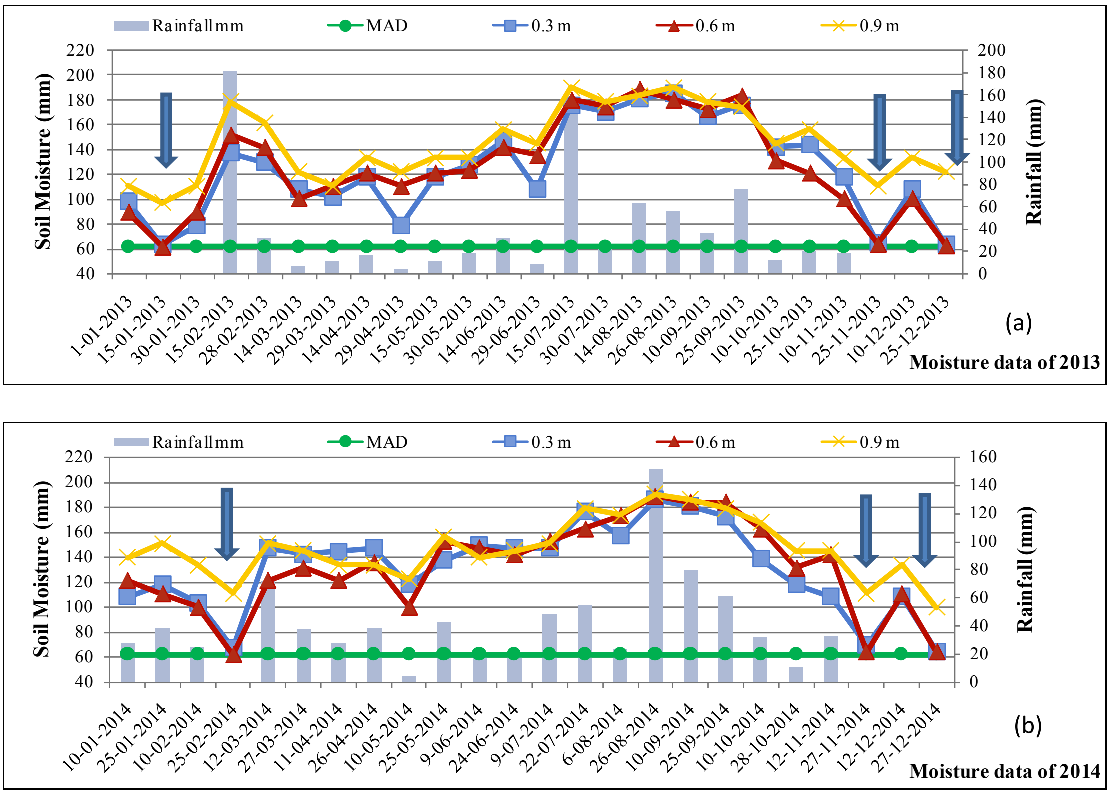

Figure 9: Soil Moisture content distribution in rectangular shape microcatchment structure (a) for the year 2013 (b) for the year 2014.

V Shape					
Irrigation event	**Date**	**Irrigation Amount (mm)**	**Water applied with bubbler (mm)**	**Water applied with flood irrigation (mm)**	**Water saving (%)**
1	15-01-2013	40	53	-	60
2	25-11-2013	39	52		
3	25-12-2013	40	53		
Total		119	159		
Square shape					
1	15-01-2013	41	55	-	59
2	25-11-2013	40	53		
3	25-12-2013	42	56		
Total		123	164		
Rectangular shape					
1	15-01-2013	41	55	-	59
2	25-11-2013	41	55		
3	25-12-2013	40	53		
Total		122	163		
Control structure					
1	1-01-2013	42	56	105	
2	14-3-2013	44	59	110	
3	29-04-2013	39	52	98	
4	10-09-2013	42	56	105	
5	25-10-2013	45	60	113	
6	10-12-2013	46	61	115	
7	25-12-2013	42	56	105	
Total		300	400	750	

Table 5a: Amount of supplement irrigation (mm) and water saving as compared to flood irrigation method for the year 2013.

V Shape					
Irrigation event	**Date**	**Irrigation Amount (mm)**	**Water applied with bubbler (mm)**	**Water applied with flood irrigation (mm)**	**Water saving (%)**
1	25-02-2014	39	52	-	61
2	27-11-2014	39	52		
3	27-12-2014	38	51		
Total		116	155		
Square shape					
1	25-02-2014	39	52	-	59
2	27-11-2014	42	56		
3	27-12-2014	41	55		
Total		122	163		
Rectangular shape					
1	25-02-2014	41	55	-	60
2	27-11-2014	39	52		
3	27-12-2014	39	52		
Total		119	159		
Control structure					
1	10-02-2014	44	58	109	
2	25-02-2014	44	58	109	
3	10-05-2014	39	53	99	
4	8-06-2014	45	60	113	
5	28/10/2014	39	52	98	
6	27-11-2014	44	59	110	
7	27-12-2014	39	53	99	
Total		294	392	735	

Table 5b: Amount of supplement irrigation (mm) and water saving as compared to flood irrigation method for the year 2014.

effective rainfall of 2013 and 2014 was recorded 594 mm, whereas in case of micro-catchments approximately 505 mm (85%) was harvested and subjected to be used by olive plants in micro-catchments. In triangular or V shape micro-catchment structures, large amount of rainwater was recorded, therefore less amount of supplement irrigation was applied in V shape as compared to other both i.e., square and rectangular shape micro-catchments (Table 5a and 5b).

Application of right quantity of irrigation water at right time through an appropriate irrigation method not only saved water but also increased yield of the olive plant. Yield increment of 6-9% was recorded in micro-catchments constructed among olive plants as compared to traditional farmer practice (Figure 10). As V shape micro-catchment stored large amount of rainwater (Figure 7), therefore higher yield was recorded. Yield was increased from 8%, 6% and 7% in 2013 to 9%, 6% and 8% during 2014 in square V, square and rectangular shape respectively, when compared with traditional practice. The yield was less in 2014 because of alternate bearing nature of olive variety (BARI Zaitoon 1).

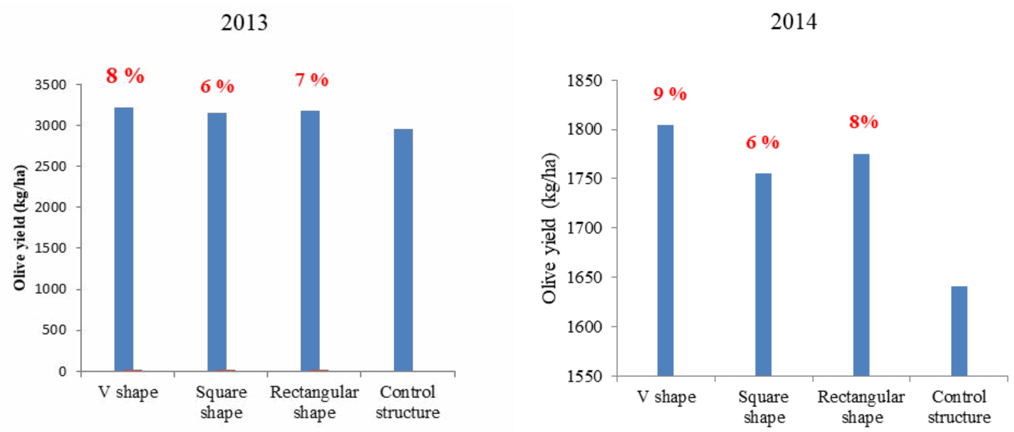

Figure 10: Comparison of yield increase of olive planted in different shapes of micro-catchment structures from control farmer practice (2013 and 2014).

Results of fruit yield increase were comparable with results of [14], that showed water harvesting through micro-irrigation method of micro-catchments saved 71% of water as compared to control practice (farmer practice) in olive. This control practice led to a water stress with low water use efficiency despite the high amount of irrigation water applied. Previous studies showed that the increased production of olives was based on the water use efficiency [15] which strongly depended on soil moisture during sensitive phenological stages during plant growth [16]. Nevertheless, increasing irrigation quantities over and above the plant water requirements not improved yields and became a financial burden. Moreover, in this study, it was also concluded that over irrigation had not induced any beneficial impacts on the olive tree. To the contrary, it can cause more harm than benefit. Deterioration of the root system and the whole tree due to water-logging is a very common outcome of excessive soil water. Fruit split caused by water swelling is another example of negative impacts from excessive water application by irrational excess irrigation at the final stages of fruit ripening.

Conclusion

Rain-water harvesting is a promising methodology that is successfully accepted all over the world and is being widely used to cope with the water scarcity problems in water deficit areas of the world. The present research study also depicted that it may be concluded by analyzing the soil moisture distribution patterns in all the three shapes at three different depths and comparing it with control practice that when only three supplement irrigations were applied through micro irrigation system (drip/bubbler irrigation system) in winter season, there was not sufficient rainfall to meet crop water requirements in micro catchment structures. Even in warm weather, no supplement irrigation was provided to the plants. Therefore, construction of micro-catchments among olive trees saved 88% irrigation water and increased yield from 6-9% when compared with traditional practice. Triangular or V shape micro-catchment structures were best suited to this terrain because it stored and effectively used large amount of rain water thus making it more preferable for undulated and hilly areas. Micro-catchment rain-water harvesting is the best technique to conserve rain water especially in rain fed areas as they are simple to construct and can be developed easily using local materials and manpower. Drip and bubbler irrigation should be used as supplement irrigation technique in micro-catchments. On the other hand, irrigating in flood applying large amount of water, the water leaches down the micro and macro nutrients which are the desired minerals for adequate plant growth. This loss of these nutrients and minerals ultimately leads to significant decline in olive fruit yield in terms of quantity as well as quality. Furthermore, disease attack on the plant is increased due to standing water in the field and further damages the root of the plant.

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