Biological Forum – An International Journal 7(1): 30-42(2015)

ISSN No. (Print):0975-1130
ISSN No. (Online):2249-3239

Deficit irrigation and sowing date as strategies to maximize water use efficiency and crop water productivity in semi-arid region

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(Received 14 December, 2014, Accepted 04 January, 2015)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Deficit irrigation has been widely investigated as a valuable and sustainable production strategy in dry regions. In this research different irrigation regimes and different sowing date were applied in an experimental field at southwest of Iran (semi-arid region) during 2011/2012 and 2012/2013 to identify suitable sowing date and optimum deficit irrigation for winter barley. The experiment was laid out as a split plot design, with irrigation factor as main plots and sowing date as sub-plots having three replications. Irrigation levels were 1 (FI), 0.75 (0.75FI) and 0.5 (0.5FI) times of the full irrigation requirements and dry land farming (dry land). The sowing dates were 23 October (T1), 6 and 22 November (T2 & T3) and 6 December (T4).The results showed that decreasing irrigation regimes, increased WUE in the first (0.82, 0.83 and 0.84 kg m^{-3} regularly for FI, 0.75FI and 0.5FI) and second year (0.70, 0.71 and 0.72 kg m^{-3} regularly for FI, 0.75FI and 0.5FI), but the differences between these regimes were not significant. On the other hand, dry-land farming showed the lowest amount of WUE (first year 0.35 kg m^{-3}, second year 0.45 kg m^{-3}) which showed significant difference in compare to irrigation treatments. The similar results were obtained for WUE_i. Deficit irrigation leads to decrease soil evaporation and the ratio of E to ET. Furthermore, by delaying in sowing date WUE, WUE_{Net}, WUE_i and WP decreased, but evaporation (E) and E/ET increased. These results indicate the benefit of deficit irrigation related to WP and WUE_{Net} in compare to full irrigation, and also, because of higher amount of all measured traits in the earliest time of sowing, it is better to planting barley at this time in this region.

Keywords: Deficit irrigation; sowing date; WUE; Barley.

INTRODUCTION

Barley is one of the important agricultural products in Iran for human and animals (livestock). To enhance food security, the promotion of barley cultivation is a priority. Shortage of irrigation water is major constraints for barley production in arid and semi-arid regions of central and southern parts of Iran.

With regard to the lack of surface water, especially in the southern Iran, groundwater becomes a very significant source of irrigation water in the area. Groundwater level is persistently declining, and there are a number of regions with large significant zones of groundwater depression (Ghaemi and Tabarzad, 2014). Therefore, it becomes critically important to reduce crop evapotranspiration (ET) to save groundwater pumped for irrigation in an irrigation area. So the needs for improving water-use efficiency (WUE) in crop production and sustainable use of water resources are clearly urgent (Saed-Moucheshi *et al.* 2012; Zhang and Oweis 1999). To cope with water scarcity, different approaches are proposed to reduce water consumption and increase water use efficiency in crop production. The methods of deficit irrigation (Ahmadi and Bahrani 2009; Pirmoradian, Sepaskhah, and Maftoun 2004a; Pirmoradian *et al.* 2004b; Sepaskhah & Akbari 2005; Sepaskhah & Ahmadi 2010; Shabani, Sepaskhah, & Kamgar-Haghighi 2013a) determining the optimum sowing date (Sun et al. 2007; Yasmeen *et al.* 2012) and identification of drought-resistant varieties (Abbasi and Sepaskhah 2011a, 2011b; Naderi and Emam 2011) have been recognized as appropriate approach of water saving by researchers.

On the other hand, many countries in the Middle East having large agricultural land where irrigation is not possible and the cultivation of field crops, chiefly cereals, is carried out under rain fed conditions (Turner 2004). The rainfall in these areas is usually low and unpredictable, varying from year to year and from location to location during each year. Most of the rainfall occurs during winter months while summers are generally very dry and hot.

Cropping practices need to be adjusted to suit these conditions, commonly known as dry land conditions(Van Duivenbooden *et al.* 2000). The choice of sowing date and cultivar are important management options to optimize grain yields in such environments (Connor *et al.* 1992; Gomez-Macpherson and Richards 1995). Numerous publications have reported an increased yield with early sowing and a reduction in yield when sowing is delayed after the optimum time (Anderson and Smith 1990; Photiades and Hadjichristodoulou 1984; Rashid and Ullah Khan 2010). These authors reported an advantage of early sowing dates that avoid frost risk at a thesis or seasons with low frost risk. In addition, McDonald & Gardner (1987) and Gregory *et al.* (1999) suggested the time of sowing and choice of the appropriate cultivars might be even more critical on soils that are prone to water logging.

Deficit irrigation strategy and rain fed cultivate are two of the management practices to cope with drought and shortage of water in arid and semi-arid region such as Iran (Sepaskhah and Akbari 2005). Furthermore, optimum sowing date could be one of the appropriate management to increase yield and water use efficiency in this region. In this study the effects of irrigation and sowing date on water use efficiency (WUE), green yield (GY), evapotranspiration (ET) and its components are considered. Based on obtained results, a guideline provided for farmers to achieve water-saving irrigation practice and efficient use of water resources for barley production. The objectives of this investigation were: I) to determine the relative response of barley cultivars under different sowing dates and to determine the optimum sowing date for barely; II) To discover the effects of amount depth of irrigation on ET, soil evaporation (E), E/ET and grain yield (GY). III) to Study the effects of deficit irrigation on water use efficiency (WUE),irrigation water-use efficiency (WUE_i), net water-use efficiency (WUE_{Net}) and water productivity of barley in a silty clay loam soil.

METHODS AND MATERIALS

This experiment was conducted at the Experimental Research Station in Agricultural College, Shiraz University, Iran in 2011-2012 and 2012-2013 growing seasons. Physical and chemical properties of soil at different depth for two years are shown in Table 1. Average electrical conductivity (EC) of irrigation water was 0.6dS m^{-1}.Experimental design was a split plot arrangement in randomized complete block design with irrigation treatment as the main plot, sowing date as the subplot in three replications. Irrigation treatments included: crop water requirement (full irrigation, FI), 75 and 50 percent of full irrigation (0.75FI & 0.5FI) and Dry land (rain fed) in both growing seasons. The sowing dates were 23 October (T1), 6 and 22 November (T2 & T3) and 6 December (T4). The dimension of each plot was 3×4 m^2 and distance between two adjacent plots was 1.0 m to prevent water invasion from one plot to another. Bahman cultivar of barley (a local cultivar) was planted. Seeds with planting rate of 200 kg ha^{-1} were planted in 13 rows with spacing between rows of 0.2 m. Each plot at the first day of cultivation was irrigated with about 110mm of water to ensure better seedling establishment. Soil water content at different depths of 0.3, 0.6, 0.9, 1.2 m was measured with neutron scattering method before each irrigation event. Regarding soil moisture content irrigation interval was determined 7-10 days.

Precipitation was recorded at a standard weather station about 50 m far from the plots. Soil water content in the root zone was used to determine the amount of net irrigation water as calculated by the following equation:

$$d_n = \sum_{i=1}^{n} (\theta_{fci} - \theta_i) \times \Delta z_i \quad \ldots(1)$$

Where d_n is the net irrigation water depth (m), θ_{fci} and θ_i are the volumetric soil water content in layer *i* at field capacity before irrigation, respectively ($m^3.m^{-3}$), Δz is the soil layer thickness (m) and *n* is the number of soil depth layers.

Table 1. Soil physical characteristics of the experimental site.

Soil depth (cm)	Soil texture			ρb (g cm^{-3})	PWP ($cm^3\ cm^{-3}$)	FC ($cm^3\ cm^{-3}$)
	Clay (%)	Silt (%)	Sand (%)			
0-30	31	57	12	1.43	0.16	0.32
30-60	38	52	10	1.43	0.18	0.33
60-90	35	49	16	1.43	0.19	0.33
90-120	30	53	17	1.43	0.19	0.33
	Silty clay loam					

The crop evapotranspiration for the irrigation intervals was estimated by the water balance procedure using the following equation:

$$ET = I + P - D - R \pm \Delta s \qquad \ldots(2)$$

Where I is the irrigation amount (mm), P is the precipitation (mm), D is the deep percolation (mm) and Δs is the change of soil water depth between two irrigations at the root zone and R is the surface runoff (mm). Since the surface runoff was not occurred because of exciting plot's borders, R was ignored in the water balance equation.

Soil evaporation (E) beneath the winter barley canopy was estimated by daily weighing of 16 micro-lysimeters (MLS), which were placed between two rows.

MLS contain small isolated volumes of bare soil mounted flush with or slightly above the soil surface (Daamen and Simmonds 1996) and these were weighed daily (or more frequently) to determine water loss using electronic balances with ±1 gr precision. The MLS cylinders were 300 mm long, 110 mm diameter and with a2 mm thick wall. They were constructed of PVC with the bottom being fixed using a cap.

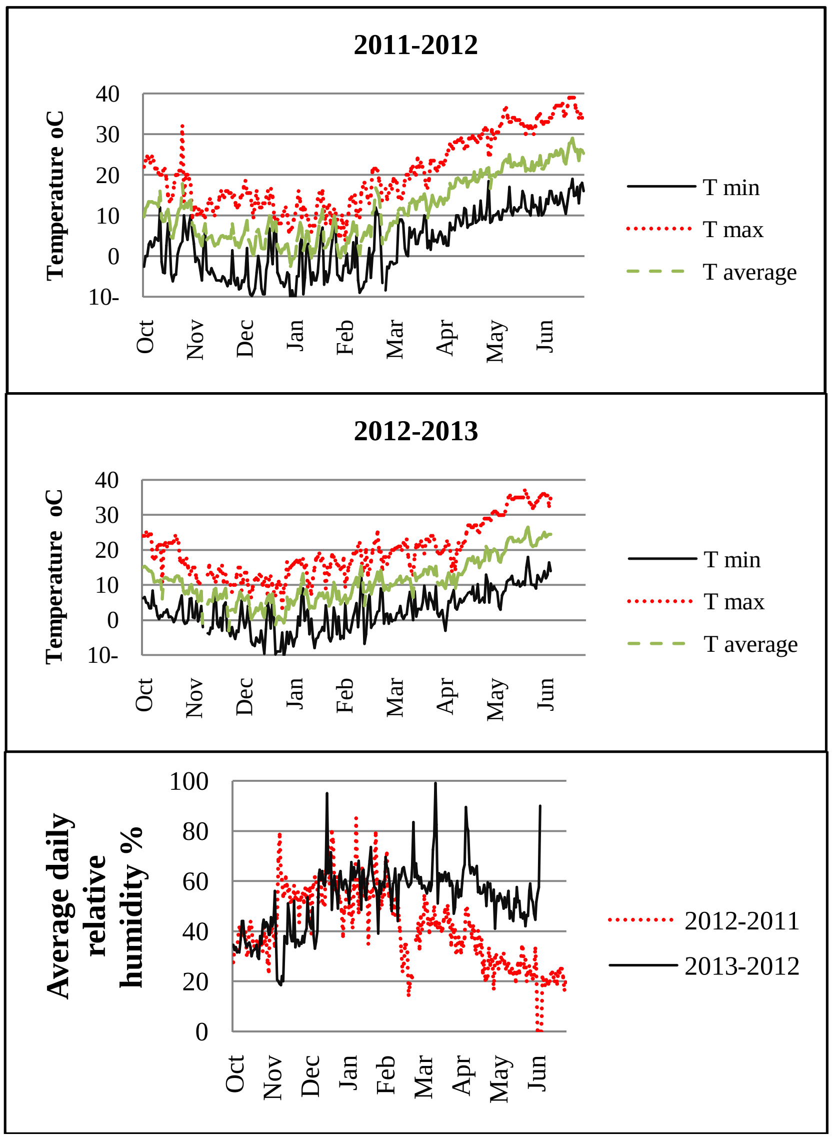

Fig. 1. Minimum, maximum and average daily temperature and average daily relative humidity of air in 2011-2012 and 2012-2013.

To make the soil moisture content in the MLS similar to plot soil moisture before each irrigation event, the MLS were taken away from the plots and an amount of water was added in to the MLS in order to increase the soil moisture content to FC, then they were placed in plots again after irrigation.

Water use efficiency was estimated by the following equation (Hussain & Al-Jaloud 1995):

$$WUE = \frac{Y}{ET} \quad \ldots(3)$$

Where *WUE* is the water use efficiency ($kg.m^{-3}$), *Y* is the seed yield ($kg.m^{-2}$) and *ET* is the crop evapotranspiration (m), calculated by Equation (2).

Net water-use efficiency (WUE_{Net}) and irrigation water-use efficiency (WUE_i) can be determined respectively as follows (Stabler & Martin 2000):

$$WUE_{Net} = \frac{Y - Y_d}{ET_i - ET_d} \quad \ldots(4)$$

$$WUE_i = \frac{Y_i - Y_d}{I} \quad \ldots(5)$$

Where Y_i is the seed yield in irrigation level *i* and ET_i is the crop evapotranspiration for the irrigation level *i*, Y_d is the seed yield in dry land treatment and ET_d is the ET for an equivalent dry land or rain-fed plot, and I_i is the amount of irrigation applied for level *i*. Also water productivity (WP_{GY} and WP_{DM}) of each plot was calculated as dry matter (DM) or seed yield (GY) divided by irrigation water applied.

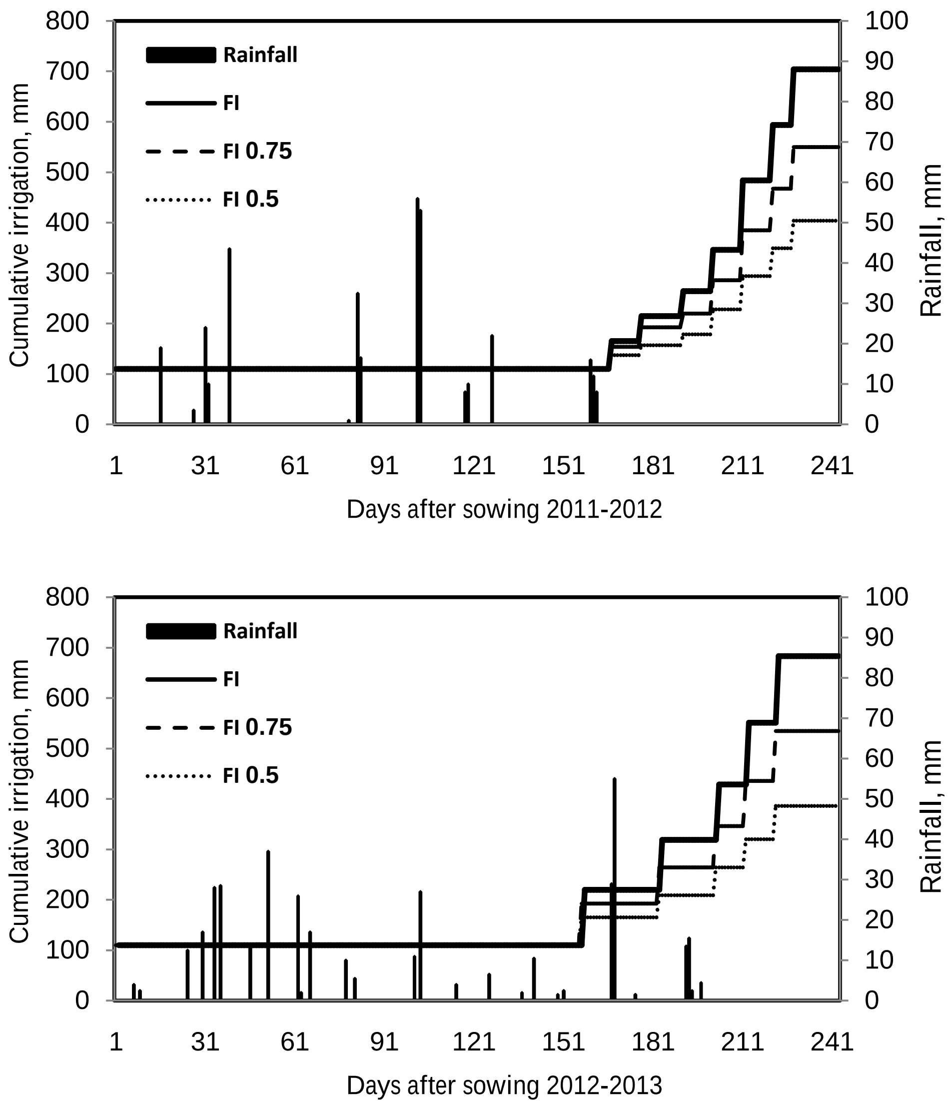

Fig. 2. Cumulative applied irrigation (FI, 0.75 FI and 0.5 FI) water in 2011-2012 and 2012-2013 for the first sowing date (23 October) and rainfall.

In the research area the most rainfall occurs in winters, so the soil surface is usually wet during winter and it can be assumed that the soil water content reduction is equal to the reference evapotranspiration (Shabani *et al.* 2013b). Therefore, soil water content before rainfall was measured approximately (water balance). Reference evapotranspiration was estimated by Penman-Monteith equation (Allen *et al.* 1998) which was calibrated by Razzaghi & Sepaskhah (2012) for the semi-arid environments in the study area. Fig. 2 and 3 show irrigation water applied for each irrigation event at different irrigation treatments and rainfall for 2011-2012 and 2012-2013, respectively. Total amount of rainfall was 335 and 390.5 mm in 2011-2012 and 2012-2013, respectively. Ammonium phosphate at a rate of 100 kg ha^{-1} was mixed with the soil at plowing. Urea (total requirement (200 kg ha^{-1}) was applied in winter and spring at two different times, i.e., before stem elongation and flowering stage. Before harvest, plant height and after harvest seed yield, above ground dry matter and 1000-seed weight were determined. Plants from the five central rows with 1.0 m distance from two edges were harvested and seeds were separated from straw and weighed.

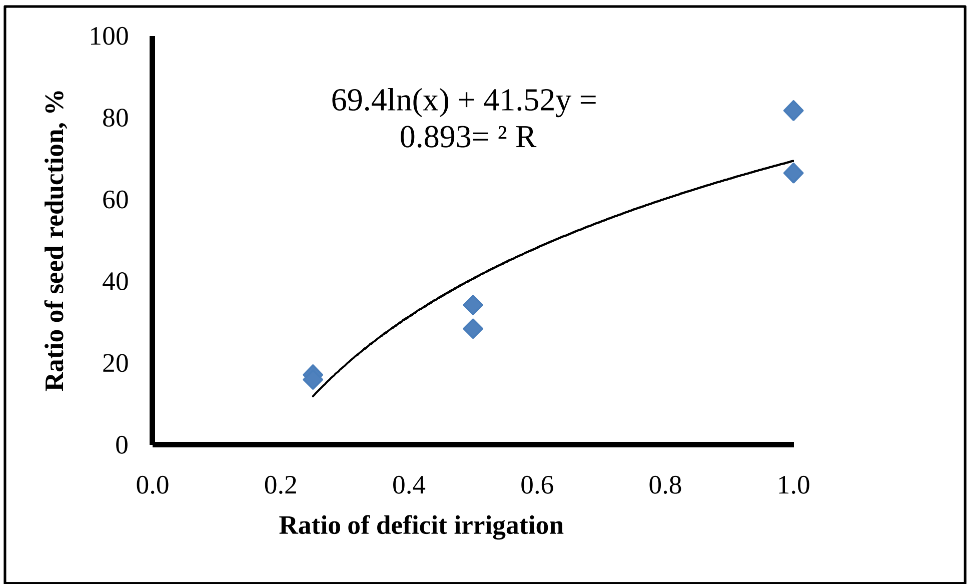

Fig. 3. Relationship between seed yield reduction and ratio of deficit irrigation.

A. Statistical analysis

The interaction effects between deficit irrigation and sowing date were evaluated by using analysis of variance test and means were compared by using Duncan multiple range test. Before means comparison, normality test from field data was done and all the data was normal. The analyses were conducted using the SPSS and SAS software programs.

RESULTS AND DISCUSSION

A. Irrigation and field water balance

Irrigation is one of the important factors affecting whether actual ET is close to the potential rate. Components of soil water balance as influenced by different irrigation treatments and different sowing dates in the two crop seasons are shown in Table 2.

The amount of irrigation water for different sowing date treatments was equal, because ET_C was approximately equal at different sowing date.

ET_c at different treatments ranged from 295 to 926.3 mm in 2011-2012 and 392 to 949.9 mm in 2012-2013. The most irrigated treatment (FI) resulted the maximum ET_c, and the dry land treatments had the lowest ET_c. The results indicated that ET_c of winter barley was greatly affected by irrigation application.

The ΔS in Table 2 showed the depletion of soil water storage during the whole growing season of winter barley. It ranged from -57 to -131 mm. The ΔS for the FI treatments were approximately the highest among all the other treatments, indicating irrigation could meet the needs of winter barley.

In 2011-2012, however, the ΔS for the dry land treatments were not the largest, but it was in 2012-2013. The reason might be that under dry land treatment in 2011-2012 winter barley was in serious water stress condition and both its canopy and its underground root system were restricted. The root might not be able to go deep to uptake soil water stored there, resulting the limitation of water utilization. In 2012-2013, because of spring rainfalls, the roots able to go deeper soil layer and uptake the soil water content. ET was controlled by the plant and meteorological factors and they were approximately consistent in the two crop seasons.

Table 2. Evapotranspiration (ET) and its components at different irrigation levels for winter barley in 2011-2012 and 2012-2013 growing season.

Years	irrigation level	Sowing date	Rainfall (mm)	Irrigation (mm)	ΔS (mm)	Drainage (mm)	ET (mm)
2011-2012	FI	T1	335	704	-99.7	212.4	926.3
		T2	335	704	-82	243.5	877.5
		T3	312.5	704	-92	241.2	867.3
		T4	235	704	-89.5	178.7	849.8
	0.75 FI	T1	335	550	-68	205.7	747.3
		T2	335	550	-88	239	734
		T3	312.5	550	-61	223.5	700
		T4	235	550	-70	177.8	677.2
	0.5 FI	T1	335	404	-96	207.4	627.6
		T2	335	404	-64	241.7	561.3
		T3	312.5	404	-61	234.5	543
		T4	235	404	-58	174	523
	Dry land	T1	335	0	-71	37	369
		T2	335	0	-65	44	356
		T3	312.5	0	-60	31.5	341
		T4	235	0	-79	19	295
2012-2013	FI	T1	390.5	649	-88.4	178	949.9
		T2	384	649	-68	187.9	913.1
		T3	354.5	649	-70	173.5	900.0
		T4	298	649	-61.5	125.3	883.2
	0.75 FI	T1	390.5	511.5	-68.7	183.3	787.4
		T2	384	511.5	-65	193.3	767.2
		T3	354.5	511.5	-71	181.4	755.6
		T4	298	511.5	-57	128	738.5
	0.5 FI	T1	390.5	374	-86	184.5	666.0
		T2	384	374	-82	194	646.0
		T3	354.5	374	-71.5	171	629.0
		T4	298	374	-66	130.5	607.5
	Dry land	T1	390.5	0	-130	0	520.5
		T2	384	0	-131	0	515.0
		T3	354.5	0	-107	0	461.5
		T4	298	0	-94	0	392.0

Table 3: Components of evapotranspiration (ET) at different irrigation levels and different sowing date[a].

Years	Irrigation level	Sowing date	T	E	ET_c	E/ET_C
2011-2012	FI	T1	817.0	109.3	926.3	0.12 e
		T2	639.2	238.3	877.5	0.27 bcd
		T3	616.4	250.9	867.3	0.29 bcd
		T4	499.8	350.0	849.8	0.41 ab
	0.75 FI	T1	622.4	124.9	747.3	0.17 cde
		T2	609.2	124.8	734.0	0.17 cde
		T3	464.0	236.0	700.0	0.34 b
		T4	473.1	204.1	677.2	0.30 bcd
	0.5 FI	T1	569.0	58.6	627.6	0.09 e
		T2	474.7	86.6	561.3	0.15 de
		T3	381.7	161.3	543.0	0.30 bcd
		T4	344.3	178.7	523.0	0.34 b
	Dry land	T1	251.7	117.3	369.0	0.32 bc
		T2	225.8	130.2	356.0	0.37 b
		T3	155.7	185.3	341.0	0.54 a
		T4	184.9	110.1	295.0	0.37 b
2012-2013	FI	T1	764.4	185.5	949.9	0.20 fgh
		T2	694.8	218.3	913.1	0.24 def
		T3	666.7	233.3	900.0	0.26 def
		T4	561.5	321.7	883.2	0.36 bc
	0.75 FI	T1	661.7	125.7	787.4	0.16 gh
		T2	602.7	164.5	767.2	0.21 efg
		T3	566.8	188.8	755.6	0.25 def
		T4	443.0	295.5	738.5	0.40 ab
	0.5 FI	T1	578.3	87.7	666.0	0.13 h
		T2	549.7	96.3	646.0	0.15 gh
		T3	466.1	162.9	629.0	0.26 def
		T4	431.0	176.5	607.5	0.29 ed
	Dry land	T1	386.0	134.5	520.5	0.26 def
		T2	390.9	124.1	515.0	0.24 def
		T3	316.9	144.6	461.5	0.31 cd
		T4	216.8	175.2	392.0	0.45 a

The reasons for the difference in values among the amounts of irrigation in the two seasons were soil water storage and the amount of spring rainfall. Thus, an irrigation strategy could be developed according to the rainfall and soil water storage. Fig. 3 shows the relationships between irrigation and ET_c. They were linearly correlated in which that as irrigation increased, ET will also increase.

The ET was driven by meteorological parameters, crop and soil factors and, is not only water consuming process but also an energy consuming process. In order to clarify the effects of irrigation on ET, regression analysis was carried out. Significant relationship ($P = 0.05$) existed between amount of irrigation with ET and their relations shown in equation (6):

$ET = 0.690 \times I + 384.5 \; ; R^2 = 0.868$ … (6)

Where *ET* is crop evapotranspiration (mm) and *I* is the total irrigation water applied in the whole growing period of winter barely (mm).

B. Impacts of irrigation on evaporation and transpiration

ET, the process in which water moves through the plants and soil into the atmosphere, consisting of soil evaporation (E) and plant transpiration (T), is expressed as equation (7):

$$ET=E+T \quad \ldots (7)$$

Table 3 shows the evaporation beneath the winter barley canopy. There were significant differences ($P<0.05$) in soil evaporation among the irrigation treatments. The values of evaporation in FI and 0.5 FI treatments were the highest and the lowest respectively. The reason might be that under high irrigation amounts the soil surface become more wet which causes higher soil evaporation. The maximum differences between the highest and the lowest soil evaporation were 115.77 and 108.82 mm in 2011-2012 and 2012-2013 respectively. Generally with the increase in irrigation, E was increased. There were no significant differences in soil evaporation between 0.5FI and dry land treatments but the amount of evaporation in dry land treatments were more than in 0.5FI treatments. It is because canopy cover in dry land treatments was less than 0.5FI treatments and during the rain events the amount of evaporation beneath winter barley canopy was more.

The ratios of E to ET_c were different and they ranged from 22.1% to 39.8% and 20.7% to 31.4% in 2011-2012 and 2012-2013 respectively. E/ET of dry land treatments was the highest and the average ratio was about 35.6% in two seasons. High ratio of E/ET in dry land treatments was due to its smaller canopy coverage, and especially after rainfall the evaporation (E) was quite bigger than that of other treatments. E/ET in 0.5FI treatments was the lowest. Results indicated that E/ET for the whole growing period of winter barley was more than 20% with the highest ratio of E/ET occurring at the beginning of the growing season, although after stem-elongation; it was getting less due to the canopy development.

C. Impacts of sowing date on evaporation and transpiration

The evapotranspiration in T1 (23 October) treatments was the highest (667.5mm in 2011-2012 and 730.9 mm in 2012-2013) and in T4 (6 December) treatment's was the lowest (586.2 mm in 2011-2012 and 655.2 in 2012-2013). Results showed that there were significant differences in evaporation between sowing date treatments (Table 3).

As the sowing date was delayed the soil evaporation increased, while transpiration decreased by delaying in sowing date (Table 3).

The reason might be due to decreasing of canopy coverage and plant height soil surface absorbed more sun radiation which increases the rate of evaporation. On the other hand, earlier sowing dates, increases the canopy coverage and root development, which causes more water uptake by crop and soil, gets dry sooner. These processes lead to reduce evaporation from the soil.

The biggest differences between the highest and the lowest soil evaporation were 115.7 and 108.82 mm in 2011-2012 and 2012-2013 respectively.

The ratios of E to ET ranged from 17.3% to 36.5% in 2011-2012 and 18.6% to 37.5% in 2012-2013 respectively. E/ET increases due to delay in sowing date. Because of delay in sowing date not only evapotranspiration decreases, but does evaporation increases.

How to decrease the soil evaporation and make it available for transpiration through the plant is an important way to save water. Result indicated that deficit irrigation and choosing suitable sowing time can decrease evaporation and save more available water for plant transpiration; this is an important way to use irrigation water more efficiently.

D. Grain yield (GY) and Inter-relationships between GY, IR, SD and ET

Deficit irrigation and delay in sowing date decreased seed yield (GY) of barley in two years (Table 4). Similar results have been reported by (Abdel-Raouf *et al.* 1983; Alam, Haider & Paul 2005; Noworolnik 2010; Rahimi 2012; Rashid & Ullah Khan 2010).

Grain yield (GY) ranged from 1353 to 7214 kg ha^{-1}. The GY of treatment FI was the highest while GY of dry land treatment was the lowest corresponding to lack of irrigation. The effect of deficit irrigation on seed yield was significant so that in 0.75 FI, 0.5 FI and dry land irrigation treatments, seed yield reduced by 17.0, 34.1 and 81.7% respectively in 2011-2012 and 15.9, 28.4 and 66.4%, respectively in 2012-2013 relative to full irrigation at different sowing date treatments. Fig. 4 shows the relationship between seed yield reduction and ratio of deficit irrigation. It is indicated that 18.7% reduction in applied irrigation water can be imposed without seed yield reduction of winter barley. Similar result reported by Shabani *et al.* (2013a) for rapeseed.

The relationships between GY and irrigation amounts were related in a second order function for the different winter barley seasons (Fig. 5). The GY of winter barley does not always increase with increasing amounts of irrigation and ET.

Table 4: Irrigation water-use efficiency (WUE_i), net water-use efficiency (WUE_{Net}), water-use efficiency (WUE) and water productivity (WP) of different treatments during two crop seasons[a].

Irrigation treatment	Sowing date: 23 October (T1)		6 November(T2)		22 November(T3)		6 December(T4)		mean	
	WUE 2011-2012 (kg m^{-3})									
FI	0.95	ab	0.81	abcd	0.79	abcd	0.72	cd	0.82	a
0.75 FI	0.94	ab	0.92	abc	0.81	abcd	0.66	de	0.83	a
0.5 FI	0.98	a	0.87	abc	0.77	bcd	0.75	bcd	0.84	a
Dry land	0.53	e	0.51	e	0.27	f	0.25	f	0.39	b
mean	0.85	a	0.78	a	0.66	b	0.59	b		
	WUE 2012-2013 (kg m^{-3})									
FI	0.74	ab	0.73	abc	0.70	bc	0.63	cd	0.70	a
0.75 FI	0.81	a	0.72	abc	0.72	abc	0.57	de	0.71	a
0.5 FI	0.82	a	0.76	ab	0.66	bcd	0.63	cd	0.72	a
Dry land	0.51	ef	0.47	f	0.43	f	0.41	f	0.45	b
mean	0.72	a	0.67	b	0.63	b	0.56	c		
	WUE_{Net} 2011-2012 (kg m^{-3})									
FI	1.23	abcd	1.01	cd	1.13	bcd	0.98	d	1.09	b
0.75 FI	1.35	abcd	1.31	abcd	1.33	abcd	0.97	d	1.24	b
0.5 FI	1.62	a	1.49	ab	1.62	a	1.40	abc	1.53	a
mean	1.40	a	1.36	a	1.27	ab	1.11	b		
	WUE_{Net} 2012-2013 (kg m^{-3})									
FI	1.03	bcde	1.06	bcde	0.98	cde	0.80	de	0.97	b
0.75 FI	1.40	b	1.25	bc	1.17	bcd	0.74	e	1.14	b
0.5 FI	1.92	a	1.93	a	1.29	bc	1.02	bcde	1.54	a
mean	1.45	a	1.42	a	1.15	b	0.85	c		
	WUE_i 2011-2012 (kg m^{-3})									
FI	0.97	ab	0.75	bc	0.84	abc	0.77	abc	0.832	a
0.75 FI	0.93	abc	0.91	abc	0.87	abc	0.67	c	0.844	a
0.5 FI	1.04	a	0.75	bc	0.81	abc	0.79	abc	0.847	a
mean	0.98	a	0.84	b	0.80	b	0.74	b		
	WUE_i 2012-2013 (kg m^{-3})									
FI	0.68	a	0.65	ab	0.66	ab	0.61	ab	0.65	a
0.75 FI	0.73	a	0.62	ab	0.68	ab	0.50	b	0.63	a
0.5 FI	0.75	a	0.68	a	0.58	ab	0.59	ab	0.65	a
mean	0.72	a	0.65	ab	0.64	ab	0.57	b		
	WP (GY-I) 2011-2012 (kg m^{-3})									
FI	1.25	bc	1.00	bde	0.97	de	0.87	e	1.02	a
0.75 FI	1.28	b	1.24	bcd	1.04	bcde	0.81	e	1.09	a
0.5 FI	1.52	a	1.20	bcd	1.03	bcde	0.97	de	1.182	a
mean	1.35	a	1.15	b	1.01	bc	0.88	c		
	WP (GY-I) 2012-2013 (kg m^{-3})									
FI	1.09	cd	1.02	d	0.97	de	0.85	e	0.98	b
0.75 FI	1.25	bc	1.08	cd	1.07	d	0.82	e	1.05	b
0.5 FI	1.45	a	1.32	ab	1.11	cd	1.02	d	1.23	a
mean	1.26	a	1.14	b	1.05	c	0.90	d		
	WP (DM-I) 2011-2012 (kg m^{-3})									
FI	2.65	b	2.07	def	2.00	ef	1.62	f	1.02	a
0.75 FI	2.59	bc	2.53	bcd	1.93	ef	1.96	ef	1.09	a
0.5 FI	3.22	a	2.69	b	2.16	cde	1.95	ef	1.18	a
mean	2.82	a	2.44	b	2.03	c	1.85	c		
	WP (DM-I) 2011-2012 (kg m^{-3})									
FI	2.67	bcd	2.43	de	2.33	e	1.96	f	2.35	c
0.75 FI	2.94	b	2.67	bcd	2.52	de	1.97	f	2.52	b
0.5 FI	3.51	a	3.34	A	2.83	bc	2.62	cd	3.07	a
mean	3.04	a	2.81	B	2.56	c	2.18	d		

When the amount of water reached to a certain level, the grain yield would decrease due to water and nutrient leaching. In this study by increasing amount of irrigation water, the GY was increase, and there was no any decline in GY, because the amount of irrigation water was not much enough to be leached and reduces the GY. In the other words the amount of irrigation water didn't reach to the certain level.

More ever, the seed yields were statistically different at different sowing date treatments. The value of GY in 23 October treatments (T1) was the highest and in 6 December treatments (T4) were the lowest level in both growing seasons (Table 4). Delayed in sowing date resulted reduction in grain yield that similar result was also reported by Noworolnik & Leszczynska (1997) and Alam *et al.* (2005).

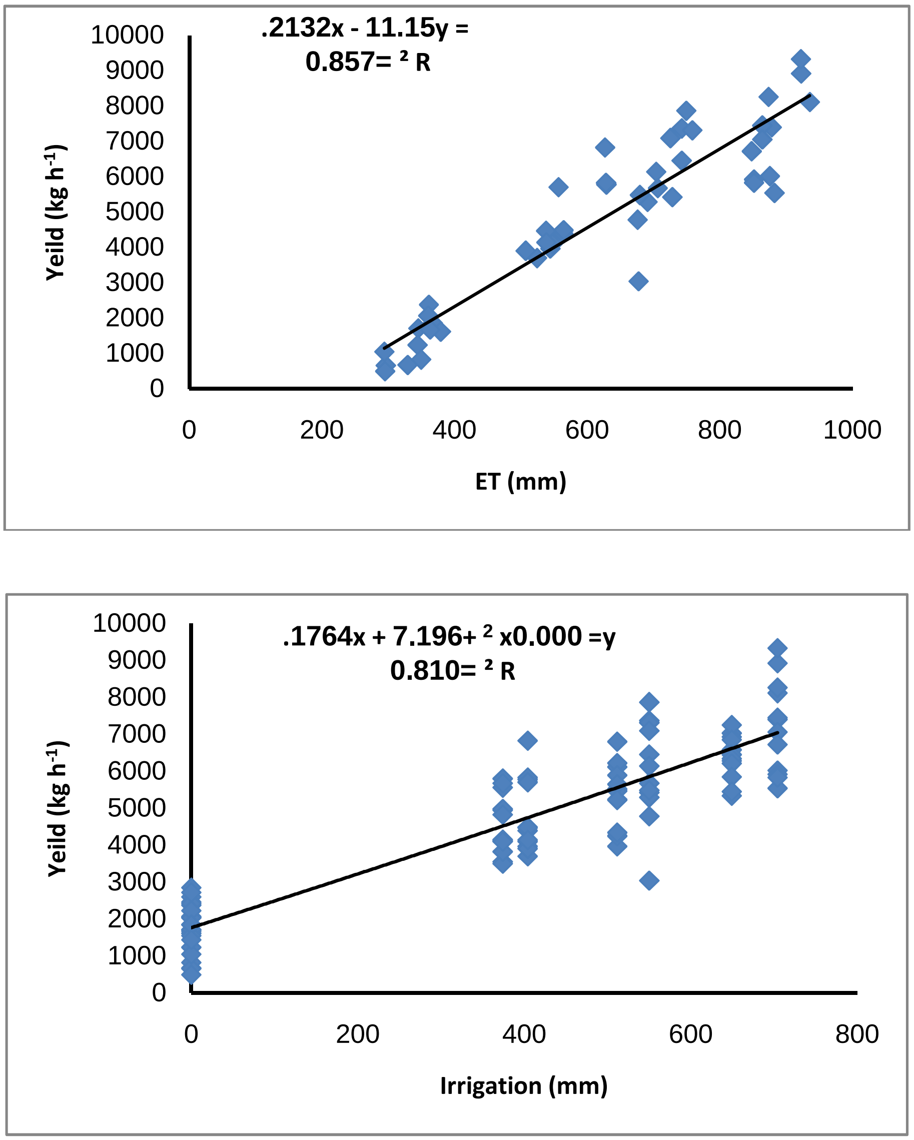

Fig. 4. Relationships between GY and irrigation amounts and GY and ETc.

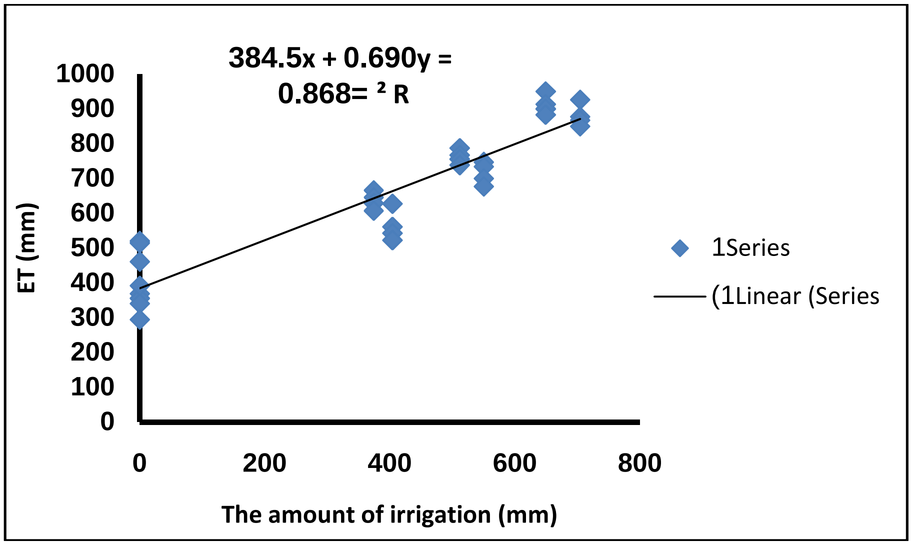

Fig. 5. Relationships between evapotranspiration (ET) and irrigation in two crop seasons.

E. Irrigation and WUE

Table 4shows the WUE, WUE_i and WUE_{net} at different irrigation treatments in two winter barley seasons. There was no significant difference in WUE_i between the irrigation treatments. The average amount of WUE_i is 0.84 kgm^{-3} in 2011-2012 and 0.64 kgm^{-3} in 2012-2013. The difference in WUE_i between the years was significant. In both years, by delaying in sowing date, WUE_i decreased. The amount of WUE_i for T1 and T4 were 0.979 and 0.743 kgm^{-3} in 2011-2012 and 0.72 and 0.565 kgm^{-3} in 2012-2013.

WUE_{Net} ranged from 0.96 to 1.54 $kgm^{-3}$for irrigation treatments and the highest value was seen in 0.5FI treatment. There was no significant difference in values of WUE_{Net} between two years. The result shows deficit irrigation, leading to increased WUE_{Net} in two years. Furthermore, delaying in sowing date decreased WUE_{Net}.

WUE ranged from 0.389 to 0.841 kgm^{-3} for irrigation treatments. There were no significant differences in WUE between FI, 0.75FI and 0.5FI treatments. The value of WUE at treatment 0.5FI was the highest and the lowest WUE occurred in the dry land treatments. The amount of WUE for dry land treatments were 0.389 and 0.454 kgm^{-3} in 2011-2012 and 2012-2013 respectively. In plant water stress condition the amount of irrigation is an important factor, which has an impact on water use efficiency. Both WUE and WUE_{Net} decreased with increasing in irrigation depth for the two growing seasons.

This shows that higher irrigation decreased WUE and WUE_{Net} of crops, which is not consistent with the findings of Hedge (1987), who found that the irrigation significantly increased WUE of crops but Sun *et al.* (2006) reported similar result.

WUE and WUE_{Net} decreased by delaying in sowing date (Table 4). The highest value for WUE and WUE_{Net} were 0.85 and 1.45 kgm^{-3} in treatments dated 23 October and the lowest value was 0.55 and 0.85 kgm^{-3} in treatments dated 6 December. In later sowing date the GY decreases but amount of ETc and irrigation water didn't change, So WUE and WUE_{Net} decrease in later sowing date.

Water productivity based on dry matter and grain yield (WP_{DM} and WP_{GY}) under irrigation and sowing date treatments is presented in Table 4. The amounts ofWP_{GY} ranged from 0.983 to 1.225 kgm^{-3} and WP_{DM} ranged from 2.09 to 3.07 kgm^{-3}. The values of WP_{GY} and WP_{DM} were statistically higher at lower levels of irrigation, in other words, WP_{GY} reached to its maximum at 0.5FI treatments. It is indicated that the optimum level of WP_{GY} and WP_{DM} could be achieved with saving some volume of irrigation water. WP_{GY} and WP_{DM} significantly decreased by delaying in sowing date.

CONCLUSIONS AND DISCUSSION

In this study ET was linearly related to the amount of irrigation. There was about 291.7 mm difference in soil evaporation among different treatments.

Maximum yield was obtained when the average amount applied of irrigation water was 704 mm and ET was 926.3 mm, for the two growing seasons. However, the seasonal irrigation application should vary with seasonal rainfall and the soil moisture condition before sowing, although the depletion in to the soil profile was considerable in the ET components.

Results indicated that the treatment 0.75 FI was the best related to WUE_{net} and WP in two growing seasons. The results showed that with the increase in irrigation, ET increased and WUE, WUE_{net} and WP decreased but the amount of WUE in dry land treatments was less than irrigated treatments. Deficit irrigation leads to decrease in soil evaporation and E/ET. Furthermore by delaying in sowing date WUE, WUE_{net}, WUE_i and WP decreased. Also by delaying in sowing date E and E/ET increased. Considering the serious water shortage situation in Iran, irrigation might be further reduced to prevent the rapidly falling groundwater level with less sacrifice in grain yield than that in ET. Furthermore, it is also useful to the other irrigated farming regions by the groundwater. Besides the irrigation scheduling to improve WUE of winter barley, reducing soil evaporation is also an effective method. The results from this experiment showed that E/ET was around 30%, it means considerable water was consumed through soil evaporation. Even under optimized irrigation scheduling and water-saving practices, winter barley still requires large amount of irrigation. From a long point of view, reducing in winter barley cropping area might be an option for water saving practice. Yang and Zehnder (2001) proposed to reduce irrigated area to deal with water scarcity in NCP through virtual water import. Policies dealing with water scarcity should be taken into account. Due to water crisis in the world and especially in Iran which is located in dry belt region, it is important to choosing an optimum sowing date and irrigation strategy to decrease water use and maximize WUE and WP.

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