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Optimisation of irrigation system in arid land pistachio orchards

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Abstract

This research was designed to evaluate and compare the applicability of two different types of irrigation including traditionally (surface irrigation) and simple sub-surface drip irrigation (using pricked-pipe covered with plastic cloth). Two plots containing 39 pistachio trees with 720 m^2 area were selected in Rafsanjan, Iran. Both plots were irrigated using exactly the same quantity and quality of water for 2 years. At the end of the second year the yield was harvested separately and compared. The weight of fresh and dried crops in sub-surface irrigation plot to those of surface irrigation plot were 1.895 and 2 respectively. Annual shoot growth of tree was measured in two plats. The value of Plot Growth Index (PGI) in surface irrigation plot and sub-surface irrigation plot calculated 2237.5cm and 4580.5cm respectively. In addition, the dried weight of weeds in surface irrigation plot was 82kg while it was only 21 kg in sub-surface irrigation plot. Results show the considerable difference in two irrigation systems efficiences and relatively higher preference of sub-surface system than traditionally surface method. Finally, due to sever shortage of agricultural water in the studied area, it has been advised to optimize traditionally used irrigation systems toward new methods with minimum water loss such as evaluated subsurface method.

Keywords: Pistachio orchards; Irrigation optimisation; Subsurface irrigation; Irrigation efficiency; Water use efficiency; Drylands water use; WUE.

1. Introduction

Considerable fart of water in regional common surface irrigation lost through channels and waterways from source (pump) to the orchards because of deep percolation and evaporation, which has not been considered here. Water is the natural resource on which human life, food security and the health of ecosystems depends to it. In the other word, water resources are one of the main essential natural resources for life as potable water, irrigation water and water for industrial uses.

In dryland environments due to high temperature, windy weather, and low humidity there is a specific condition, where water shortage is the main limitation of development.

Much of the available water for living people in dryland regions is found in large rivers that originate from higher elevation. Groundwater resources can be available to support development. However, the relatively limited recharge of groundwater resources depend largely on the amount, intensity, and duration of the rainfall as well as soil properties, the latter including infiltrations capacities and water-holding characteristics of the soil, which also influence the amount of surface runoff. However, dryland environments including studied area are of this research are characterized generally by inadequate and fluctuating rainfall. Rainfall variability and occurrence of prolonged periods of droughts are dry lands characteristics that must be considered in the planning and management of natural and agricultural resources. Rainfall intensity is

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another parameter that must be considered in planning and management of natural resources in these regions.

The area of this research is typically windy, largely because of the scarcity of vegetation and other obstacles that can reduce air movements. Wind moves the moist air that surrounds plants and soil bodies and as a consequence, decreases atmospheric moisture and increases evapotranspiration rates. Therefore, low precipitation and high evaporation causes inadequate water especially for irrigation. To be able to keep the orchards alive and productive, there is no way except operation of efficient methods of irrigation. Subsurface irrigation especially Subsurface Drip Irrigation (SDI) is one of the new irrigation methods with high efficiency particularly in arid land environments. At first time tested in California in 1959, and was developed in other parts of the World. Several investigation projects have been completed about suitability and applications of SDI in crop production during last decades. Phene et al., (1992) realized that SDI caused increasing yield of maize in comparison to other types of irrigation [11]. Huthmeture et al., (1992) compared the efficiency of SDI to furrow surface irrigation in alfalfa yield and resulted in about 20 percent more yield and 6 percent less water use for SDI in comparison to the other type of irrigation [4]. Orron et al., (1999) after some investigations reported that water loss control, weed growth control and better control of irrigation process are the main advantages of SDI [8]. Camp (1998) evaluated the relevancy of SDI for different crops and specified more than 30 types of crops that can get benefit from SDI [2]. Phene and Lamme (1995) compared SDI and DI (Drip Irrigation) for irrigation of tomato, reported better performance of SDI over DI [10]. Martins et al., (1991) evaluated the effect of fertilizers on growth and the yield of maize using SDI and DI and reported higher performance of SDI to DI [6]. Zoldosk et al., (1995), and Soloman and Jerjenson (1995) evaluated the efficiency and suitability of SDI on turfgrass and mentioned several advantages for this type of irrigation [14 and 13]. Present research project was designed to compare the applicability of two different types of irrigations including surface irrigation (which is traditionally used by local farmers) and sub-surface irrigation using pricked-pipe covered with plastic cloth, which is tested as a new technique of irrigation.

2. Materials and methods

2.1. Study area

Quantity and quality limitation of irrigation water is the main problem of agricultural development in the research area (Rafsanjan Pistachio orchards). Study area was a part of the pistachio orchards of Tajabad Kohneh in Rafsanjan, Kerman province in Iran. This area is a dryland region with mean annual precipitation less than 100 mm and potential evapotranspiraion over 3000 mm. In this region much of the precipitation is lost by evapotranspiration and as a result ground water is recharged only locally by seepage through the soil profile. Surface runoff events, soil moisture storage, and groundwater recharge in this region are generally more variable and less reliable than in humid regions. However, groundwater is frequently over used.

It needs to be mentioned that in the area of Rafsanjan plain there is no permanent river stream as well as no considerable reservoir to provide required water. Therefore, groundwater has been the only main available water source to relatively rapid growing population during last decades. However, more discharge and less recharge to the groundwater has led to approximately one meter (in average) fall of water table in some parts of the plain every year. During the last ten years many productive pistachio orchards has been left without irrigation and destroyed just because of water scarcity. Due to large fall of water table occurred in last few decades, extraction of water is too expensive in addition to its decreasing quality. Therefore, quantity and quality limitation of irrigation water is the main problem of agricultural development in the studied area (Rafsanjan pistachio orchards). In this situation, one of the most important priorities could be irrigation system optimization. Systems with high efficiency can help farmers to use available water more efficiently to mitigate the accelerating damages of irrigation water shortage, and get more benefit from less amount of water. In this way, relevant investigations could help and encourage farmers to choose and establish preferred irrigation systems. This research was designed to evaluate the applicability of a traditionally used irrigation method in comparison to new one.

2.2. Research plots preparation

Two plots each containing 39 pistachio trees and about 720 m^2 area were selected in an orchard near Rafsanjan, and isolated (hydrologically) from each other as well as from other parts of the orchard. For isolation a channel of 1.2m depth was dug all around the plots and then a sheet of tick plastic was placed through this channel and the excavated soil. Trees in both plots were acceptably similar in terms of age, canopy and stem diameter as well as the outward appearance. Then one of the plots was prepared for surface irrigation which is common in the area and other plot for sub-surface irrigation. For the later one two lines of P.V.C pricked-pipe covered with plastic cloth were located in two sides of the tree line with about 1.5-2 m distance from it, and in whole length of the tree line, in depth of 50 cm (Figure 1). Fine sand with the thickness of about 10 cm was used as filter around the pipes to prevent obstruction of the pipe holes (Figure 2).

Fig. 1. A schematic plan of the experimental units (surface irrigation plot as well as subsurface irrigation plot showing the position of pipe lines

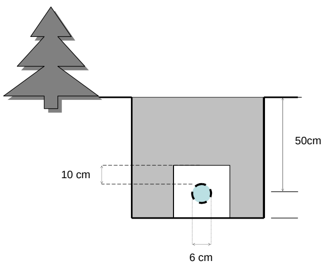

Fig. 2. A schematic cross section of pricked PVC pipe used for sub-surface irrigation together with the fine sand filter around to prevent blockage

It needs to be emphasized that in this research it has been tried to compare the efficiency of a new simple operable subsurface irrigation method to a common regional one. To be able to de this comparison, preparation of a plot for subsurface irrigation (as explained above) beside a plot of surface irrigation (which its irrigation schedule is exactly similar to regional common irrigation systems) was enough to fulfil the purpose of this research project.

Therefore, preparation of replications for the treatments was not necessary as no statistical method has been used for this comparison. Comparison has been simply made using the quantity of defined parameters (growing index, crop yield and weed growth) in two plots.

Both plots were irrigated using exactly equal quantity and quality of water for 2 years (years 2004 and 2005).

At the end of the first year we had no crop in the region due to frost. Therefore, comparison of the crop yield was left to the end of the second year.

For reliable comparison between irrigation plots in terms of annual growth, crop yield and especially probable effects of irrigation method on soil properties, soil samples were taken from different depths in both plots before starting the project, end of the first year and also end of the second year (end of the experiment).

3. Results

As there was no crop to harvest at the end of the first year, comparison of the product was left to the second year.

At the end of the second year the crop yield in plots was harvested separately and the weight of fresh and dried crop were measured. The weight of the fresh crop in surface and sub-surface irrigation plots was respectively 38 and 72 kg, and the dried weight in these plots was respectively measured 10.5 and 21 kg. The weight of fresh and dried crop in sub-surface irrigation plot to surface irrigation plot is respectively 1.895 and 2 (Table 1 and Figure 3).

In addition to total weight of harvested crop in each plot, the quality of crop was also compared. The mean weight and size of pistachios were also measured (using a random sample) for crops in both plots. The mean weight of each pistachio produced in surface irrigation plot was 0.6341 g. where it was 0.7082 g. in sub-surface irrigation plot.

In the other word the mean weight as well as dimensions of the pistachios produced in sub-surface irrigation plot to those produced in surface irrigation plot was about 1.12 Table 1 shows more details about this measurement.

Table 1. The rate of yield (Pistachio) and quality of pistachio produced in surface and subsurface irrigation plots

Experimental unit	Weight of dried crop (kg)	Weight of fresh crop (kg)	Mean weight of each pistachio (g)
sub-surface irrigation plot	21	72	0.7082
surface irrigation plot	10.5	38	0.6341

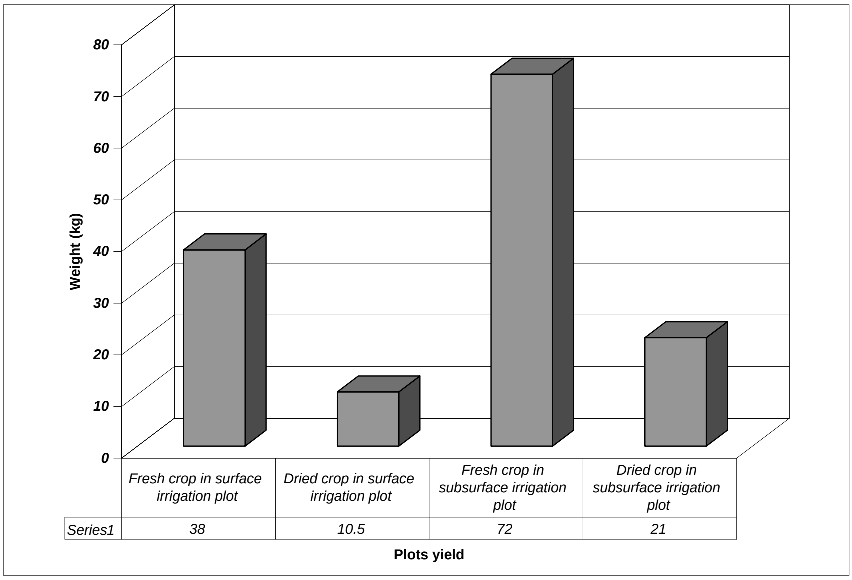

Fig. 3. The weight of fresh and dried crop produced by surface and subsurface irrigation plots

Another parameter measured for the trees of two plots was the annual shoot growth. This parameter was defined as Tree Growing Index (TGI) as follows:

Tree Growing Index=TGI= $\sum_{1}^{N} n_i d_i$

Where:

d_i is the length of shoot in cm.

n_i is the number of shoots with the length of

N is the total number of annual shoots for each tree.

Table 2 shows growing index calculation for tree number 1 in both plots. In each plot 10 trees were randomly selected and the above index was calculated for each tree. Then plot growing index was calculated for each plot as follows:

Plot Growing Index=PGI= $\sum_{1}^{10} TGI$

The value of PGI in surface irrigation plot was obtained 2237.5 cm while in sub-surface irrigation plot it was 4580.5 cm (table 3). In fact, PGI in sub-surface irrigation plot to PGI in surface irrigation plot was 2.05.

Figures 4 and 5 shows a graphical comparison of growing index for the trees in both surface and sub-surface irrigation plots.

Last measured parameter was the amount of weed growth in each plot. At the end of second growing season the dry weight of weed in surface irrigation plot was 82kg, it was only 21 kg, in sub-surface irrigation plot.

Table 2: Growing index for tree no. 1 in surface and sub-surface irrigation plots

Tree no. 1 in surface and subsurface irrigation plots					
Surface irrigation plot			Surface irrigation plot		
(1) The length of shoot (cm)	(2) The number of shoots	(3) (1)*(2)	(1) The length of shoot (cm)	(2) The number of shoots	(3) (1)*(2)
0.5	11	5.5	0.5	38	19
1	11	11	1	26	26
1.5	4	6	1.5	6	9
2	5	10	2	8	16
3	3	9	3	6	18
3.5	5	17.5	3.5	2	7
4	1	4	4	6	24
4.5	4	18	4.5	3	13.5
5	2	10	5	2	10
6.5	1	6.5	5.5	2	11
7	2	14	6	3	18
8	1	8	8	1	8
9	1	9	8.5	1	8.5
9.5	1	9.5	11.5	1	11.5
10.5	1	10.5	12	1	12
11.5	1	11.5	12.5	1	12.5
12	2	24	13	1	13
14	2	28	13.5	1	13.5
15	1	15	14.5	1	14.5
16.5	1	16.5	16.5	1	16.5
19	1	19	18	1	18
Tree growing index		262.5	Tree growing index		299.5

Table 3. Total growing index in trees of surface and sub-surface irrigation plots

Tree's growing index in surface and sub-surface irrigation plots		
Tree no.	Surface irrigation plot	Sub-surface irrigation plot
1	262.5	299.5
2	139	945.5
3	262.5	550.5
4	280.5	299.5
5	281.5	252.5
6	196	322
7	201.5	639.5
8	142	357
9	91.5	343
10	380.5	571.5
Plot growth index (tree's index summation)	2237.5	4580.5

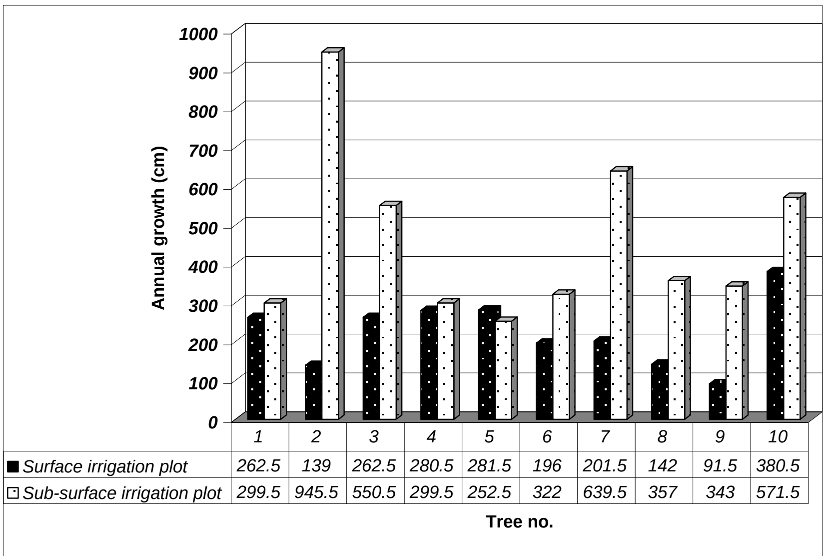

Fig. 4. Graphical comparison of annual growth in tree samples from both surface and sub-surface irrigation plots

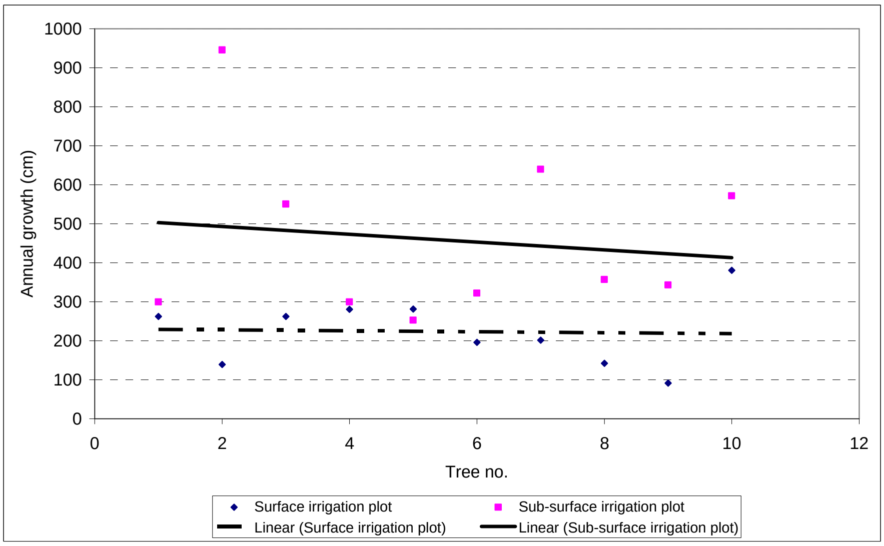

Fig. 5. Level of annual growth in trees sample of the irrigation plots

The results of laboratory analysis of the soil samples taken from various depths in each plot at the beginning and end of the research period showed no considerable change in pH and EC of soil during the study (Table 5).

Table 5. Results of soil sample analysis collected from plots in different times

Time of sampling	Factor	Depth (cm)	Surface irrigation plot	Sub-surface irrigation plot
	PH		*7.59*	*7.80*
	EC	0-30	*5.81*	*5.34*
	Texture		*S.L.*	*S.L.*
	PH		*7.69*	*7.97*
Beginning	EC	30-60	*12.28*	*12.61*
	Texture		*L.*	*L.*
	PH		*7.70*	*7.89*
	EC	60-90	*22.2*	*20.3*
	Texture		*L.*	*L.*
	PH		*7.64*	*7.60*
	EC	0-30	*8.78*	*6.1*
	Texture		*S. L.*	*S.L.*
	PH		*7.55*	*7.58*
End of year 2	EC	30-60	*16.34*	*14.89*
	Texture		*L.*	*L.*
	PH		*7.66*	*7.65*
	EC	60-90	*22.3*	*21.5*
	Texture		*L.*	*L.*

According to the results of this research, the efficiency difference of two irrigation systems is considerable for the pistachio orchards in Rafsanjan area. In this area where the irrigation water shortage is the main issue, surface irrigation system which is traditionally used by farmers is not an efficient method as the main part of irrigation water is lost from soil surface and top soil profile due to high evaporation rate during the year. The amount of water lost from channels and water resources in this irrigation system considered in this research and water was taken by tank directly to the plots. Groundwater recession in this region, and consequently the serious water limitation for pistachio orchards (which almost is the only crop for local farmers) necessitates optimization of irrigation systems toward new systems with minimum water loss such as sub-surface irrigation.

It needs to be mentioned that the new sub-surface drip irrigation implemented in this research has some advantages over the conventional drip irrigation and sub-surface drip irrigation methods used elsewhere. These advantages can be summarised as follows:

1- It is a quite simple method and can be operated by farmers. As mentioned earlier plastic cloth is sewn in the shape of long sleeves and then pricked PVC pipes are put through the sleeve shape cloths, then it is ready to lay through the 50 cm depth channel, after using the filter which is provided from local sand dunes, the channel is covered by carved soil. After this, the system is ready for operation.
2- Its durability is acceptable. In this method the pipes are relatively wide (9 cm diameter) and covered with relatively strength plastic cloth and also surrounded by a layer of filter, durability against obstruction and also uniform exudation of water is almost guaranteed. It needs to be added that in the other part of the orchard where this research project was carried out, exactly the same system has been operated in 1997 and after more than 9 years it was evaluated and tested, and there was no obstruction, blockage or damage to the pipes. It must be mentioned that although it was not implemented as a research project at that time and the purpose was just to keep orchard alive and productive. However, the present research project was started based on this successful experience.
3- This is a quite cheap method. As mentioned earlier, from economical point, an initial analysis of the costs for operation and maintenance against benefits from crop increase shows that invested money will be returned normally in 4 years. However, the irrigation system durability is much longer and increase the income of the farmers.
4- No booster pump is needed in this method (in most of subsurface drip irrigation systems booster pumps are required).
5- In this method filtration of water is not required.
6- This method is quite compatible to the local area water-right condition. Most of the farmers in the related region own less than 3-4 hours of water-right in a period of two weeks and need a sufficient method that can also deliver water to the soil during this short time.
7- This method is relevant to the local ownership condition. The region is under small ownership condition (farmer own small parts of lands), and it is not economically possible for owners to establish comprehensive and expensive systems for their few hectares of orchard. However, the tested method can be easily operated in these small peaces of lands.
8- In this method the pipes can be easily cleaned by flushing out (at the end of each pipeline there is an out let and can be opened for this purpose).

4. Conclusion

The results taken from this research indicates that the amount of crop yield as well as annual shoot growth in sub-surface irrigation plot was about twice as much as surface irrigation plot. In addition, the weight of grown weed in sub-surface irrigation plot has been about one fourth of grown weed weight in surface irrigation plot. For the pistachio orchards in the research area the difference in water use efficiency of two irrigation methods is significant for the. As the main issue of the area is irrigation water shortage, surface irrigation system which is traditionally used by farmers is not an efficient method for long time due to considerable loss of water. Groundwater recession in the area and the serious water scarcity for pistachio orchards necessitates optimization of irrigation systems toward new methods with minimum water loss such as sub-surface method. Although this optimization has costs for farmers, but due to considerable differences between efficiency of two irrigation methods and significant increase in crop yield in sub-surface irrigation, the cost would be returned in a reasonable period of time. The total cost for preparation and operation of this kind of subsurface irrigation was estimated about 1500 US$ per hectare. An initial cost/benefit analysis for this optimization shows that the cost will be returned (only from crop increase) approximately in 4 years.

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