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Economic analysis of the optimal level of supplemental irrigation for rain-fed figs

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ABSTRACT- The aim of this study is economic analysis of supplemental irrigation (SI) for rain-fed fig trees in the south of Iran, with and without micro-catchment water harvesting systems (MCWHS). Under no MCWHS, by decreasing about 55 % of applied water, the fig yield decreased about 28% and net income increased twice compared with the maximum yield condition. In general, the optimal amount of SI water would be lowered by using MCWHS in comparison with no using MCWHS. By using MCWHS, decreasing about 50 % of applied water causes about 14 % decrease in fig yield and net income increased twice compared with maximum yield condition. In order to obtain high net profit with a given amount of annual rainfall, the amount of optimal SI water decreased by increasing the unit price of water. An equation **is** proposed for the prediction of annual precipitation which may be used for planning SI for the fig trees in the study region.

INTRODUCTION

Rain-fed fig is one of the most important exportable products in Iran, especially in Istahban area, Fars province where its annual production is about 20000 tons. However, because of recent drought occurrence and drastic decrease in the annual rainfall in this area, the fig production decreased to about 6000-7000 tons.

By the year 1996, the total fig cultivated area in Fars province was 30578 ha and about 99.2 % of these areas were rain-fed. About two-third of the fig production in Fars province is produced in Istahban region. This region has more than 2500000 rain-fed fig trees in an area of 20000 ha. Due to recent droughts, the amount of annual rainfall is not enough to supply water requirement for economic production of rain-fed fig trees and further, these trees are dried in drought conditions. Therefore, these trees are irrigated with supplemental water to be preserved and produce economic yield. However, Supplemental Irrigation (SI) cannot provide enough water for the crop full water requirement.

On the other hand, irrigation water supplies are decreasing in many areas. Some of the reasons for this decrease are drought periods, and decline in groundwater levels. Scarcity of irrigation water and decreasing water resources with suitable quality are the most important limiting factors in the crop production in arid and semi-arid regions such as Iran, especially in Istahban area. Therefore, research for optimization of water use in the rain-fed fig orchard to achieve maximum water productivity is important.

Mazaheri-Tehrani et al. (2016) reported that supplemental irrigation (SI) on the rain-fed Yaghouti grape in Bajgah area (Fars province) increased the growth (dry matter) and yield of this cultivar. Kamyab (2014) studied the effects of SI timing and volume on the growth and yield of Asgari grape cultivar in the same region. She indicated that SI in April and May with 1.2 m^3 $tree^{-1}$ resulted in higher growth and yield.

Mervin et al. (2008) found that SI increased the growth and yield of white grape in Cornel Research Institute (New York). Besinger and Hellman (2006) studied the effects of regulated SI on grape yield at west of Texas and indicated that this irrigation strategy promoted the water productivity in grape production and the effects of SI on grape yield were influenced by irrigation timing and volume.

For fig tree, Tapia et al. (2003) reported that in a region with annual rainfall of 37 mm, SI of 220 mm (2200 m^3 ha^{-1}) could produce economic yield. Al-Desouki et al. (2009) studied the effect of SI on growth and yield of 15-year-old fig tree (cv. Soltani) in western shore area of Egypt under rain-fed conditions. Results indicated that SI increased fig tree growth and yield. Bagheri and Sepaskhah (2014) analyzed the effect of annual, monthly and seasonal rainfall distribution on rain-fed fig yield in Istahban area and indicated that winter rainfall, especially March rainfall, was the most effective parameter on the fig yield. Therefore, based on these findings, SI in March was recommended in years with low annual rainfall.

In rain-fed areas in I.R. of Iran, water resources for SI are not readily available. Therefore, micro-catchment water harvesting systems (MCWHS) are used to collect surface runoff for storage in a surface reservoir, or directly for use by crops in this system as SI (Sepaskhah et al., 1992; Sepaskhah et al., 1997; Sepaskhah and Fooladmand, 2004). In this way, the amount of water available from rainfall is increased. The use of this system increases the crop productivity in rain-fed areas.

Different types of MCWHS as square and semi-circular bunds are used. In square MCWHS, each micro-catchment for each grape tree is constructed by surrounding the tree by bunds with 0.2-0.3 m height (square basin) and the tree is planted at down slope corner in a small circular basin as described by Sepaskhah and Fooladmand (2004). Use of MCWHS for four different grape cultivars was economically analyzed by Fooladmand and Sepaskhah (2004). Results indicated that annual profit for MCWHS with 9 m^2 area for each grape tree was higher than those obtained in vineyard with no MCWHS, and this profit was higher for black Rishbaba and Rotabi compared with those for Asgari and black grape. For rain-fed fig trees in Istahban area, semi-circular bunds were constructed (Karami et al., 2006) to collect the rainfall runoff.

In general, in drought conditions, SI is needed for rain-fed trees; however, the amount of optimal SI water and the optimal time of irrigation water application are not known

The aims of this study were to conduct an economic analysis of supplemental irrigation (SI) for rain-fed fig trees in Istahban region in the year 2008, under land limiting conditions and also to derive an equation for the prediction of annual rainfall in this region for planning SI for these trees.

MATERIALS AND METHODS

Conceptual Model

In this research, the fig trees were planted 50 years ago and it is not possible to increase the cultivated area of the fig orchard as a result of water saving analysis; therefore, only land limiting conditions were investigated to optimize the SI of the rain-fed fig trees with 10 m spacing between the trees.

In the conceptual model, w_m is the amount of irrigation water that would maximize the yield and w_l is the amount of irrigation in land limiting conditions for optimization of the net profit. Therefore, in this condition, the optimal irrigation strategy would be obtained to maximize the net profit derived from unit land area.

By developing an equation to estimate the values of variables (w_m, w_l), it is possible to obtain the optimal water use for different system design and operation for water applications (Hargreaves and Samani, 1984). The net profit from irrigation optimization is determined by the amount of water applied, the shape of crop production function, the variable and fixed costs of irrigation, and crop price (Sepaskhah and Akbari, 2005). The detail of analysis and related equations are given in the next section. The amount of applied water may be complemented by annual rainfall that is a variable parameter in different years. The volume of applied water for each tree was determined volumetrically. The amount of rainfall was measured in a weather station nearby the study area. The purpose of this study was an economic analysis of SI for rain-fed fig trees at different annual rainfalls. This analysis was conducted under the presence of annual rainfall, with and without MCWHS. The crop production function and production cost function were quadratic and linear, respectively. The variable and fixed costs for the production cost equation and the crop price were obtained from the experts at Fig Research Station in Istahban area.

Mathematical Formulation Under the Absence of Rainfall

The mathematical formulation of deficit irrigation was presented by English (1990) as follows:

$$I_f(w) = A.I_l(w) \tag{1}$$

$$I_l(w) = P_c y(w) - c(w) \tag{2}$$

where A is the total irrigated area in ha, w is the applied water per unit of land in m^3 ha^{-1}, y(w) is the yield per unit of land in kg ha^{-1} that is expressed as a function of w, c(w) is the production costs equation per unit of land in Rls ha^{-1} that is expressed as a function of w, P_c is the crop price in Rls kg^{-1}, *Ii(w)* is the net profit per unit of land in Rls ha^{-1}; and $I_f(w)$ is the net income from total irrigated land in Rls.

The amount of water use that maximizes yield, w_m, can be determined by taking the derivative of the yield function and equalizing it to zero:

$$\frac{\partial y(w)}{\partial w} = 0 \tag{3}$$

English (1990) developed the model for both land-limiting and water limiting optimization cases. As the fig tree area is fixed at short term, therefore, the land-limiting case was used in this study, and the water was considered as not limiting for optimization analysis. To determine the amount of water use that will maximize net profit when land is limiting, the partial derivative of Eq. (1) is taken with respect to w:

$$\frac{\partial I_f(w)}{\partial(w)} = A\frac{I_l(w)}{\partial w} + I_l\frac{\partial A}{\partial w} \tag{4}$$

When land is limiting, factor A is presumed constant; therefore, by setting derivative to zero and eliminating A, the optimal amount of water can be determined by Eq. (5):

$$\frac{\partial I_l(w)}{\partial(w)} = 0 \tag{5}$$

Eq. (5) can be rewritten as:

$$\frac{\partial I_l(w)}{\partial(w)} = P_c \frac{\partial y(w)}{\partial(w)} - \frac{\partial c(w)}{\partial(w)} \quad (6)$$

Therefore, when land is limiting, the optimal amount of water can be determined by:

$$P(c)\frac{\partial y(w)}{\partial(w)} = \frac{\partial c(w)}{\partial(w)} \quad (7)$$

The aforementioned equations can be used to determine w_m [Eqn (3)], w_l [Eqns (7)].

By substituting w_m (water for maximum yield) into Eq. (2), the net profit per unit area under full irrigation is determined as:

$$I_l(w_m) = P_c y(w_m) - c(w_m) \quad (8)$$

Different functional forms have been used for the yield-water response and production cost (Berbel and Mateos, 2014). However, the quadratic and linear functions were used in this study for yield and production cost, respectively, due to their simplicity and frequency of use by others (English and James, 1990; Sepaskhah and Akbari, 2005; Sepaskhah et al., 2006; Sepaskhah et al., 2008). For optimization of the water consumption and also the net profit, the yield and costs functions can be represented by equations as follow (English and James, 1990):

$$c(w) = a_2 + b_2 w \quad (9)$$

$$y(w) = a_1 + b_1 w + c_1 w^2 \quad (10)$$

Where a_1, b_1, c_1, a_2 and b_2 are the parameters of this equation, y(w) is the yield per unit land in kg ha^{-1}, expressed as a function of w, c(w) is the production costs per unit land in Rls ha^{-1} and w is the water consumption under the scarcity of annual rainfall. The two levels of water use can then be shown as:

$$w_m = -\frac{b_1}{2c_1} \quad (11)$$

$$w_l = \frac{b_2 - P_c b_1}{2P_c c_1} \quad (12)$$

Equation (11) was obtained by derivative of Eq. (9) and equating it with zero. Equation (12) was obtained by inserting the derivations of Eqs. (9) and (10) in Eq. (7). To provide an equation for predicting the annual precipitation in Istahban area for schematization of the SI for the fig trees, a simple model was proposed by Sepaskhah and Taghvaie (2005) which predicts the annual precipitation for southern and western provinces of Iran. In this model, the relationship between the annual precipitation and the duration of occurrence for 47.5 mm of precipitation since the onset of autumn were significant. Therefore, this relationship was used to predict the annual precipitation of Istahban area as follows:

$$R = a \times t_{47.5} + b \quad (13)$$

where: R is the annual precipitation in mm and $t_{47.5}$ is the duration of occurrence for 47.5 mm of precipitation since the onset of autumn in days, and a and b are the constants that were determined for the study area by Sepaskhah and Taghvaie (2005). The value of $t_{47.5}$ was determined by the number of days since the onset of autumn at which the cumulative daily precipitation reached 47.5 mm.

Site Description

Data for the economic analysis were obtained from the Istahban Fig Research Station located at 175 km south-east of Shiraz with latitude of 29° 15' N, longitude of 54° 15' E, and mean sea level of 1767 m. The general climate of the region is semi-arid with long-term mean annual precipitation of 354 mm (minimum and maximum annual precipitation of 92 and 739 mm, respectively) and mean annual temperature and relative humidity of 14.9° C and 45%, respectively. The rainfall distribution occurs mainly from November to May with number of rainy days varied between 19 and 46. The average of minimum and maximum air temperatures are -9 and 40 ºC, respectively. The growing season for rain-fed fig starts in April and ends at the end of October. The soil texture is gravelly sandy loam (fine carbonate, thermic, typic, calcixerept).

Data were collected from the rain-fed fig orchard with slope of 3-5% that is representative of the study region. Thirty six 50-year-old uniform fig trees (cv. Izmir/Sabz) were selected. The tree spacing was 10×10 m with 100 trees per hectare. Fig yield was harvested four times in 12-21 August, 23 August-5 September, 6 September-21 September, and 23 September- 22 October. The total yield of these harvests was considered as the final yield.

The data used in this research were daily precipitation, annual yield of fig since 1995 until 2007 in Istahban area and the fig production cost. Table 1 shows the annual rain-fed fig yield, the annual rainfall and runoff in MCWHS in different years. Total fig yields in growing seasons of 1995 to 2003 (9 years) were reported for rain-fed fig orchard for no MCWHS (Table 1). Semi-circular bund for the MCWHS was constructed at the beginning of autumn 2003 and data collection continued for the growing seasons of 2004 to 2007 (4 years) for MCWHS (Table 1). MCWHS was installed for the last 4 years; therefore, runoff occurred for these years. The value of annual runoff was determined using the equation presented by Sepaskhah et al. (1992) for a similar watershed condition with comparable slope, soil water content and soil surface conditions as follows:

$$R_o = 0.0875(R - 106.5) \quad (14)$$

where: R_o is the annual runoff in mm and R is the annual precipitation in mm. The depth of runoff over the micro-catchment area (10 m×10 m) was converted to runoff volume that is infiltrated in the soil under the tree canopy with diameter of about 4.3 m.

Table 1. Annual rain-fed fig yield, annual rainfall and runoff in water harvesting system in different years

Year	Annual rainfall (mm)	Runoff (mm)	Fig yield (kg ha^{-1})
1994-1995	406.4	0	689.2
1995-1996	475.5	0	730.2
1996-1997	234.1	0	575.2
1997-1998	559	0	464.2
1998-1999	441.9	0	760.2
1999-2000	206.2	0	385.5
2000-2001	177.4	0	387.2
2001-2002	288.1	0	390.2
2002-2003	537.1	0	410.2
2003-2004	620.6	313	1041.8
2004-2005	590.5	294	862.9
2005-2006	180.5	45	703.8
2006-2007	409.7	184	1081.1

The collected rainfall runoff in the soil under the tree canopy was considered as SI that is practically similar to the SI applied by the farmers in winter in the study region. However, farmers usually use a large volume of water that may be much higher than the optimal amount; so, the precious water is lost. As the water in the region is supplied from scarce groundwater resources, the economic analysis for determining the optimal SI is very important. In this analysis, fig-water production function is needed. Rain-fed fig production function for no MCWHS was obtained by using 13 observations (9 observations from no MCWHS with no SI and 4 observations with SI in the MCWHS). Furthermore, the last 4 observations were used to obtain the rain-fed fig production function for MCWHS.

RESULTS AND DISCUSSION

Optimal irrigation water in land limiting condition without MCWHS

Fig Production Function

The applied water plus rainfall production function was obtained by multiple regression analysis as follows:

$$y(w') = -0.0008w'^2 + 1.6962\,w' + 72.832,\quad R^2 = 0.74,\ SE = 138,\ Sig\ F = 0.004 \qquad (15)$$

where: $y(w')$ is the fig yield in kg ha^{-1}, w' is the applied supplemental water plus annual rainfall (w+R) in mm, R^2 is the coefficient of determination, SE is the standard error and Sig. F is the probability level. The relationship between $y(w')$ and (w') is shown in Fig. 1.

Production Cost Equation

The production cost of fig (not included irrigation cost) was calculated to be 3000000 Rls ha^{-1} (35000 Rls is equal to 1 $).

This cost included land preparation, fertilizer, pesticides and herbicides, plow, harvest and etc. Irrigation cost as variable cost is 20000 Rls m^{-3} that includes the water transportation by tanker and application. This variable cost is the slope of the linear equation for production cost. Therefore, the production cost which included fixed and variable cost is as follows:

$$c(w) = 20000w + 3000000 \qquad (16)$$

Economic Analysis Under Land Limiting Condition Without MCWHS

Due to the different distance between the water source and the point of water application, the irrigation water cost (20000 Rls m^{-3}) might be variable; therefore, the relationship between the optimal SI and annual rainfall at different irrigation water costs is as follows:

$$w_l = -.00026w_c - 0.0125R + 8.73,\quad R^2 = 0.75,\ SE = 2.29701E\text{-}16,\ Sig\ F < 0.0001 \qquad (17)$$

where: w_l is the optimal SI in m^3 per tree, w_c is the irrigation water cost in Rls m^{-3}, R is the annual rainfall in mm.

Fig. (2) shows the relationship between optimal supplemental irrigation (SI) and different unit water prices at different annual rainfalls.

This figure indicated that at a given value of rainfall, the amount of SI increased as the unit price water decreased. Table (2) shows the unit price of water that is related to zero w_l in different amounts of rainfall.

The relationship between net profit and applied water (SI) at different unit water prices and a given annual rainfall (200 mm) is shown in Fig. 3.

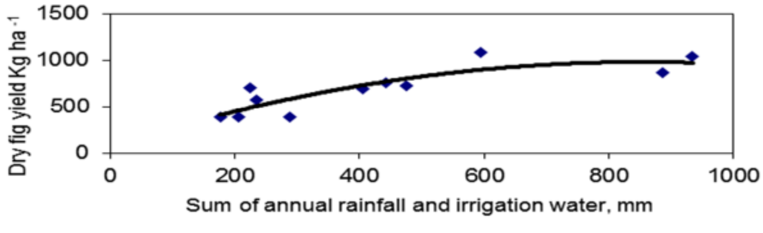

Fig. 1. Relationship between fig yield and sum of annual rainfall and irrigation water

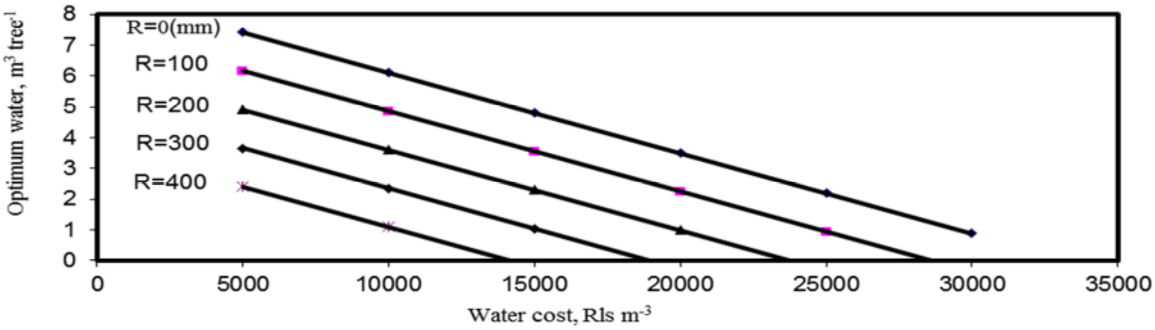

Fig. 2. Relationship between optimal water and different unit water prices at different annual rainfalls with no MCWHS

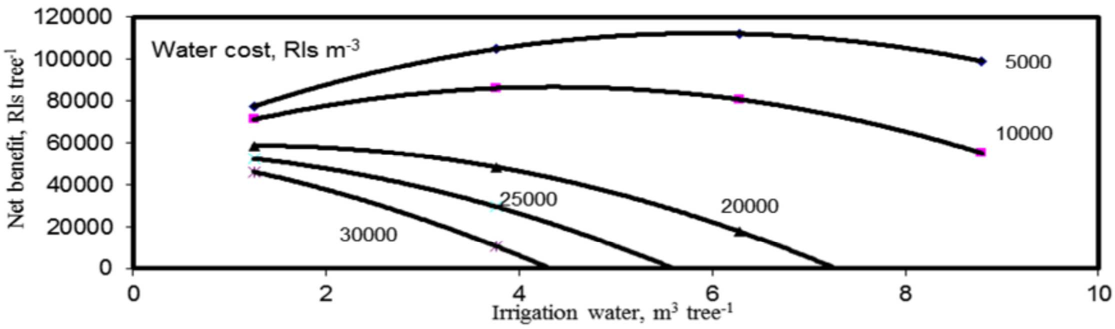

Fig. 3. Relationship between net profit and applied SI water at different unit water prices and at given annual rainfall (200 mm) with no MCWHS

This figure indicated that in order to attain more net profit, the values of w_l in a given amount of rainfall decreased by increasing the unit water price. That concurs with the basic economic concept. Table 3 shows the amount of w_l that resulted in maximum net profit in different unit prices of water. Table 4 shows the amount of optimal SI, the net profit and fig yield under land limiting and maximum yield conditions with no MCWHS. According to the basic economic concept such as maximum production and economic optima, the net profit in land limiting conditions is higher than that obtained for maximum yield conditions, and also by decreasing about 55% of applied water (SI), the fig yield is decreased about 28% and the net profit at the land limiting condition increased 5 to 2 times compared with the maximum yield condition under different rainfalls.

Table 2. Unit price of water at different annual rainfalls with no w_l and no MCWHS

Rainfall (mm)	Unit price of water (Rls m^{-3})
0	33577
100	28770
200	23961
300	19153

Table 3. The amount of W_l that resulted in maximum net profit at different unit prices of water with MCWHS

W_l, (m^3 $tree^{-1}$)	Unit price of water (Rls m^{-3})
5.9	5000
4.35	10000
1.2	20000
0	25000
0	30000

Optimal Irrigation Water in Land Limiting Conditions with MCWHS

Fig production Function

Fig yields from MCWHS with fewer number of observations were used in obtaining the production function. In this case, the produced runoff in the MCWHS was also added to the rainfall. The relationship between fig yield and annual rainfall plus the amount of runoff due to MCWHS is shown in Fig. 4. Their relationship is obtained by multiple regression analysis as follows:

$$y(w') = -.0011\, w'^{2} + 1.8729\, w' + 268.22, \quad R^2 = 0.86, \quad SE = 64, \ Sig\ F = 0.0026 \qquad (18)$$

where $y(w')$ is the fig yield in kg ha^{-1}, w' is the annual rainfall plus runoff in mm

Equation (18) is quite similar to Eq. (15) in first and second coefficient (-0.0011 and 1.8729 compared with -0.0008 and 1.6962, respectively); however, the third coefficient, 268.22 is higher than 72.832. This indicated that fig yield in MCWHS is higher than that in regular rain- fed orchard with no MCWHS. This might be due to nutrient transportation from the adjacent soil to the cultivated area to enhance the tree growth and yield. Furthermore, the difference in the number of observations might have caused these differences between Eq. (15) and (18).

Table 4. Optimal SI water, fig yield and net profit under different amounts of rainfall and different conditions with no MCWHS.

Analysis	Rainfall (mm)	Optimum supplemental water (mm ha^{-1})	Fig yield (kg ha^{-1})	Net profit (Rls ha^{-1})
Condition				
Land limiting	100	359	798	5577968
	200	259	798	7633768
	300	159	798	9859568
	400	59	798	11754368
Maximum yield				
	100	788	1018	1175588
	200	688	1018	3231358
	300	588	1018	5287158
	400	488	1018	7342958

When rainfall and runoff that is collected in MCWHS is not adequate for tree water requirement for sustainable yield and preservation of the fig trees, SI should be applied. In these conditions, the production cost equation is as follows:

$$c(w) = 20000\ w + 4000000 \qquad (19)$$

Irrigation cost as variable cost is 20000 Rls m^{-3} that includes water transport by tanker and application. This variable cost is the slope of the linear function for the production cost equation [Eq. (19)]. Furthermore, the fixed cost (4000000 Rls) is higher than that for rain-fed orchard with no MCWHS due to the implementation of the system.

Economic Analysis for Optimal Water with MCWHS

The relationship between the optimal SI water and annual rainfall at different unit water prices is as follows:

$$w_l = -0.000147w_c - 0.0125R + 6.85, \quad R^2= 0.99, \text{SE}= 2.14\text{E-}14, \text{Sig } F<0.0001 \qquad (20)$$

where w_l is the optimal SI water in m^3 per each tree, w_c is the unit water price in Rls m^{-3} and R is the annual rainfall in mm.

Fig. 5 shows the relationship between optimal water and different unit water prices at different annual rainfalls. This figure indicated that by using MCWHS and collected rainfall runoff for irrigation of fig trees as compared with the conditions without using MCWHS (Fig. 2), the amount of optimal SI water decreased.

Furthermore, the amount of optimal SI water is decreased by increasing unit water price. Fig. 6 shows the relationship between net profit and applied SI water at different unit water prices at a given amount of annual rainfall (200 mm). This figure indicated that in order to attain more net profit, the amounts of w_l at a given amount of rainfall decreased by increasing the unit water price, which concurs with the basic economic concepts. Furthermore, by using MCWHS and runoff, the net profit increased at a given amount of rainfall and unit water price compared with that obtained in the condition of no MCWHS.

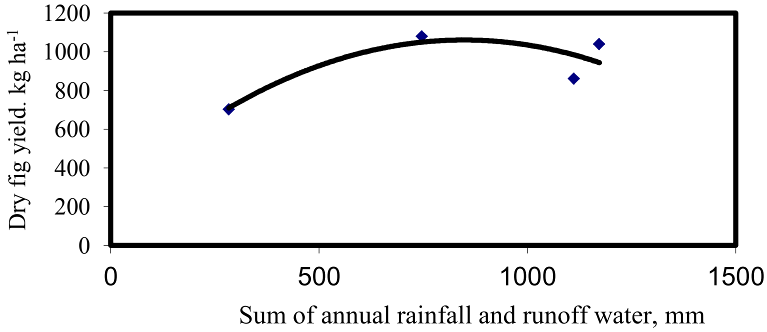

Fig. 4. Relationship between fig yield and annual rainfall plus runoff

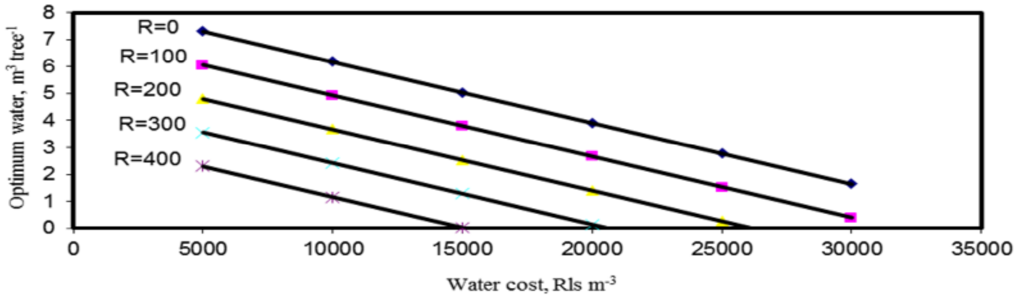

Fig. 5. Relationship between optimal SI water and different unit water prices at different annual rainfalls with MCWHS

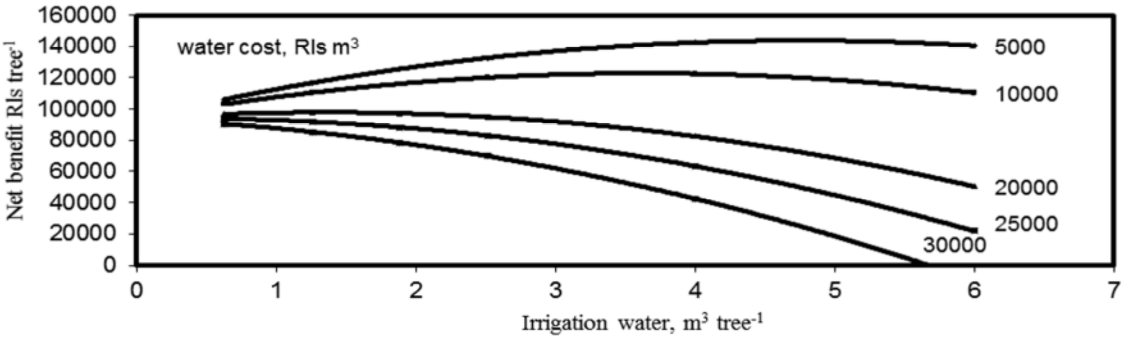

Fig. 6. Relationship between net profit and applied SI water at different unit water prices and at given annual rainfall (200 mm) with MCWHS.

Table 5 shows the unit water price that resulted in zero w_l at different amounts of rainfall (i.e., 0 to 400 mm). Table 6 shows the amount of w_l that resulted in maximum net profit at different unit water prices with MCWHS.

Table 5. Unit price of water at different annual rainfalls corresponding with zero w_l under MCWHS

Rainfall (mm)	Unit price of water (Rls m^{-3})
0	46632
100	38095
200	29591
300	21088
400	12585

Table 7 shows the value of optimal SI water, net profit and fig yields under land limiting and maximum yield conditions, with MCWHS. According to the basic economic concept such as maximum production and economic optima, the net profit in land limiting conditions is higher than that obtained in the maximum yield conditions. Furthermore, by decreasing about 50% in applied SI water, the fig yield is decreased about 14% and net income at land limiting conditions increased about twice as compared with the maximum yield conditions.

Table 6. The amount of w_l that resulted in maximum net profit at different unit prices of water with MCWHS

Unit price of water (Rls m^{-3})	w_l, (m^3 $tree^{-1}$)
5000	4.76
10000	3.6
20000	1.35
25000	0.26
30000	0

Supplemental Irrigation Planning

Study of Bagheri and Sepaskhah (2014) indicated that rainfall in winter or March is the most effective parameter for the rain-fed fig yield production in the study area. Therefore, in case of lack of adequate rainfall in winter, supplemental irrigation in March could be the most effective parameter in rain-fed fig yield production. However, the amount of SI should be determined. Supplemental irrigation planning can be conducted based on the prediction of annual precipitation. For prediction of the annual precipitation in Istahban area, a relationship between annual precipitation and the duration of 47.5 mm of precipitation since the onset of autumn was used as follows:

Therefore, by using Eq. (21), the annual precipitation is predicted and based on Eq (17) and (20), it is possible to plan for the fig tree supplemental irrigation.

In drought and scarce annual rainfall, the rain-fed fig yield is reduced and even these trees are dead. Therefore, SI for tree preservation and yield improvement is needed. However, the optimal SI water and application timing is not used by the orchard owners. They usually use a large volume of SI water and mostly throughout the growing season. By this inappropriate SI management, the rain-fed fig trees are converted to irrigated fig trees and their fruit quality and resistance to drought conditions is lowered.

Table 7.The amount of optimal SI water, the net profit and yield under land limiting conditions and maximum yield with MCWHS

Analysis condition	Rainfall (mm)	Optimum supplemental water (mm ha^{-1})	Fig yield (kg ha^{-1})	Net income (Rls ha^{-1})
Land limiting				
	100	296	934.6	14360742
	200	196	934.6	16901141
	300	96	934.6	19441541
	400	0	934.6	21981942
Maximum yield				
	100	594	1114.8	7171852
	200	494	1114.8	9712252
	300	394	1114.8	12252652
	400	294	1114.8	14691000

$R = -679.78 \text{ Ln } t_{47.5} + 3540, \quad R^2 = 0.62, \text{ SE} = 140, \text{ Sig F} = 0.002 \qquad (21)$

Therefore, the optimal SI water was determined by the proposed economic analysis. Results indicated that with no MCWHS and water price of 20000 Rls m^{-3}, SI is not needed when the annual rainfall of 310 mm occurres. This rainfall is 280 mm for the case with MCWHS. Furthermore, with MCWHS, SI of 0.41, 1.03 and 166 m^3 $tree^{-1}$ is needed corresponding with the annual rainfall of 250, 200, and 150 mm, respectively. These values for SI in no MCWHS are 0.79, 1.41, and 2.04 m^3 $tree^{-1}$, respectively. Kamgar-Haghighi et al. (2014) studied the effect of different SI water amounts at different application times on rain-fed fig growth and yield in Istahban area for three years. They concluded that with mean annual rainfall of 213 mm, the SI application of 0.75-1.50 m^3 $tree^{-1}$ (mean of 1.13 m^3 $tree^{-1}$) in March and March and May promoted the growth and yield compared with that obtained with no SI. Furthermore, the economic analysis in our study indicated that with annual rainfall of 200 mm and with no MCWHS, the optimal amount of SI water is 1.03 m^3 $tree^{-1}$ which is in accordance with those reported by Kamgar-Haghighi et al. (2014) in the study region.

CONCLUSIONS

In order to obtain high net profit, the amounts of w_l at a given amount of rainfall decreased as the unit water price increased. With no MCWHS, the net profit in land limiting conditions is higher than that obtained at maximum yield conditions. Furthermore, by decreasing about 55% in applied SI water, the fig yield decreased about 28% and net profit increased twice as much as at land limiting conditions under different rainfalls compared with maximum yield conditions. By using MCWHS and collected excess rainfall (runoff) for irrigation of fig trees, the amount of optimum SI water decreased as compared with that obtained in conditions with no MCWHS. Furthermore, by decreasing about 50% in applied SI water, the fig yield decreased about 14% and net profit at land limiting conditions increased twice compared with maximum yield condition. For predicting annual precipitation in Istahban area, a relationship between annual precipitation and the duration of 47.5 mm of precipitation since the onset of autumn was used for possible planning of supplemental irrigation for fig trees.

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تحلیل اقتصادی مقدار بهینه آبیاری تکمیلی انجیر دیم

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چکیده– هدف از این مطالعه تحلیل اقتصادی آبیاری تکمیلی انجیر دیم در جنوب ایران با استفاده و بدون استفاده از آبگیر می باشد. با کاهش حدود ۵۵ درصد در آب کاربردی محصول انجیر ۲۸ درصد کاهش یافت و سود خالص در مقایسه با حداکثر محصول دو برابر افزایش یافت. به طور معمول میزان بهینه آبیاری تکمیلی با به کار بردن آبگیر در مقایسه با شرایط بدون آبگیر کمتر است. بدون به کارگیری آبگیر سود خالص در شرایط کمبود آبیاری تکمیلی بیشتر از شرایط آبیاری تکمیلی کامل می باشد. بعلاوه با کاهش حدود ۵۰ درصد در آب کاربردی میزان محصول حدود ۱۴ درصد کاهش و سود اقتصادی دو برابر نسبت به حداکثر محصول افزایش یافت.برای دستیابی به حداکثر سود اقتصادی با درنظر گرفتن بارندگی سالانه،مقدار بهینه آبیاری تکمیلی با افزایش قیمت آب کاهش یافت. معادله ای جهت پیشبینی بارندگی سالانه ارایه گردید که می تواند جهت برنامه ریزی آبیاری تکمیلی درختان انجیر استفاده گردد.