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Growing fruit trees with rainwater harvesting in arid environments: the case of almond in Northwest Iran

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Abstract

Fruit trees are grown in arid environments under irrigation. In most of the dry environments, irrigation water is not available or is scarce during the growing season; therefore, irrigation may not be possible or feasible. Yet farmers continue to grow trees under this dry rainfed condition. Low precipitation and the occurrence of frequent drought spells stress trees and cause low yields or crop failure. Farmers, to avoid crop failure, supplement rainwater with costly irrigation water often transported to the sites by tankers. Through rainwater harvesting, precipitation is concentrated through runoff from larger catchments to the basins of trees to be stored in the root zone for using during the dry period. It is however important to evaluate the capacity of system and its design parameters to ensure sufficient and efficient water supply for individual trees over the drought periods. Field trials for almond orchards were conducted over 7 years in a dry area in Northwestern Iran with mean annual rainfall 250 mm. The objective is to evaluate the impact of a range of micro-catchment rainwater harvesting practices and soil amendments on the performance of two varieties of almond trees widely grown in the area. Treatments include catchment size and geometry, surface treatment, soil water absorbent and fermented manure. Results showed that a 49 m^2 compacted catchment is sufficient to generate enough runoff to supplement rainfall for each almond tree with no effect of catchment geometry. The addition of a super absorbent material to increase soil-water storage of the root zone did not outperform the use of fermented manure. Threshold rainfall for initiation of runoff ranged from 3.5 to 5.5 mm. In a 7 mm rainfall event and basin size of 49 m^2, the runoff coefficients ranged from 13.1, to 48.4 percent. At maturity, almond trees yielded 612 kg dry nuts/ha using water-harvesting system where no irrigation was needed. In this dryland environment, farmers can grow economical rainfed almond orchards with appropriate micro catchment rainwater harvesting system.

Keywords: Micro catchments, rainwater harvesting, fruit trees, drylands.

1- Introduction

Almond trees grow in cold and moderately cold regions. The areas of irrigated and rainfed almonds orchards in Iran are 150,000 and 76,000 ha with average yield of 1030 and 487 kg/ha, respectively. Iran stands 5th among almond producing countries after USA, Spain, Syria, and Italy. Eastern Azerbaijan province is one of the prone areas for cultivation of almonds. The cultivation of almonds in areas with annual rainfall of 200 to 400 mm is common. Due to insufficient precipitation and/or suboptimal spatial and temporal distribution, rain-fed cultivation of almonds is highly risky. It is inevitable therefore to supplementally irrigate dryland almonds few times during the dry season. Tankers with high cost often carry water.

In rainfed systems, water is the most limiting factor to sustainable agricultural production. Maximizing water productivity is more relevant strategy than maximizing land productivity in such a water scarce environments (Oweis and Hachum, 2003). The process of collecting and concentrating runoff from rainwater into smaller basins to be stored in the root zone of the trees is called micro-catchment water harvesting (MCWH). The system consists of two parts: runoff surface and infiltration basin (Sepaskhah and Fooladmand, 2004; Tavakoli, 2013; Tavakoli and Oweis, 2005). Various shapes of catchment including diamond, square, or rectangular shape may be formed by small earth bunds on gently sloping land with an infiltration area at the lowest corner where the crop is grown (Oweis and Taimeh, 1996).

The main parameters of water balance are precipitation (intensity-duration-frequency), runoff, evaporation, evapotranspiration, changing water storage of the soil and deep percolation (Boers *et al.*, 1986). The size of water collection basins varies from 5 to 1000 m^3 (Sharma, 1986). The ratio of runoff surface to infiltration basin is a key parameter for designing the system. This ratio range from 1 to 20 (Boers et al., 1986). The area of micro- catchment water harvesting system for trees, shrubs and row plants has been reported from 0.5 Evenari et al., (1971) to 1000 m^2 Sharma, (1986) and the average annual precipitation needed for micro-catchment water harvesting systems varies from 100 (Evenari et al., 1971) to 650 mm (Anaja and Tovar, 1975). Some reports show that micro-catchment water harvesting systems should be used in areas having 250 mm or more annual rainfall (Boers et al., 1986; Hashemi-Nia, 2004). The small runoff basins have the advantages of being simple and cheap in construction, and therefore easy to build and adopt. They also have the advantage of producing runoff from small and low intensity storms due to the low conveyance losses within the catchment area (Oweis and Taimeh, 1996). This technique is usually used to support trees, bushes, grasses and field crops in arid regions (Oweis and Taimeh, 1996).

Sharma (1986) reported runoff coefficients of 0.13 to 0.32 for 0.5% slope, 0.36 to 0.45 for 5% slope and 0.26 to 0.46 for 10% slope. Tabatabaee Yazdi et al. (2010) in a research in Mashhad, reported runoff threshold of 4 mm, and also in another study based on linear regression analysis of 40 basins with sizes of 100-120 m^2 in a clay loam soil, runoff coefficient was 0.53-0.58, and rainfall threshold was measured as 2.1-3.2 mm (Boers, 1994).

Oweis (1994) reported that runoff coefficient for hard natural soil varied from 6 to 77% depending on precipitation amount and intensity. In the same site in Jordan, average runoff coefficient in a 20, 50 and 75 m^2 catchments were 55.9, 37.6, and 21.7%, respectively. Boers (1994) reported appropriate size of small catchments for trees as 20-150 m^2 and appropriate size for semicircular bunds with 2-5 m radius. Sharma (1986) in a research on different methods of micro-catchment water harvesting systems in small basins in India, concluded that by using different treatments the rainfall threshold reduced to half and the runoff coefficient increased 2 times higher than control treatment (Sharma, 1986).

As water harvesting is runoff dependent, the rate of runoff relative to that of the rainfall (runoff coefficient) is critical for successful implementation. In situation where runoff coefficient is low, runoff inducement intervention may be needed (Oweis et al 2012). Those may include: cleaning the surfaces from weeds and gravels, removing vegetation, smoothing and compacting the catchment surfaces, reducing soil infiltration by using chemicals, slope modification and covering the surface with impermeable materials Runoff inducement interventions can be costly but applying it at small scale and for cash crops may be feasible (Parvizi and Sepaskhah, 2016). In dry environments, evaporation from soil surfaces is significant. It is essential that it be minimized to keep the limited water available for transpiration. One way for controlling evaporation is by covering the surface with mulch. Researches show that plastic mulch and the like are successful in terms of adaptation and growth improvement of rainfed plants through preventing weed growth and suppressing surface evaporation (Hira et al., 1990; Holt, 1989; Karpiscak, et al., 1984, Barzegar- Ghazi et al., 2001; Tavakoli, 2007 & 2013). Soil polymers with water absorption and conservation characteristics increase the water storage of the light soils. Materials include manure, compost, perlite, zeolite, plant debris and super water absorbent, where each has its own unique characteristics. Although, some researchers have confirmed the performance of super-absorbent in small scales and limited time, the lack of economic justification, ineffectiveness over time and at large scale had made its application limited (Banedjschafie et al., 2006; Kochak-Zadeh et al., 2000; Haghayeghi-Moghaddam, 2005; Geesing and Schmidhalter, 2004; Hafeez and Rafique, 1995).

Eastern Azarbaijan, the experimental site, is located in North-west of Iran and is one of the most suitable areas for planting stone fruits like almond. About 12000 ha of the horticultural fields are allocated to almond production, which equals to 11.6% of all the horticultural crops of the province. The improper distribution and low amount of precipitation are among general indices of rainfed regions; variations in these parameters cause a high risk in almond production, low productivity and great fluctuation over years. Conventional ways to overcome this situation is either difficult or very costly; therefore, MCWH systemhas been researched as an alternative to help reduce the risk of failure in rainfed almond plantation.

The objectives of the research reported here are:

1. Evaluate the effectiveness of MCWH in sustainable development of almond trees under dry rianfed systems.
2. Determine appropriate design parameters of micro-catchment water harvesting system and runoff coefficients under various soil surface conditions and catchment sizes.
3. Evaluate evaporation reduction by mulching and the effect of soil super absorbents on the growth and productivity of almond trees.

2- Materials and Methods

The experimental design is a split-split factorial plot in the frame of randomized complete block design with three replications. The treatments are:

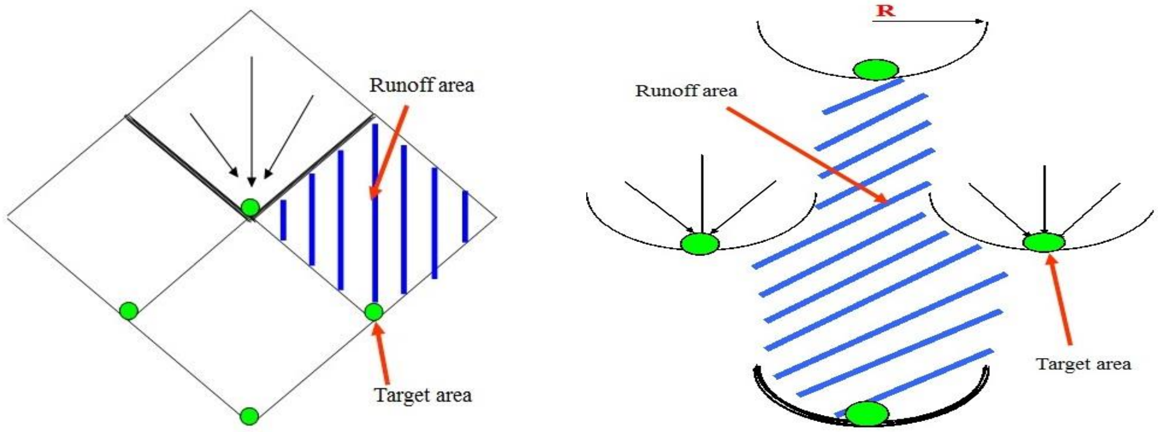
A) Two MCWH types Figure (1): A1-Rectangular negarim, A2-Semicircular bunds

B) Three catchment (runoff) sizes: B1= 25 m^2, B2= 49 m^2 and B3= 81 m^2

C) Three runoff inducement methods: C1= Control (no intervention); C2= clearing vegetation; and; C3= clearing vegetation and compaction.

D) Two soil treatments: D1- Control, (no intervention); D2- Applying one kilogram of super absorbent polymer (Novazoub-A Superabsorbent polymer materials).In the control treatment, no physical change was made, gravels were not collected, surface topography was not smoothed, and weeds were not removed from the surface area, just large grasses were removed each year. In smoothed and compacted treatments, weeds were completely removed and the surface was cleaned and cleared each year.

The experiment was established in 2000.Total of 108 pits were dog with dimensions of 1m × 1m × 1m, Half of the pits were filled with surface soils + 15 kg manure + one kilogram of super absorbent polymer l and the other half was filled with surface soils + 15 kg manure. One-third of catchments areas were kept untreated, one-third were cleaned and the rest was cleaned and compacted. For the compacted surface treatments, the compaction was conducted as soon as possible in spring when the soil water content was sufficiently suitable to conduct the compaction by a roller with one pass of a roller with weight of 38 kg. In the late fall when the trees were in physiologic dormancy, two late flowering almond cultivars, Azar and Shokofeh, were prepared for plantation. The origin of Azar cultivar is Iran with semi hard shell, late flowering, good taste, self-incompatible, average maturation, and 38-40% yield on shelling. The origin of Shokofeh cultivar is Iran, with thin shell, late flowering, good taste, self-incompatible, average maturation, and 60-55% yield on shelling.



A_1 –Negarim A_2 -Semicircular bounds

Fig. 1- Runoff area in square basin (A_1) and semicircular layouts (A_2) in micro catchments water harvesting system

Almond trees were planted in November, 2000 after wetting the roots in the solution of fungicides, clay, manure, and water, and top pruning. Due to low soil moisture, 20 liters of water was applied for each pit. For protecting the seedling against wind and snow, stakes were also used to keep them upright. The planting area was covered by plastic sheets of dimensions 1.25 × 1.25 m.

Figure (1), shows the dimensions of the basins:

Negarim: 25 m^2 (5 m x 5 m); 49 m^2 (7 mx 7 m); 81 m^2 (9 mx 9m)

Semi-circular: 25 m^2(R = 2.04 m); 49 m^2(R = 2.86 m); 81 m^2(R = 3.67 m)

The layout of the negarim and semicircular bunds including, catchment areas and infiltrating basins are shown in Figure (1). Collection barrels to determine runoff coefficients were placed downslope in six basins in a separate experiment as shown in Figure (2).

The volume of runoff was measured volumetrically manually. The runoff areas were 10, 25, 49, 81 m^2 in this experiment with no replication (Figure 2). Runoff coefficient was determined as the ratio of runoff volume collected from each catchment area to the amount of rain falling on the same area. The following equation was used (Oweis and Taimeh, 1996):

$$ER\,(\%) = \frac{Rv \times 100}{Pt \times Ac} \tag{1}$$

Where:

ER = runoff coefficient of a storm (%),

Rv = volume of runoff water collected after each storm (m^3),

Pt = total storm amount (m) and,

Ac = total catchment area including the infiltration basin (m^2).

Data on weather parameters was obtained from Sahand weather station. The effects of treatments were evaluated by measuring the stem diameter and its growth rate through different growing seasons. A soil analysis (sandy loam) analysis is shown in Table (1). Soil quality was improved by modifying the bed of planting pit and substituting it with topsoil and manure; therefore, the soil water holding capacity was increased. Soil water content at each tree basin was measured immediately after runoff and then after 10 days at both bare and mulched basins to examine the effectiveness of the plastic covers on soil surface evaporation. Weather data was collected from Sahand synoptic station as a closest station for the study site (10 Km).

Table 1- Physical and chemical properties of soil

S.P (%)	EC (dS/m)	pH	Total N (%)	O.C (%)	Clay (%)	Silt (%)	Sand (%)
34	1.11	7.6	0.049	0.49	7	43	50
Cu (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)	K (ppm)	P (ppm)		
1.48	1.1	3.94	2.22	370	15.2		

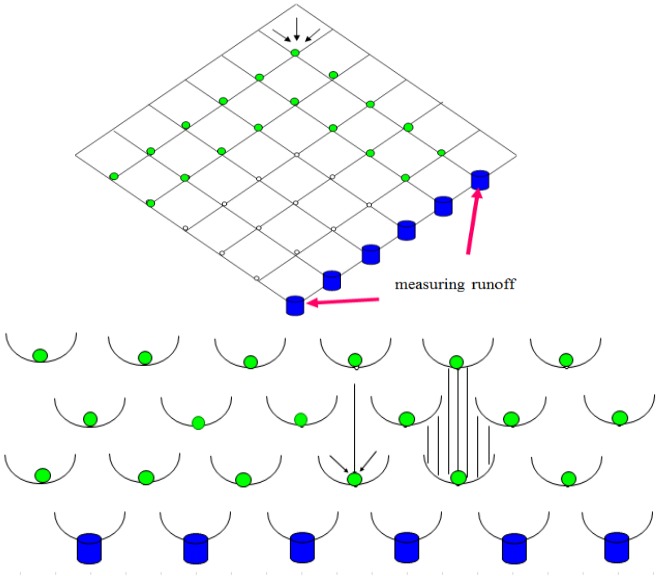


Fig. 2- Layout of the MCWH systems with runoff collection devices

3- Results and Discussion

Precipitation

Precipitation data for different growing seasons of 1995-1996 until 2004-2005 (10-year period) were used to determine the probability of occurrence by the following equation (Chow, 1953):

$$P(X<x) = i/(n+1) \quad (2)$$

Where $p(X<x)$ is the occurrence probability, i is the descending order, and n is the number of observation.

The probability of having a precipitation of 258 and 226 mm in a growing season is 9% and 36 % respectively (Table 2). Average precipitation during the given 11 years was 201 mm, which is considered lower than almonds crop water requirement for economic production. It should also be mentioned that rainfall distribution was not optimal in the region.

Growing season of 2000-2001 was the first year of tree planting. In this growing season, the first precipitation event was 25.8 mm occurred over the period 23-25 October in 2000. The last precipitation event was 18.2 mm occurred during 2-3 May in 2001. There was no precipitation until the end of the growing season and the first precipitation of the next growing season occurred in October 2001. There was a 186 days of no rainfall during the growing season. Enhancing tree soil water during this period guarantees tree survival in following years droughts.

The number of days with no precipitation in 2001 to 2005 was 186, 185, 214, 160, and 216, respectively. During this period there was no irrigation and water needs of the trees was supplied from soil water storage collected by the MCWH system.

Rainfall-runoff relations

One of the important parameters in micro-catchment water harvesting systems is determining rainfall-runoff threshold and runoff coefficient. For determining these parameters, the initial soil water content, initial surface status, size of the runoff catchment and shape, amount and intensity of precipitation, land surface slope, surface cover and soil texture are considered. For this study, the rainfall-runoff threshold in compacted catchment (CC) sizes of 25, 49, and 81 m^2 was measured as 2.5 to 3.5 mm, for clean and smooth surface (C), 3.5 to 4.5 mm, and for the control treatment (N) 4.5 to 5.5 mm. In a 7 mm rainfall event in catchment size of 49 m^2, the amounts of collected runoff volume for CC, C and N treatments were measured as 45, 115 and 165 liters respectively (Figure 3.). Accordingly, runoff coefficients were 13.1, 33.5 and 48.4 percent, for CC, C and N treatments respectively.

Table 2- Probability of precipitation occurrence based on 10-year data precipitation

Growing season	Precipitation (mm)	I	P(X<x) = i /(n+1)
1996-97	258	1	9
2004-05	249.5	2	18
2003-04	245	3	27
1995-96	226	4	36
2001-02	217.5	5	45
1998-99	185.3	6	55
1997-98	177.1	7	64
2000-01	176.4	8	73
2002-03	176.4	9	82
1999-00	163.3	10	91

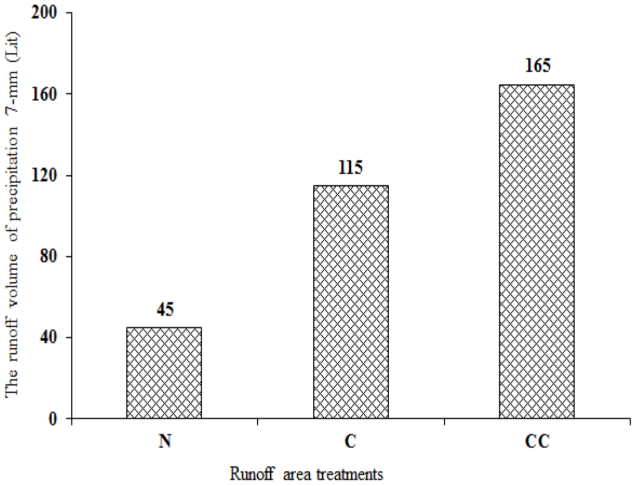


Fig. 3- Amounts of collected runoff volume in a 7 mm rainfall event, in catchment size of 49 m^2

Clearly, when precipitation exceeds the runoff threshold it produces runoff especially in clean and compacted treatments. This indicated that higher precipitations produced higher runoff and consequently the runoff coefficient is improved, particularly under clean and compacted surface.

Soil-water relations

The soil-wetted depth at different distances from the tree is shown in Figure 4. The non-regular variation in the wetted depth of soil in control treatment (N) is due to uneven topography.

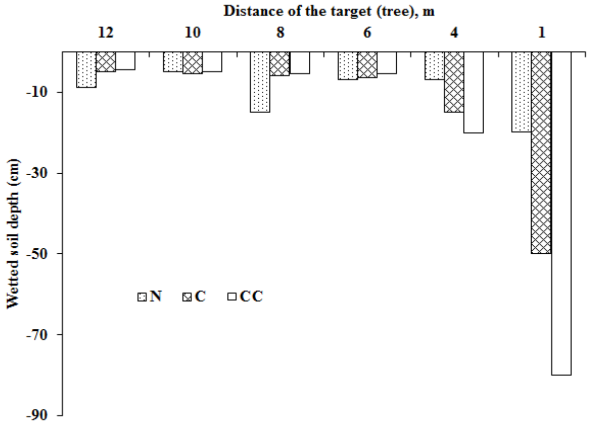


Fig. 4- Profile of soil wetted from the farthest point of runoff surface to the planting area

In the collection basin around the tree, the soil-wetted depth increased due to runoff accumulation and infiltration into the soil profile. Non-uniform catchment surface allows more runoff surface storage, which ends up being lost in evaporation. According to Figure 4, the soil-wetted depth was down to 21 cm over one meter diameter around the tree, while in the compacted treatment the wetted depth reached 80 cm with higher amounts of water stored. Cleaning and compaction of the runoff surface lead to an increase in wetted soil depth by over 2.33 times the normal conditions at the planting area.

Volume of the water collected at the planting area is dependent on the dimensions and size of the catchment. Runoff storage efficiency depends mainly on the soil storage capacity available in the root zone at the time when runoff occurs (Oweis and Taimeh, 1996). The volume of water collected in each treatment is shown in Figure 5. According to the amount and distribution of precipitation in the area, small surfaces (10 m^2) did not produce a significant volume of runoff so the harvested volume of water did not satisfy trees water requirements. Accordingly, it was necessary to determine the minimum catchment areas that can provide the needed water for the trees and hence the trees spacing and plant density. Although the 81-m2 treatment produced the highest volume of runoff water to the planting area, it is not favorable as it results in lower land productivity. Therefore, the 49-m2 treatment was found more appropriate. In this treatment, the collected runoff volume at the planting area in smoothed and compacted treatments has shown increase of 37.6 and 73.9%, respectively.

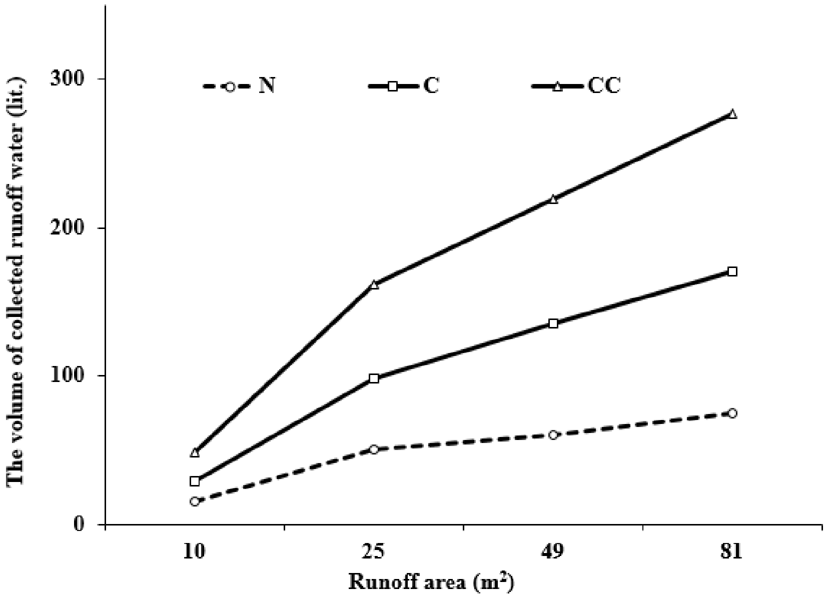


Fig. 5- The volume of collected runoff water as a function of catchment area

For examining the effectiveness of the plastic cover in decreasing soil water loss by evaporation at the planting area, soil water contents were measured one day after precipitation and then after 10 days. Results are shown in Figure (6).

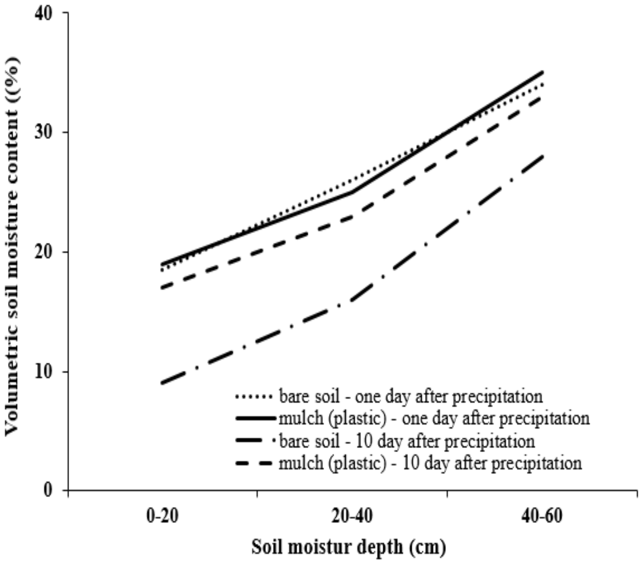


Fig. 6- Soil moisture content at different soil depths in bare and plastic mulch conditions

Ten days after precipitation, soil water content in the bare soil has dramatically decreased, whereas, moisture decrease has been lower in the soil with plastic cover. After 10 days, about 60% of bare soil moisture was lost compared to 8 percent decreased in plastic mulch condition. This water saving has been used for the tree transpiration. The difference between the two treatments shows that evaporation can be substantial part of the collected runoff in bare soil.

Crop growth and yield

Impacts on crop growth

Results of variance analyses (average or mean squares) of growth characteristics are shown in Table (3). Growth characteristics are total growth of tree branches in first year (2001), maximum growth of the main branch in first year (2001), stem diameter in years 2002 and 2003**,** and also stem diameter growth over 1 year (percent).

The effect of runoff-collecting basin's shape (layout) was significant at the 5% levels of probability on total growth of branches in the first year; however, this was affected by basin area and surface treatments at 1% level (Table 3).

The effect of size and dimensions of the runoff-collecting basin and the status of runoff surfaces were similar to that of basin arrangement, statistically significant difference at 1% level (Table 3).

Table 3- Summary variance analyses of almond growth characteristics

		Mean squares (MS)				
Source of Variation	d	Total produced branches in first year (cm)	Maximum growth of the main branch in first year (cm)	Stem thickness (Third year) (mm)	Stem thickness (Forth year) (mm)	Stem growth rate (%)
R	2	29211^{ns}	106^{ns}	15.61^{ns}	19.69^{ns}	289.4^{ns}
Sh (A)	1	334000*	334.3^{ns}	7.11^{ns}	37.81^{ns}	98.65^{ns}
Error for A	2	14647	56.5	6.37	5.36	358.6
B	2	353282**	157.2^{ns}	8.1^{ns}	60.39^{ns}	1237.2^{ns}
A*D	2	49549*	178.1^{ns}	54.64*	70.42^{ns}	890.1^{ns}
Error for B	8	7641	112.9	11.36	18.79	527.6
Runoff (C)	2	219035**	131.5^{ns}	3.52^{ns}	6.02^{ns}	8.32^{ns}
A*C	2	61933**	187.2^{ns}	26.19*	16.57^{ns}	904.1^{ns}
A*C	4	29335^{ns}	89.9^{ns}	6.78^{ns}	6.79^{ns}	666.4^{ns}
A* B*C	4	42418*	43.1^{ns}	11.71^{ns}	28.8*	1362.4^{ns}
Pol.(D)	1	40600^{ns}	3^{ns}	19^{ns}	28.73^{ns}	137.1^{ns}
A*D	1	385^{ns}	156.5^{ns}	0.39^{ns}	23.99^{ns}	3192.3*
B*D	2	1378^{ns}	426.7*	9.1^{ns}	0.3^{ns}	1855.6^{ns}
A*B*D	2	42024*	45.8^{ns}	11.76^{ns}	19.09^{ns}	1115.3^{ns}
B*C	2	36215^{ns}	201.1^{ns}	1.05^{ns}	20.04^{ns}	2002.4^{ns}
A* C *D	2	51469*	97.3^{ns}	0.025^{ns}	7.8^{ns}	633^{ns}
B* C *D	4	34189*	68.2^{ns}	3.93^{ns}	2.24^{ns}	308.3^{ns}
A*B* C*D	4	16889^{ns}	18.9^{ns}	12.41^{ns}	8.67^{ns}	513.2^{ns}
E	60	13487	108.9	8.14	10.15	849.7
CV(%)		28.13	23.18	20.19	15.7	61.77

R (replication), Sh (Basin shape), B (Dimension or size), Runoff (Runoff area condition), Pol (Polymer), E (Error)
ns, * and ** : non-significant and significant at the 5 and 1% levels of probability, respectively

Tree growth trend, survival percent and change of appearance of trees were compared with farmers' trees under irrigation for evaluation. The survival rate was about 100%, compared to 40-60% in farmers' fields under supplemental irrigation in the vicinity of the study area.

Barzegar-Ghazi et al (2001) after a 4-year study (quadrennial) in On-ibn-Ali district, Tabriz, Iran, reported that tree survival for all the tree species was very high, and varied from 96% to 58%. They attributed the reason of this success to adopting appropriate tree species that were resistant to low rainfall condition, adverse soil conditions and using crescent banquettes and plastic film mulch on the soil. In such researches, evaporation reduction under the trees is of great importance and sometimes it is vital. Different types of mulch have been used for preserving the runoff water helping in tree survival and growth of tree species in dry areas (Balvinder et al, 1998; Gupta and Muthana, 1985; Najafi et al, 1997; Tavakoli and Oweis, 2005).

Hira et al. (1990) placed a plastic sheet with area of 1-2 m^2 on soil surface for each tree and made a hole in the middle for planting the tree and water infiltration. Then they covered the plastic sheet with a layer of soil. This technique increased the survival percent, height, diameter and biomass of the trees. It should be mentioned that burying plastic sheets under soil might prevent water infiltration, soil aeration and resulted root respiratory aeration as well as water stress.

In the first year (2001), the main branch growth was up to 70 cm but the main branch growth in farmers' conditions was 20-40 cm long. Total length of branches in 2001 in a single tree was 15.5 m. These results were obtained in 2001 with precipitation 186 mm and tree planting with top and root pruning.

Combined effects on growth characteristics

There was no significant effect of super absorbent polymer on growth, probably because there were no notable differences in soil water stress between the treatments. Ganji-Khorramdel, and Keikhaei, (2004) in a research studied the application of different amounts of super absorbent polymer (PR3005A) in various soils and pots. They showed that the cost of these materials makes their use in cultivation of agricultural plants unjustifiable. Different application rates by the author had not increased total porosity of the soil. However, in sandy soil, its application increased micro porosity and showed higher capacity of water absorption and conservation of water. Pourmeidani and Khalil-Poor (2007) showed that addition of Hydroplus polymer to heavy and semi-heavy soils was not very effective on increasing soil porosity, but more effective in light and medium soils.

The effect of the basin shape on the growth characteristics was significant. It showed that square basin is superior over other shapes (Table 4). Total growth of branches and stem diameter in the fourth year was higher than those are in semi-circular shape. This may be related to the shorter concentration time that resulted in less infiltration and hence higher runoff. As the surface area increased, the totally produced branches and stem thickness in the fourth year were significantly higher (Table 4).

Increasing runoff surface area supplies more runoff water to individual trees with positive impact on yield and growth characteristic (Table 4), but the number of trees per hectare is as a result decreased. The optimal tradeoff between the two requires further research.

For catchments of 25, 49, 81 m^2, the number of tree planted are 400, 204, 123 per hectare, respectively. Large catchments secure sufficient runoff for individual trees but can be inefficient if runoff is beyond the soil capacity to store. On the other hand, small catchments may increase the risk especially with periods of drought and can threaten the orchard especially under conditions of farmer's management (Oweis and Taimeh 1996). Therefore, it is necessary to determine the optimum catchment size according to the amount and distribution of the precipitation in addition to the soil and crop water requirements.

Table 4- Mean growth characteristics for different shapes, basin areas and runoff surface status

Treatments		Total produced branches in first year (cm)	Stem thickness (forth year) (mm)
Basin shape	A1	468.5 a	20.9 a
	A2	357.2 b	19.7 a
Size of runoff area	B1	308.4 c	19.0 b
	B2	424.7 b	20.4 ab
	B3	505.4 a	21.6 a
	LSD 5%	47.5	2.36
Runoff area status	C1	327.3 b	19.8 a
	C2	431.3 a	20.4 a
	C3	480.0 a	20.6 a
	LSD 5%	54.75	1.5

The effect of the surface treatment on the average growth characteristics is shown in Table (4). The smooth and compacted treatments resulted in an increase in growth and other measured parameters.

The significance of the effects of arrangement dimensions of the basin and the runoff surface status on the growth characteristics showed the role of these factors in producing runoff to almond plantations and resulting in its growth improvement. Semicircular bounds are longer (more extended) than square basin and the time lag (span during which a runoff drop reach the infiltrating area of the tree from the last (farthest) point) is longer than the square basin arrangement, i.e., the concentration time in semicircular layout is higher than the square basin. In addition, in semicircular bound, due to open form, the surface on which the runoff is infiltrated is larger, while in square basin, infiltrating area is small and most of the runoff is infiltrated in a small surface under the tree. Furthermore, the evaporation of the water in semicircular arrangement is higher than that of square basin.

The interaction effect of the basin shape and the runoff surface status on the characteristics of growth and stem diameter is significant at statistical level of 1% and 5%, respectively (Table 3). Results showed that the clean and clear (smooth) runoff surfaces and compacted surfaces in both square basin and semicircular bounds are far superior in comparison with control runoff surface (Table 5).

In the first year, the transplanted tree passed through a critical period due to the root pruning, top pruningand leveling height of the tree as well as lack of root development for using the soil water storage. Therefore, cleaning and smoothing (clearing) the basin surface and compaction increased the volumes of runoff, and decreased the rainfall threshold. In fact, these treatments resulted in inducing runoff from light storms.

The effect of interaction between basin size and surface treatment on the measured growth characteristics is shown in Table (6). By clearing and smoothing the basin surface, compaction and increasing the basin size, the volume of the runoff was increased and the rainfall threshold was decreased. These two factors showed a positive and increasing effect on the runoff volume.

Table 5- Mean interaction effects of basin shape, basin area and runoff surface status on growth characteristic

Basin shape × basin area and Basin shape × surface status	Total produced branches in first year (cm)	Maximum growth of the main branch in first year (cm)	Stem thickness (third year) (mm)	Stem thickness (forth year) (mm)
A1 × B1	329.4 de	43 b	14 ab	19.2 b
A1 × B2	475.8 b	45.9 ab	13.1 b	19.8 b
A1 × B3	600.2 a	51.4 a	16.1 a	23.7 a
A2 × B1	287.4 e	43 b	13.6 b	18.8 b
A2 × B2	373.7 cd	43.8 ab	15 ab	20.9 b
A2 × B3	410.7 bc	42.9 b	13.2 b	19.4 b
LSD 5%	77.43	6.96	1.9	2.12
A1 × C1	335 b	42.8 b	13.1 a	19.6 ab
A1 × C2	510.3 a	46.7 ab	15.3 a	21.4 ab
A1 × C3	560.1 a	50.8 a	14.8 a	21.6 a
A2 × C1	319.6 b	44.4 ab	14.5 a	20 ab
A2 × C2	352.3 b	41.8 a	14.3 a	19.4 b
A2 × C3	399.8 b	43.6 ab	13.8 a	19.6 ab
LSD 5%	77.43	6.96	1.9	2.12

Table 6. Mean interaction effects of basin and runoff surface status on growth characteristics

Basin size and surface status	Total produced branches in first year (cm)	Maximum growth of the main branch in first year (cm)	Stem thickness (forth year) (mm)
B1 × C1	262.8 e	43.6 ab	18.4 c
B1 × C2	319.6 e	41.6 b	19.5 bc
B1 × C3	342.7 de	43.9 ab	19 bc
B2 × C1	361.7 de	45.1 ab	20.7 ab
B2 × C2	433.3 cd	43.2 ab	19.8 abc
B2 × C3	479.2 bc	46.2 ab	20.6 ab
B3 × C1	357.3 de	42.2 b	20.4 abc
B3 × C2	541.1 ab	47.9 ab	22 a
B3 × C3	618 a	51.5 a	22.3 a
LSD 5%	94.8	8.52	2.6

Basin shape and its size are important. Gupta and Mohan (1991) by making a stack by height of 20 cm around each tree provided a small basin (pond) surface. In another method, using semicircular furrows for storing rainwater, the trees were planted in the middle of the furrows (Gupta and Mohan, 1991; Swatantra, 1994; Barzegar-Ghazi et al, 2001). Kaarakka (1996) after planting 4 tree species in the intersection point of crossover furrows [small basin (pond) surfaces] reported that by this way the survival percent and growth rate of the species was increased. Abdulaziz and Turbak (2000) confirmed that the method of terracing in micro-catchment water harvesting system for revitalizing the arid and semi-arid areas of Arabia is effective. Barzegar-Ghazi et al (2001) reported that crescent banquettes showed capability in collecting and conservation rainwater, as during heavy rainfalls they collected the surface runoff, and prevented water loss and soil erosion and provided adequate water storage for plant growth during growing season. Swatantra (1994) in India used semicircular banquettes for optimum use of rainwater and pointed the increase in growth of the cultivated plants. Banquettes have the responsibility of collecting and conducting the rainwater toward the ending of the banquette.

Collecting rainwater and conducting it to small stacks, occurred in areas with average annual precipitation of 240 mm, and by prevention of surface evaporation, pistachio trees were planted (Boers, 1994; Boers and Ben-Asher, 1980). By using this technique, the potentiality of lodging plants and increasing their biomass production in wastelands was provided (Copra, 1994). Collecting rainwater through small systems for cultivating rain-fed grape (Sepaskhah and Fooladmand, 2004; Fooladmand and Sepaskhah, 2003; Sepaskhah and Kamgar Haghighgi, 1989) and collecting rainwater from hillside surfaces that are covered with petroleum mulch, were performed that led to growth increase and quantitative and qualitative increase of the product rainfed forestry (Kossar, 1973).

In the present research, and due to insufficient initial soil water content, 20 liters irrigation water was added after transplanting. No irrigation water was applied afterword (Tavakoli, 2007). Many consider initial irrigation essential for tree survival. Kinhal (1998) studied the effect of early planting and irrigating in critical conditions (establishing the species), indicated that irrigation in the first year is essential for establishment of the saplings.

Crop yield

The yield of a tree planted in in 81 m^2 of square catchment, with compacted surface was 4 kg in June 2006 harvest. According to the size of runoff surfaces, the number of trees in this treatment was 123 in hectare, and the yield was 492 kg ha^{-1}. However, in 7*7 m^2 square basin, compacted and without super absorbent polymer application, the yield of a tree was about 3 kg, and with 204 trees per hectare, the yield of this treatment was 612kg.ha^{-1}. The 5*5 m^2 square basin with a high risk of water shortage is not recommended. Zare (2008) showed that despite low yield of almond, its production under these conditions is profitable.

Economical aspects

Dried almonds under rainwater harvesting systems yield about 600 to 1500 kilograms per hectare. Gross return ranges from 1332 to 3330 US$ per hectare. This is 4 to 8 times the return of rainfed wheat production in the same area.

The average cost of cultivation of almond trees is about 2222 US$ per hectare (Table 7). The annual cost of repairing and maintaining the garden is between 333 and 444 US$ per hectare.

The annual investment with the interest rate of 12% and life cycle of 30-50 years is about 0.12; therefore, the amortization rate is 0.12. Based on this rate, the annual investment is about 267 and the total cost is 600 to 711 $ per hectare. Difference between the total income and the total cost is considered as net income that is about 732 to 2619 $ per hectare. These are 2-4 time of that for the rainfed wheat in the study area.

Table 7- Average cost of creation of almond gardens

activities	cost	Percent (%)
Digging the pits by machine	266.6	12
Runoff area correction	444.4	20
Late flowering almond cultivars	444.4	20
Animal manure	88.9	4
Mulch	133.3	6
Mycorrhiza fungus	66.7	3
Filling pits and planting	355.5	16
Watering after planting	88.9	4
Location, technical services, training and empowerment	222.2	10
Total	2222	100

1 US$ = 45000 Iranian Rials

4- Conclusions

Almond trees can grow and produce well in dry environments without irrigation by providing a micro catchment water harvesting system. In addition, applying soil-water conservation practices such as mulching and soil amendments to reduce evaporation and maximize soil water storage can increase the system efficiency. Farmer’s benefits from dry land almonds under rainwater harvesting systems may exceed that from rainfed wheat production.

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6- Conflicts of Interest

No potential conflict of interest was reported by the authors.

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