Optimization of Irrigation Water Depth under Water Limiting Condition

Mohammad Ismaeil Kamali (kamalipasha@yahoo.com)
Ferdowsi University of Mashhad, Water Engineering Department https://orcid.org/0000-0001-9175-8957
Hossein Ansari
Ferdowsi University of Mashhad
Rouzbeh Nazari
University of Alabama at Birmingham

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Optimization of Irrigation Water Depth under Water Limiting Condition

Mohammad Ismaeil Kamali[1], Hossein Ansari*[2], Rouzbeh Nazari[3]

Abstract

Water productivity is a major challenge in all agricultural regions and despite the use of pressurized irrigation system, it has not increased as expected in Iran. In addition, in spite of water shortage in Iran, gardeners because of lack of knowledge in economic consequences do not welcome deficit irrigation and irrigation scheduling. To this end, optimization of irrigation water depth in an orange orchard was conducted for two irrigation scheduling methods (with and without 4 days irrigation frequency) under water and land limitations conditions by mathematical analysis of production and cost functions. Then, their effect on the net income by changing in water and fruit price was assessed. Production and cost functions were developed based on two scenarios of applied water including only irrigation water depth and irrigation water depth plus rainfall. According to results, when water is limiting, by using the optimum water depth (W_w), 26% of irrigation water use can be saved that causes only 3% to 4% decrease in the net income per unit of land and 16% increase in the net income per unit of irrigation water. In addition, when water limiting is serious, using 46% deficit irrigation (W_{ew}) is more useful and resultes the highest water productivity, even though it causes 14% to 17% decrease in the net income per unit of land. However in water limiting condition, if land is not limiting, using W_{ew} causes the maximum net income per unit of land even 50% to 60% more than full

[1] Postdoc Fellow, Water Engineering Department, Ferdowsi University of Mashhad, Mashhad, Iran.
[2] Professor, Water Engineering Department, Ferdowsi University of Mashhad, Mashhad, Iran. (*_Corresponding Author, Email: Ansary@um.ac.ir)
[3] Associate Professor, Department of Civil, Construction And Environmental Engineering, University of Alabama at Birmingham

irrigation. Moreover, using the optimum water depths in water limitation conditions (W_w and W_{ew}) increases the water productivity 26% to 47% relative to full irrigation. On the other side, the net income and the amount of optimum water depths are not sensitive to the price of water at the present value of water. However, they are highly sensitive to the price of fruit. Furthermore, having an irrigation schedule causes 27% increase in the net income per unit of land. According to positive effects of deficit irrigation and irrigation scheduling on the water productivity and the income, they are highly recommended for addressing water scarcity in Iran.

Key words: Optimum water depth; Production function; Soil readily available water; Water limitation; Water productivity

Introduction

Increasing need to food production in Iran that has limited water resources and is subject to water risks remains a major challenge in the recent years. In addition, water shortage in Iran threatens its environment, food security and economic that without further action would be a hotspot region with domestic and global repercussions. Groundwater as the largest available source of freshwater is under natural and anthropogenic pressures in Iran (Ashraf et sl., 2021). Intensive groundwater use for agriculture depletes aquifers so that the total and annual groundwater deficit in Iran is 131.1 and 5.2 bm^3 (Iran cabinet approval, 2021). Since agriculture is the biggest using sector of water and highly water-dependent in Iran, agricultural water productivity must be improved. Although Iran is known as an arid to semi-arid country, Mazandaran province located in the north of Iran has an average annual rainfall about 620 mm.

Then, many gardeners do not pay enough attention to the irrigation scheduling. However, the annual rainfall is not solely a good indicator for irrigation management, and temporal distribution of rainfall and the amount of rainfall in each rainfall occurrence must be considered, as well. The 20-year rainfall in Mazandaran shows that only 30% of the annual rainfall occurs from April to September and 18% of the annual rainfall occurs in 4 months from June to September (that is the important time for orange fruit set). Whereas, the evaporation during these periods are 814 and 623 mm, respectively. In addition, according to National Adaptation Plan for Water Scarcity report (Iran cabinet approval, 2021), the 10-year precipitation decreased 10% compared to 50-year precipitation in the north of Iran such as Mazandaran province. Therefore, water supply especially during April to September is a big challenge that lie ahead for farmers and deficit irrigation coupled with irrigation scheduling are important pathways to address this problem. A study in the humid climate of Uruguay showed that despite having an average annual rainfall of 1150 mm, irrigating increased orange and lemon trees yields by 41% and 29% compared to non-irrigated trees (Petillo, 1995).

On the other side, to increase the irrigation efficiency and water productivity in Iran, the government has financially supported gardeners to use the drip irrigation in orchards so that from 1991 to 2017, more than 30,000 hectares of orchards in Mazandaran province were equipped. However, despite using the drip irrigation system, water productivity have not increased as expected. One of the main problems is irrigating without scheduling. Irrigation experts suggest 3 to 4 days irrigation frequency, however, many gardeners irrigate the trees without a proper irrigation schedule.

Furthermore, the total and annual groundwater depletion in Mazandaran province is around 162.2 $mm^3$and 6 mm^3 and based on National Adaptation Plan for Water Scarcity in Iran (Iran cabinet approval, 2021), agricultural water withdrawal in Mazandaran must decrease 117.8 and

302 mm^3 from groundwater and surface water sources until 2026, respectively. More than 60% of orange in Iran (84 thousand hectares) is produced in Mazandaran province (Ahmadi et al., 2019). As such, applying deficit irrigation on orange orchards in Mazandaran can have a central role to play in addressing these challenges. However, deficit irrigation policies are not welcomed by gardeners because of lack of knowledge in economic consequences. Thus, for the irrigation management in an orchard, it is necessary to determine the appropriate level of deficit irrigation (Ballester et al., 2011; Ginestar and Castel., 1996) and the economic profit (English and Raja, 1996).

To economically assess the applied water use and determine the optimum water depth, English (1990) presented a proper method. This method is developed based on production, cost and income functions. The production function is a quadratic function that has been proven by other researchers (Sepaskhah and Kashefipour, 1994; Capra et al., 2011; Hughes, 2011; Yasin and ghazal, 2020). In this method, optimum water use is calculated by mathematical analysis and the net income then would be determined. This method was used to find optimum irrigation water management of wheat in the northwestern USA, cotton in California (USA), and corn in Zimbabwe that showed 15 to 59 percent reduction in water use was economically acceptable (English and Raja, 1996). In addition, economic analysis of seasonal and intra-seasonal models of deficit irrigation of sorghum (Sepaskhah et al., 2006) and corn (Ghahraman et al., 2001) were conducted and results showed that intra-seasonal method (decision making based on water allocation at different stages of plant growth) produces more reduction (23%) of optimal water. Economic evaluation of deficit irrigation on 20 citrus orchards in Italy showed that the appropriate amount of deficit irrigation for land and water limitation conditions is 12.7% and 25.6% of full irrigation (Capra et al., 2011). In a study on orange in Spain, deficit irrigation up to 30% increased 47% net income per unit of water use (Pérez-Pérez et al., 2010). Another study in Spain on tangerine also showed that irrigation up to 80% tree water requirement did not reduce gross income (Ballester et al., 2011). In a study, the optimal applied water for sugar beet was determined under land and water limiting conditions and at variable crop price (Shabani et al., 2018). The crop price was depended to the yield quality. Results showed that the optimum water depth in land limiting condition increased 1.2% the net income per unit of land. In addition, under water limiting condition, the net income per unit of water was maximized and increased the net income by 12%. In a study in Iran, optimum water use for citrus were obtained by English method (Ebadi et al., 2016). In this study, water use for maximum yield was obtained 199.8 mm, which did not differ significantly from the water use when land is limiting. Results showed by using optimum water depth in water limiting condition, water use was decreased by 36% and water productivity and net income per unit of water use was increased by 42% and 23%. Economic assessment of deficit irrigation and its effect on yield and water use efficiency of Basil was conducted by English 1990 method (Naderianfar et al., 2017). Optimization of production, cost and income functions showed that 25% decrease in water use caused maximum water use efficiency and led to the maximum net income per unit of water. Optimization of deficit irrigation of sugar beet in different levels of irrigation water salinity was conducted under water and land limitation (Shamshiri et al., 2020). The production function was determined by using English method when the price of sugar beet is variable and dependent on sugar content rate. For salinity of 0 ds/m, optimum amounts of water to obtain the maximum yield, maximum net income under limited land and maximum net income under limited water were 1.87, 1.77 and 1.52 m, respectively. In addition, by using the optimum water depth under water limiting condition, 19% of irrigation water can be saved.

To evaluate the effects of deficit irrigation on the gardeners' net income and to determine the optimum irrigation water depth, in the current study, economic assessment of different irrigation scheduling under water and land limitations have been conducted.

Materials and Methods

The current study was conducted on 60 Thomson navel orange trees (25 years old) in 2018 in Sari (Mazandaran province, Iran) (53^0, 4.69' E and 36^0, 45.11' N). Trees were spaced at 6×6 m and were drip irrigated. The climate of the study area is Moderate Caspian weather with hot and humid summers, and mild and humid winters. According to the 20-year meteorological data up to 2018, the average annual rainfall and evaporation were 750 and 1100 mm. The average temperature was 18.2 ^{0}c. Many orchards and farmlands have been suffered from water shortage in different years especially in summers. To obtain production, cost and net income functions, a split plot experiment in the form of a randomized complete block design with five replications was performed in 2018. Four irrigation levels that supplies 100%, 80%, 65% and 50% of soil readily available water (RAW) were applied. This condition was considered for two methods of irrigation scheduling including A1= without fixed irrigation frequency and A2= 4 days irrigation frequency and in five replications. For A1, the soil moisture was monitored daily and the irrigation was performed when the soil moisture reached the maximum allowable depletion. Irrigation water depth for this case was RAW (equation 1). For A2, the soil moisture was measured on the irrigation day and irrigation water depth (D) and irrigation water volume (V) was calculated using equations 2 and 3.

$$\mathrm{RAW} = (\mathrm{FC} - \mathrm{PWP}) \times \rho b \times \mathrm{MAD} \times \mathrm{Z} \times \mathrm{Pw} \quad (1)$$

$$\mathrm{D} = (\mathrm{FC} - \theta) \times \rho b \times \mathrm{MAD} \times \mathrm{Z} \times \mathrm{Pw} \quad (2)$$

$$\mathrm{V} = \mathrm{D} \times \mathrm{A} \quad (3)$$

Where, FC= gravimetric field capacity (%), PWP= gravimetric permanent wilting point (%), θ= gravimetric soil moisture (%), ρb= soil bulk density (gr/cm^3), MAD= Maximum allowable depletion, Z= root depth (m), P_W= percentage of the wetted area (%) and A= tree spacing (m^2). To determine the soil characteristics, the soil was sampled (Figure 1) and the soil texture was determined by hydrometer method. It showed that topsoil had clay loam texture and bulk density was 1.34 gr/cm^3 and subsoil had loam texture and its bulk density was 1.38 gr/cm^3. Water productivity (WP) was also obtained using Equation 4.

$$WP = \frac{\text{Yield}}{\text{Applied Water}} \tag{4}$$

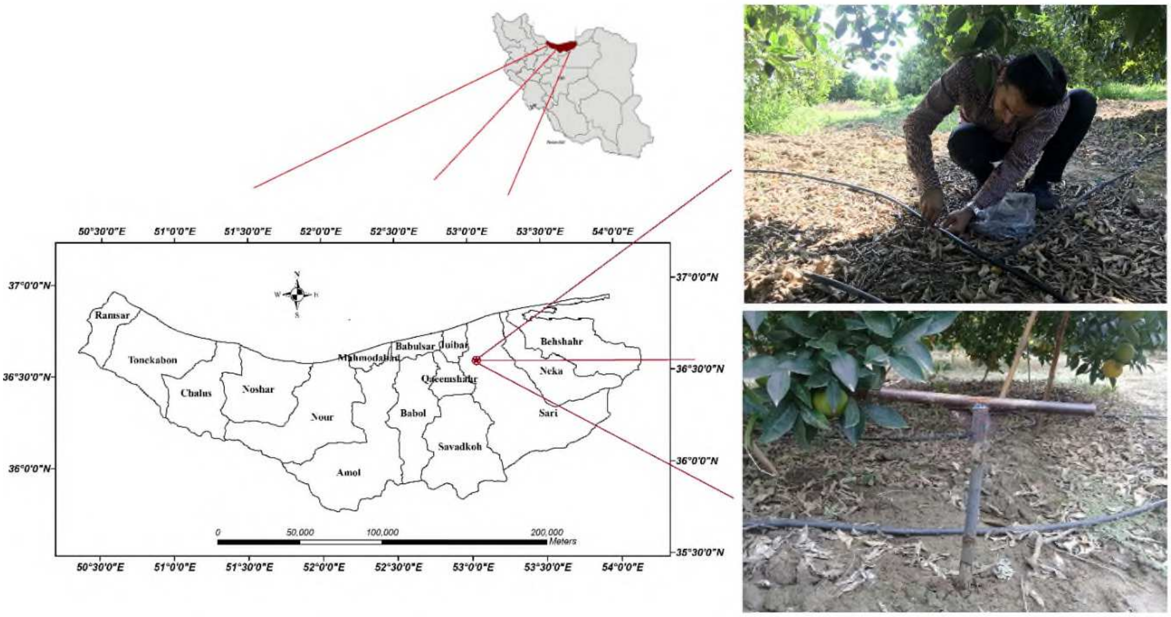

Fig. 1- The study area, drip irrigation installation on orange trees and soil sampling

For economic assessment, English (1990) method was used in which the optimum water use for growing season is obtained by mathematical analysis of production-water and cost-water functions. In this method, production (y(w)), cost (c(w)), and net income ($i_L(w)$) functions are as equations 5, 6, and 7, respectively. The total irrigated area and net income for the total irrigated area were also calculated by equations 8 and 9.

$$y(w) = c_1 w^2 + b_1 w + a_1 \tag{5}$$

$$c(w) = b_2 w + a_2 \tag{6}$$

$$\mathrm{i_L(w) = Pc \times y(w) - c(w)} \quad (7)$$

$$\mathrm{A = \frac{W_t}{W}} \quad (8)$$

$$\mathrm{i_f(w) = A \times [Pc \times y(w) - c(w)]} \quad (9)$$

Where, y(w) is yield per unit of land (kg/ha), w is water use depth (mm), c(w) is cost per unit of land (Rls/ha), $i_L(w)$ is net income per unit of land (Rls /ha), Pc is fruit price (Rls /kg), $i_f(w)$ is net income for the total irrigated area (Rls), A is the total area of the orchards (ha), W_t is total water supply (mm) and a_1, b_1, c_1, a_2 and b_2 are constants (Note that the monetary unit in this study is based on Iranian currency, Rial). In these functions, applied water (W) was considered in two scenarios including 1-only irrigation water depth, 2- irrigation water depth plus rainfall. Variable costs include water, fertilizer, horticultural oil, insecticides, pesticides and fungicides, herbicides, fertilizing operations, spraying operations, herbicides operations (including mechanical and chemical control), pruning, depreciation of irrigation equipment, transportation, electricity and fruit harvesting costs. Fixed costs also include land preparation, buying seedlings, planting seedlings and land (leasing land) costs. After determination of production, cost and income functions, the optimization was performed to maximize the net income. Therefore, the derivative of the function of net income for the total irrigated area must be zero (equation 10).

$$\frac{\partial i_f(w)}{\partial \mathrm{w}} = \mathrm{A} \times \frac{\partial i_l}{\partial w} + i_l \times \frac{\partial A}{\partial w} = 0 \quad (10)$$

Based on this optimization, six optimum water depth (OWD) were determined as follows.

1. Optimum water depth for the maximum yield (W_m):

For maximizing the yield, the derivative of the production function must be zero (Figure 2 and Equation 11) (Sepaskhah and Akbari, 2005). Then, the water use for maximum yield is as equation 12.

$$\frac{\partial(y(w))}{\partial w} = 0 \tag{11}$$

$$\mathrm{w_m} = \frac{-\mathrm{b_1}}{2\mathrm{c_1}} \tag{12}$$

2.Optimum water depth when land is limiting (W_l):

If land is a limiting factor, the derivative of the total area with respect to the water use depth must be zero (Equation 13). Therefore, the optimal function of net income is as equation 14 and the optimum water use when land is limiting is as equation 15.

$$\frac{\partial A}{\partial \mathrm{w}} = 0 \tag{13}$$

$$\frac{\partial i_f(w)}{\partial \mathrm{w}} = \mathrm{A} \times \frac{\partial i_l}{\partial w} = 0 \qquad \rightarrow \qquad Pc \times \frac{\partial(y(w))}{\partial w} = \frac{\partial(C(w))}{\partial \mathrm{w}} \tag{14}$$

$$\mathrm{w_l} = \frac{\mathrm{b_2} - \mathrm{b_1 P_c}}{2\mathrm{c_1 P_c}} \tag{15}$$

3.Optimum water depth when water is limiting (W_w):

When water is limiting, the derivative of the total area with respect to the water use depth is as equation 16 and the optimal function of net income is as equation 17. Therefore, the optimum water use when water is limiting is as equation 18.

$$\frac{\partial A}{\partial w} = \frac{-W_t}{w^2} \tag{16}$$

$$\frac{\partial i_f(w)}{\partial \mathrm{w}} = \mathrm{A} \times \frac{\partial i_l}{\partial w} + i_l \times \frac{-W_t}{w^2} = 0 \tag{17}$$

$$\mathrm{w_w} = \sqrt{\frac{\mathrm{a_1 \times Pc - a_2}}{\mathrm{Pc \times c_1}}} \tag{18}$$

4.Equivalent water depth when water is limiting (W_{ew}):

This water depth produces the net income per unit of water equal to that of full irrigation (Equation 19). Therefore, the equivalent water use in water limiting situation is as equation 20.

$$\frac{i_l(w_{ew})}{w_{ew}} = \frac{i_l(w_m)}{w_m} \tag{19}$$

$$W_{ew} = \frac{-\left(\frac{P_c.b_1^2+4P_c a_1 c_1-4a_2 c_1}{2b_1}\right)+\sqrt{\left(\frac{P_c.b_1^2+4p_c a_1 c_1-4a_2 c_1}{2b_1}\right)^2-4P_c c_1(P_c a_1-a_2)}}{2P_c c_1} \tag{20}$$

5.Equivalent water depth when land is limiting (W_{el}):

This water depth is the depth at which the net income per unit of land is equal to the net income per unit of land under full irrigation (Equation 21). Therefore, the equivalent water depth in land limiting situation is as equation 22.

$$i_l(w_{el}) = i_l(w_m) \tag{21}$$

$$W_{el} = \frac{-(P_c b_1-b_2)+\sqrt{(P_c b_1-b_2)^2-4P_c C_1\left(\frac{P_c b_1^2}{4c_1}-\frac{b_1 b_2}{2c_1}\right)}}{2P_c c_1} \tag{22}$$

6.Water depth in breakeven situation (W_k):

This depth is the depth at which gross income is equal to costs (Equation 23) and is obtained from Equation 24.

$$i_l(w_k) = 0 \tag{23}$$

$$W_k = \frac{-(P_c b_1-b_2)+\sqrt{(P_c b_1-b_2)^2-4P_c C_1(P_c a_1-a_2)}}{2P_c bc_1} \tag{24}$$

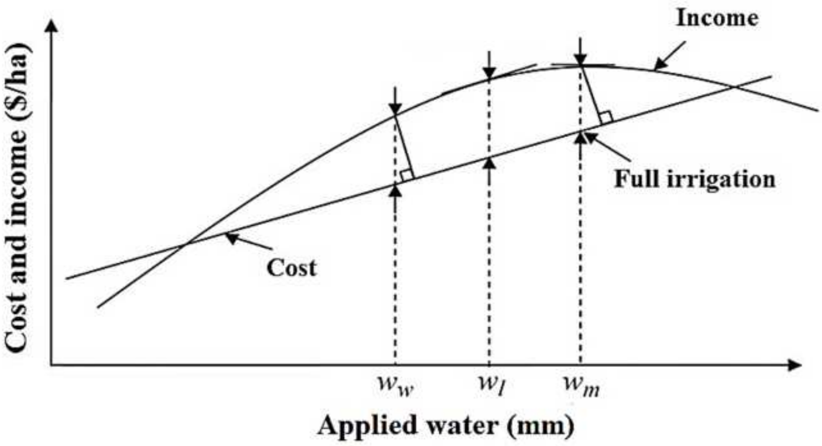

Fig. 2- Mathematical view of optimum irrigation water depths under water or land limitation

Economic evaluation of optimum irrigation water depths

For economic evaluation of the calculated optimum water depths, some indices have been used as follows.

1.Water saving (WS) (%):

$$WS = \frac{(W_m - W_{OWD}) \times 100}{W_m} \quad (25)$$

Where W_m is the water depth for full irrigation and W_{OWD} is other optimum water depths. WS is the water, which can be saved when OWD is used, compared to when W_m is used.

2.Yield reduction (YR) (%):

$$YR = \frac{(Y_{W_m} - Y_{OWD}) \times 100}{Y_{W_m}} \quad (26)$$

Where Y_{W_m} and Y_{OWD} are the yield values when W_m and other OWD are used, respectively. YR is yield reduction when OWD is used compared to when W_m is used.

3.Net income reduction per unit of land (IRUL) (%):

$$IRUL = \frac{\left(i_L(w)_{w_m} - i_L(w)_{OWD}\right) \times 100}{i_L(w)_{w_m}} \quad (27)$$

Where $i_L(w)_{W_m}$ and $i_L(w)_{OWD}$ are the net income per unit of land for W_m and other OWD, respectively. IRUL is net income per unit of land when OWD is used compared to when W_m is used.

4.Net income per unit of water use (IUW) ($/m^3)

$$IUW = \frac{i_L(w)_{OWD}}{W_{OWD}} \quad (28)$$

Where $i_L(w)_{OWD}$ is the net income per unit of land ($/ha) and W_{OWD} is optimum water use (m^3/ha).

5.Net income increase per unit of water use (IIUW) (%)

$$\mathrm{IIUW} = \frac{(\mathrm{IUW_{OWD}} - \mathrm{IUW}_{w_m}) \times 100}{\mathrm{IUW}_{w_m}} \quad (29)$$

Where $\mathrm{IUW_{W_m}}$ and $\mathrm{IUW_{OWD}}$ are the net income per unit of water use for W_m and other OWD, respectively.

6.Net income per unit of yield (IUY) ($/kg)

$$\mathrm{IUY} = \frac{(\mathrm{i_L(w)_{OWD}}) \times 100}{\mathrm{Y_{OWD}}} \quad (30)$$

Where $\mathrm{i_L(w)_{OWD}}$ is the net income per unit of land and $\mathrm{Y_{OWD}}$ is the yield value for OWD.

7.Net income reduction per unit of yield (IRUY) (%)

$$\mathrm{IRUY} = \frac{(\mathrm{IUY_{W_m}} - \mathrm{IUY_{OWD}}) \times 100}{\mathrm{IUY_{W_m}}} \quad (31)$$

Where $\mathrm{IUY_{W_m}}$ and $\mathrm{IUY_{OWD}}$ are the net income per unit of yield for W_m and other OWD.

Note that by using W_w, W_l, W_{el}, W_{ew} and W_k, water use per unit of land (one hectare) decreases compared to when W_m is used and therefore the area which can be irrigated will be more than one hectare. This equivalent irrigated area (IA), equivalent yield (EY) and increased equivalent yield (IEY) were obtained using equations 33, 34 and 35. Moreover, the net income increase per unit of land (IIUL) when W is equivalent to W_m was calculated.

$$\mathrm{IA_{OWD}} = \frac{\mathrm{W_m}}{\mathrm{W_{OWD}}} \quad (32)$$

$$\mathrm{EY_{OWD}} = \mathrm{IA_{OWD}} \times \mathrm{Y_{OWD}} \quad (33)$$

$$\mathrm{IEY_{OWD}} = \frac{(\mathrm{EY_{OWD}} - \mathrm{EY_{W_m}}) \times 100}{\mathrm{EY_{W_m}}} \quad (34)$$

Results

Technoeconomic analysis when only irrigation water depth is considered (W= I)

In order to economic assessment, production and cost functions for each irrigation management were obtained by equations 5 and 6 (Table 1 and Figure 3). In this scenario, only the irrigation water depth was considered as the applied water. Then, the optimum irrigation water depths for two irrigation scheduling methods were calculated (Table 2).

Table 1- Production and cost functions in different irrigation managements (w= I)

Irrigation scheduling	Production	Cost
A1	$Y(w) = -0.00219w^2 + 0.64989w + 3.1397$, $R^2=0.93$	$C(w) = 189.416w + 586428$, $R^2=0.86$
A2	$Y(w) = -0.00174w^2 + 0.64929w - 3.1303$, $R^2=0.93$	$C(w) = 179.525w + 589763$, $R^2=0.84$

Results showed that the optimum water depth to obtain the maximum yield for without irrigation frequency was 148.3 mm, whereas it was 186.5 mm for 4 days irrigation frequency, which according to economic analysis (table 3), this 26% more applied water causes 12% increase in the yield and 27% increase in the net income per unit of land.

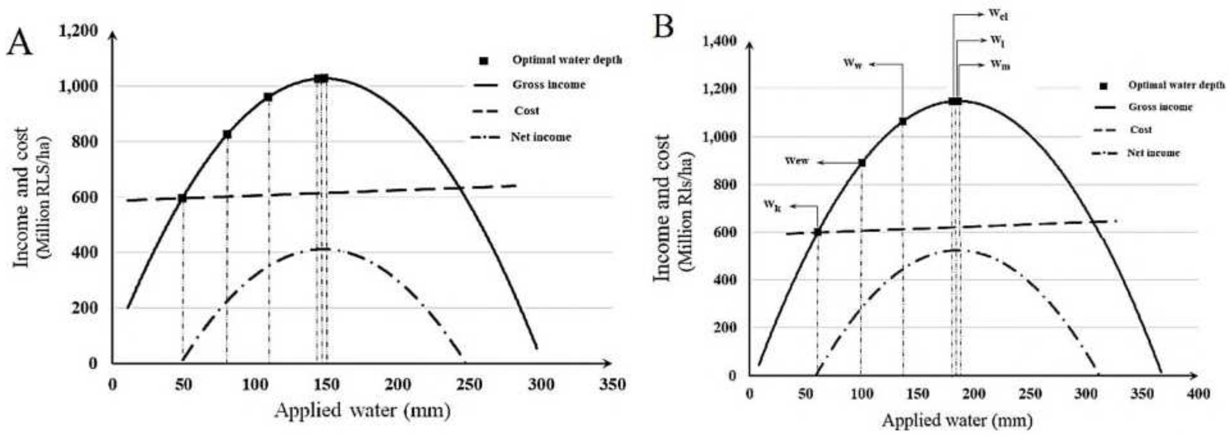

Fig 3- Income and cost functions and optimal water depths for variable irrigation frequency (A) and 4 days irrigation frequency (B) (W= I)

Table 2- Optimum water depths in different irrigation managements (W= I)

Irrigation scheduling	W_m (mm)	Y_m (ton/ha)	W_w (mm)	W_l (mm)	W_{el} (mm)	W_{ew} (mm)	W_k (mm)
A1	148.3	51.3	109.3	146.2	144.0	80.6	49.1
A2	186.5	57.4	136.9	184.0	181.4	100.5	61.1

When water is limiting, the optimum water depth (W_w) for A1 and A2 were 109.3 and 136.9 mm that reduced irrigation water use by 26% and 27% and then increased the net income per unit of water by 16% and 16%. Although using W_w had positive effect on the water productivity, it reduced the net income per unit of land by 14% and 15% for A1 and A2, respectively. However, in this case, if there is no land limitation, with this amount of saved water, 36% and 36% more land can be irrigated, which leads to 26% and 27% increase in yield. This status increases the net income per unit of land by 16% and 16% that is the highest net income per unit of land.

The equivalent water depth when water is limiting (w_{ew}) for A1 and A2 were 80.6 and 100.5 mm that reduced water use by 46% and 46%. However, this status reduced the yield by 20% and 22%. Therefore, although using W_{ew} had a positive effect on water use, water productivity and the net income per unit of water, it resulted the lowest net income per unit of land (exclude W_k)

Table 3- Economic analysis of optimum water depths in different irrigation managements (W= I)

index	Irrigation scheduling	W_m	W_w	W_l	W_{el}	W_{ew}	W_k
WS	A1	--	26.3	1.5	2.9	45.7	66.9
(%)	A2	--	26.6	1.4	2.8	46.1	67.3
YR	A1	--	6.5	0.02	0.1	19.6	42.0
(%)	A2	--	7.5	0.02	0.1	22.4	47.7
IRUL	A1	--	14.4	0	0	45.7	100
(%)	A2	--	14.6	0	0	46.1	100
IIUW	A1	--	16.2	1.5	3.0	0	-100
(%)	A2	--	16.3	1.4	2.8	0	-100
IRUY	A1	--	8.4	0	0	32.4	100
(%)	A2	--	7.7	0	0	30.5	100
	A1	34.6	43.9	35.1	35.6	51.2	60.6

WP	A2	30.8	38.8	31.2	31.6	44.3	49.2
IA	A1	--	1.36	1.01	1.03	1.84	3.02
(ha)	A2	--	1.36	1.01	1.03	1.86	3.05
EY	A1	51.3	65.1	52.1	52.8	76.0	89.9
(ton/ha)	A2	57.4	72.4	58.2	59.0	82.7	91.7
IEY	A1	--	26.9	1.5	2.9	48.0	75.1
(%)	A2	--	26.1	1.4	2.8	44.0	59.7
IIUL	A1	--	16.2	1.5	3.0	0	-100
(%)	A2	--	16.3	1.4	2.8	0	-100

When land is limiting, the optimum water depth for A1 and A2 were 146.2 and 184.0 mm, respectively. This condition has almost no significant change on water use, yield and water productivity. The highest net income per unit of land was obtained from this case, which is the same with full irrigation. This result is almost the same when w_{el} is used. These findings matches well with Ebadi et al. (2016) and Ballester et al. (2011) results.

For water productivity, the best beneficial water productivity was obtained from W_{ew} and W_w. When W_{ew} was used, the water productivity were 51.2 and 44.3 kg/m^3 and when W_w was used, they were 43.9 and 38.8 kg/m^3 for A1 and A2, respectively. In addition, the lowest water productivity was obtained from full irrigation (W_m).

Technoeconomic analysis when irrigation water depth plus rainfall is considered (W= I + R)

In this scenario, the applied water was considered as the sum of irrigation water depth and the effective rainfall depth during the irrigation season. Then, production and cost functions for each method of irrigation scheduling were obtained by multiple regression analysis that resulted the coefficient of determination (R^2) of 0.93 and 0.93 for A1 and A2 for production function and 0.86 and 0.83 for cost function (Table 4 and figure 4). The irrigation season in the study area is April to September and the effective rainfall during this period was 129.1 mm. For the rainfall lower than 5 mm, the effective rainfall was considered zero.

Table 4- Production and cost functions in different irrigation managements (W= I + R)

Irrigation scheduling	Production	Cost
A1	$Y(w)= -0.00219w^2 + 1.2156w - 117.276$, $R^2=0.93$	$C(w)=189.416w+561975$, $R^2=0.86$
A2	$Y(w)= -0.00174w^2 + 1.0987w - 115.961$, $R^2=0.93$	$C(w)=179.525w+566586$, $R^2=0.84$

Then, the optimum water depths for two methods of irrigation scheduling were calculated (Table 5). Results showed that the optimum water depth to obtain the maximum yield for without irrigation frequency was 277.4 mm, whereas it was 315.6 mm for 4 days irrigation frequency, which this 14% more applied water caused 12% increase in the yield and 27% increase in the net income per unit of land.

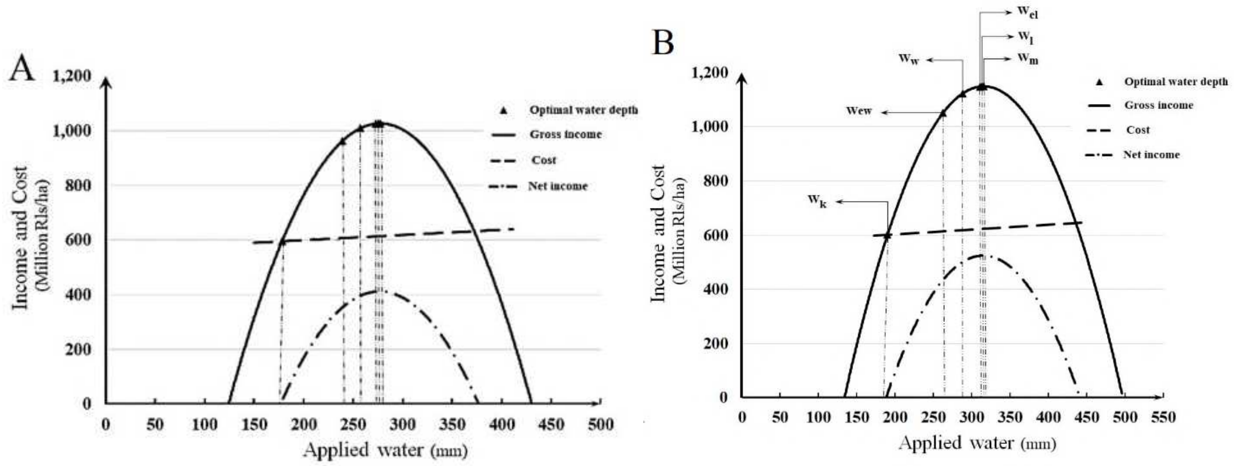

Fig 4- Income and cost functions and optimal water depths for variable irrigation frequency (A) and 4 days irrigation frequency (B) (W= I + R)

Table 5- Optimum water depths at different irrigation managements (W= I + R)

Irrigation scheduling	W_m (mm)	Y_m (ton/ha)	W_w (mm)	W_l (mm)	W_{el} (mm)	W_{ew} (mm)	W_k (mm)
A1	277.4	51.3	257.6	275.3	273.1	239.2	178.2
A2	315.6	57.4	287.9	313.1	310.5	262.7	190.2

In this scenario when water is limiting, the optimum water depth (W_w) for A1 and A2 were 257.6 and 287.9 mm. According to economic analysis (table 6), using W_w increased the water productivity and the net income per unit of water. However, it reduced the yield and the net income per unit of land. If there is no land limitation, with the saved water, 8% and 10% more land can be irrigated, which led to an increase in the yield and the net income per unit of land that is the highest net income per unit of land. The equivalent water depth in water limiting condition (w_{ew}) were 239.2 and 262.7 mm for A1 and A2 that increased the water productivity by 9% and 10%; however it reduced the net income per unit of land by 8% and 9%.

Table 6- Economic analysis of optimum water depths in different irrigation managements (W= I + R)

index	Irrigation scheduling	W_m	W_w	W_l	W_{el}	W_{ew}	W_k
WS	A1	--	7.1	0.8	1.6	13.8	35.8
(%)	A2	--	8.8	0.8	1.6	16.8	39.8
YR	A1	--	1.7	0.0	0.1	6.2	42.0
(%)	A2	--	2.3	0.0	0.1	8.5	47.7
IRUL	A1	--	3.3	0	0	13.8	100
(%)	A2	--	4.1	0	0	16.8	100
IIUW	A1	--	4.2	0.8	1.6	0	-100
(%)	A2	--	5.1	0.9	1.7	0	-100
IRUY	A1	--	1.6	0	0	8.0	100
(%)	A2	--	1.8	0	0	9.0	100
WP	A1	18.5	19.6	18.6	18.8	20.1	16.7
(kg/m^3)	A2	18.2	19.5	18.3	18.5	20.0	15.8
	A1	--	1.08	1.01	1.02	1.16	1.56

IA	A2	--	1.10	1.01	1.02	1.20	1.66
EY	A1	51.3	54.4	51.7	52.1	55.8	46.4
(ton/ha)	A2	57.4	61.5	57.9	58.3	63.2	49.9
IEY	A1	--	5.9	0.8	1.5	8.8	-9.7
(%)	A2	--	7.1	0.8	1.6	10.0	-13.2
IIUL	A1	--	4.2	0.8	1.6	0	-100
(%)	A2	--	5.1	0.9	1.7	0	-100

When land is limiting, the optimum water depths were 275.3 and 313.1 mm for A1 and A2, respectively. This condition has almost no remarkable change on water productivity and yield. The net income per unit of land in this status is the same with full irrigation.

Overall, when irrigation water depth plus rainfall is considered to obtain production and cost functions, using the optimum water depths has the weaker effect of the net income.

Discussion

To investigate the effect of applied water on the income, their relationship were plotted according to according to 1- only irrigation water depth was considered (Figure 3) and 2- irrigation water depth plus rainfall was considered (Figure 4). Results showed that for both variable and 4 days irrigation frequency, by increasing the applied water, the net income increases up to a maximum and then decreases. In addition, applying full irrigation and using W_m resulted the highest yield and net income per unit of land. However, when the land is not limiting, applying the deficit irrigation and using W_w resulted the highest net income per unit of land. Because by the saved water resulted from the deficit irrigation, the larger areas of the orchard can be put under irrigation. Furthermore, having an irrigation schedule causes 27% increase in the net income per unit of land.

To obtain the exact effect of deficit irrigation on the income, the optimum water depths were determined and then were assessed economically. In the previous studies, the effect of deficit irrigation were assessed under two scenarios of applied water for determining of production and cost functions including only the irrigation water use and (such as English, 1990; Capra et al, 2011; Ebadi et al, 2016) and irrigation water use plus rainfall (such as English and Raja, 1996; Sepaskhah and Akbari, 2005; Sepaskhah et al., 2008: Mousavi et al., 2010; Shabani et al., 2018). In the current study, both scenarios were used to have the proper assessment. Since the trees use the rainfall for the production, it is logical to consider the irrigation water plus rainfall as the applied water in production and cost functions. According to this fact, by using 178 and 190 mm water, the net income per unit of land was zero and using 277.4 and 315.6 mm applied water resulted the highest net income per unit of land for A1 and A2, respectively.

An important point in this scenario that have been missed out in the past studies is about the equivalent irrigated area (IA) for the deficit irrigation when there is no land limiting condition. In the previous studies, the equivalent irrigated area (IA) for the deficit irrigation when there is no land limiting condition was obtained by using the optimum water depths resulted from when irrigation water depth plus rainfall is considered. Whereas, to extend the irrigated area only the irrigation water is needed (W=I) and it is not needed to consider the rainfall (W=I+R). Then, although the irrigation water use plus rainfall must be considered to obtain the production and cost functions, to calculate the equivalent irrigated area (IA) for the deficit irrigation when there is no land limiting condition, only the irrigation water depth must be considered. On the other hand, when land is not limiting, both tables 3 and 6 can be used only when all applied water is supplied by irrigation. Therefore, the exact assessment of economic effects of deficit irrigation is presented in table 7.

Table 7- Economic assessment of deficit irrigation in different irrigation managements

index	Irrigation scheduling	W_m	W_w	W_l	W_{el}	W_{ew}	W_k
Saved irrigation water (%)	A1	--	26.3	1.5	2.9	45.7	66.9
	A2	--	26.6	1.4	2.8	46.1	67.3
Yield Reduction (%)	A1	--	1.7	0.0	0.1	6.2	42.0
	A2	--	2.3	0.0	0.1	8.5	47.7
Net income reduction per unit of land (IRUL) (%)	A1	--	3.3	0	0	13.8	100
	A2	--	4.1	0	0	16.8	100
Net income increase per unit of irrigation water (%)	A1	--	16.2	1.5	3.0	0	-100
	A2	--	16.3	1.4	2.8	0	-100
IA (ha)	A1	--	1.36	1.01	1.03	1.84	--
	A2	--	1.36	1.01	1.03	1.86	--
EY (ton/ha)	A1	51.3	68.5	52.1	52.8	88.6	--
	A2	57.4	76.4	58.2	59.0	97.6	--
IEY (%)	A1	--	33.4	1.5	2.9	72.6	--
	A2	--	33.1	1.4	2.8	69.9	--
Equivalent net income increase per unit of land (IIUL) (%)	A1	--	31.2	1.5	3.0	60.0	--
	A2	--	30.6	1.4	2.8	50.0	--

Based on these results using W_w resulted 26% saved irrigation water and reduces the net income per unit of land about 3% to 4% (it can be approximately called as 25% deficit irrigation). In addition, using W_{ew} resulted 46% saved water and reduces the net income per unit of land about 14% to 17% (it can be approximately called 45% deficit irrigation). Therefore, when there is water limitation coupled with land limitation, the optimum water depth can be W_w or W_{ew}. Selecting W_w or W_{ew} is depending on how much our limitation is critical. Gardeners generally select based on the net income per unit of land that causes them to select W_w. Using W_w (25% deficit irrigation) has the most beneficial results in this condition and caused the highest net income per unit of irrigation water. However, if there is a serious problem in water availability, using W_{ew} is much better.

It is worthy of note that although for the maximum yield, 45% more irrigation water is applied by using W_m, the net income per unit of land is increased 14% to 17%. This is due to the big difference in the price of unit of fruit compared to the price of unit of water. On one hand, many farms are irrigated by illegal wells and farmers do not pay the water cost. On the other hand, the irrigation water price in Iran is subsidized and based on government pricing that is too low. The changes in the optimum water depths relative to the percentage increase in water price was plotted in figure 5 that shows by increasing even up to 500% in water cost, the optimum water depths do not have any remarkable change.

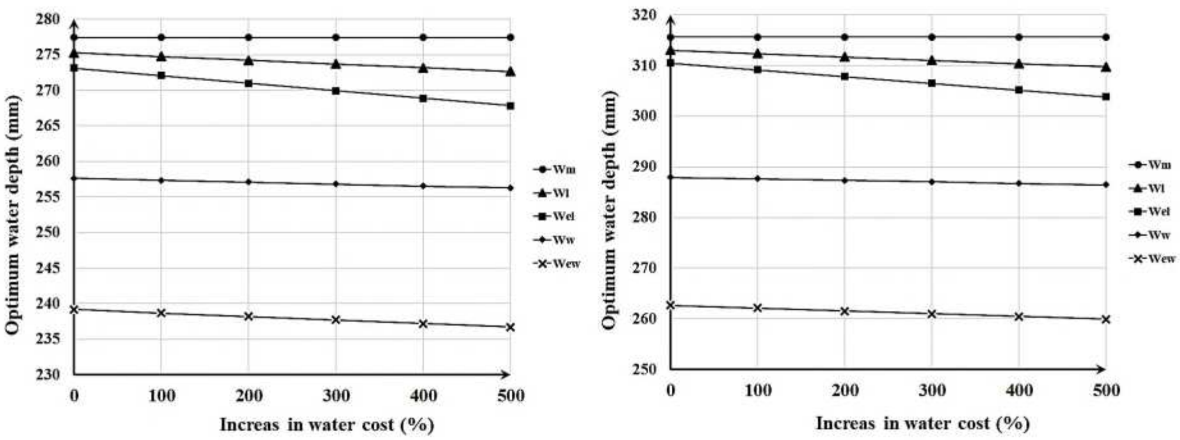

Fig. 5- The changes in the optimum water depths relative to the percentage increase in water price

In addition, the changes in the net income relative to the applied water at the base water price, 100% and 300% increase in the water price for 4 days irrigation frequency was plotted in the figure 6. According to this figure, although by increasing the price of water, the applied water for the maximum yield (W_m) is reduced, this reduction is not significant. On the other hand, the net income is not sensitive to the water price and by increasing in the water price even up to 300%, there is no remarkable change in the net income.

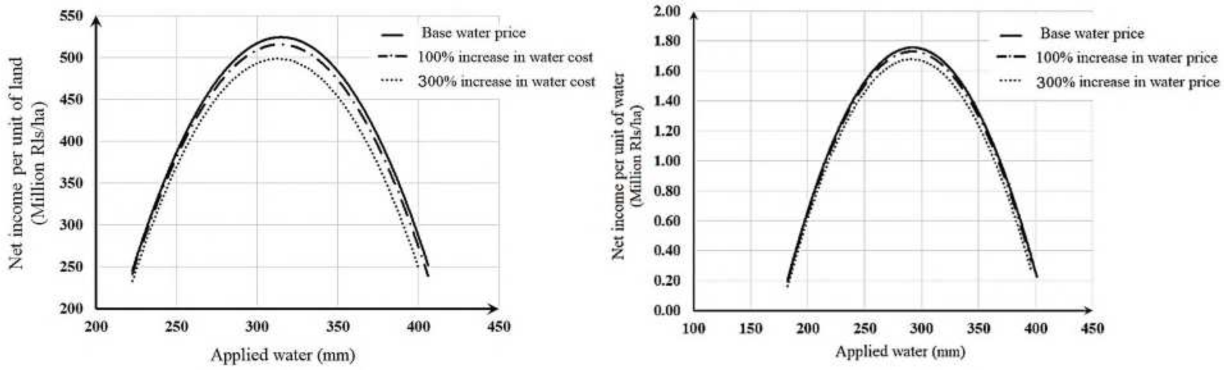

Fig 6- Relationship between the net income and the applied water at different water price for 4 days irrigation frequency

On the other side, the changes in the net income relative to the applied water at the base fruit price, 10% and 50% increase in the fruit price for 4 days irrigation frequency was plotted in figure 7. This figure shows that 50% increase in the fruit price causes a remarkable increase (more than 100%) in the net income. These issues show that the yield plays a greater role than the water on the net income.

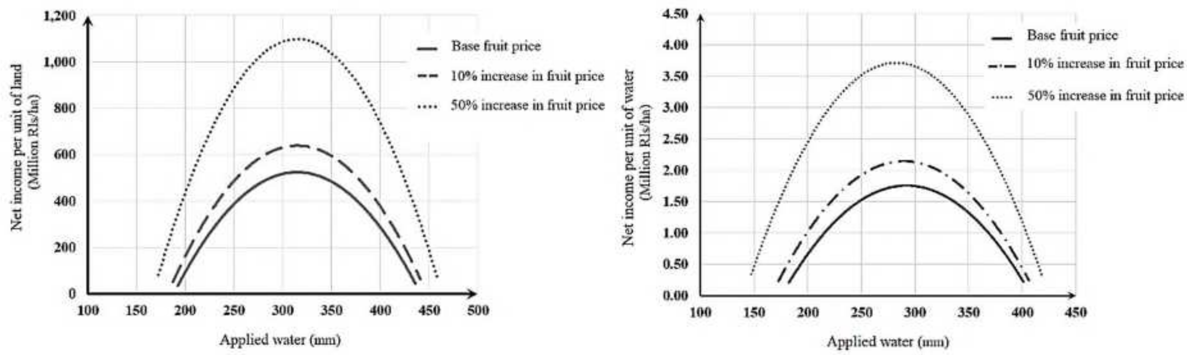

Fig 7- Relationship between the net income and the applied water at different fruit price for 4 days irrigation frequency

The water and wastewater price in Iran compared to other countries (Figure 8) shows that water price in Iran is much lower than other countries. In developed countries, however, higher water price encourages farmers to use more advanced irrigation and water management methods.

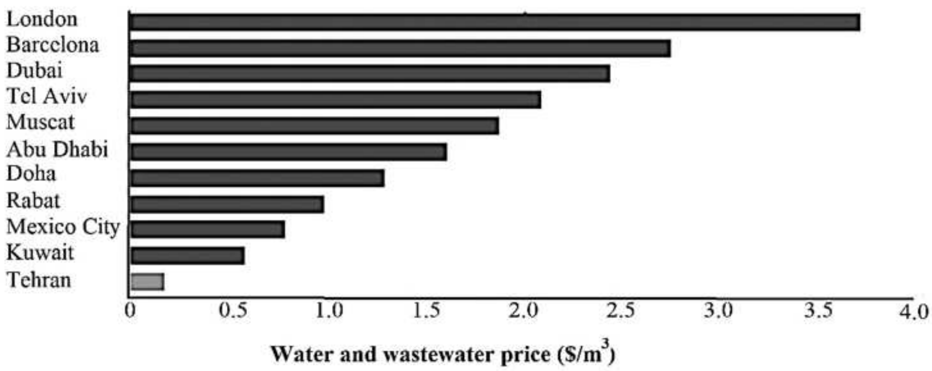

Fig 8- Water and wastewater price in Iran compared to other countries (World Bank Group, 2017)

When water is limiting and there is no land limitation, the highest net income per unit of land was obtained by using W_{ew} (45% deficit irrigation). Whereas, in the previous studies, W_w was expressed. As it is shown in figure 9, when the irrigation water plus rainfall is considered to obtain the equivalent irrigated area (IA), W_w has the most beneficial results. However, as it was mentioned in the current study, only the irrigation water must be considered and in this situation, when W_{ew} is used, the larger areas of the orchard can be put under irrigation by applying the saved water that results in the highest net income per unit of land.

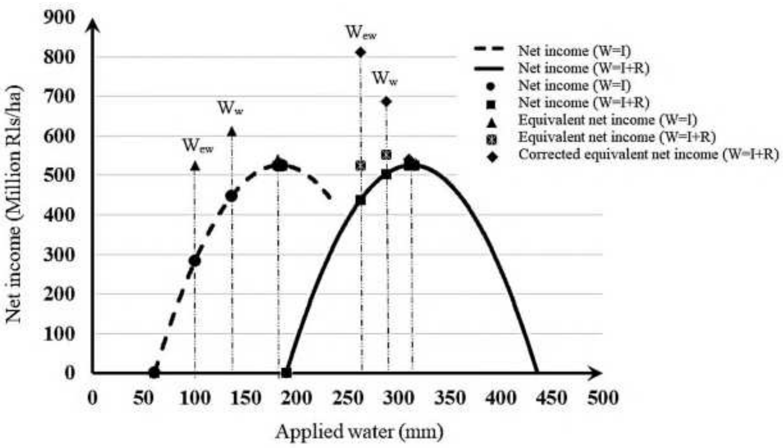

Fig 9- The net income and equivalent net income in water limiting condition for 4 days irrigation frequency

Conclusion

The following conclusion can be drawn from the current study is that having an irrigation schedule causes 27% increase in the net income per unit of land. In addition, if water is not limiting, using W_m causes the highest net income per unit of land. In water and land limiting condition, if there is minor to moderate water limiting, using the optimum water depth (W_w) can save 26% of irrigation water use that causes 3% to 4% decrease in the net income per unit of land but 16% increase in the net income per unit of irrigation water. Whereas, when there is sever water limiting condition, using W_{ew} is more useful that although it causes 14% to 17% decrease in the net income per unit of land, it saves 46% of irrigation water use.

Based on results, when rainfall occurs, the irrigation water plus rainfall must be considered to obtain production and cost functions. However, to assess the effect of deficit irrigation, only the irrigation water must be considered to determine the equivalent irrigated area (IA). Therefore, when there is water limiting condition with no land limiting, using W_{ew} (46% deficit irrigation) causes the maximum net income per unit of land even 50% to 60% more than full irrigation. Because by using W_{ew}, the larger areas of the orchard can be put under irrigation. Moreover, the maximum water productivity was obtained from the optimum water depth in water limitation conditions (W_w and W_{ew}). On the other side, at the present price of water and fruit, the net income and the amount of optimum water depths are not sensitive to the price of water. However, they are highly sensitive to the price of fruit. It was due to the big difference in the price of unit of fruit compared to the price of unit of water which causes the yield to play a greater role than water on the net income.

Overall, this study points out that having an irrigation schedule and using 25% and 45% deficit irrigation in water limiting condition are proper solution to address water scarcity in Iran.

In addition, economic return is a key factor doubled with technical analysis that experts should consider to have the irrigation scheduling acceptable by farmers. Moreover, it is necessary to focus on efforts that highlight the water value among water users. The policy makers also can assist in addressing this challenge by realistic pricing of water and removing the regulations that support excessive use of water to move agriculture toward sustainable production.

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Declarations

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