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Optimizing Water Use for Wheat Production under Drought Conditions

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Abstract

In order to compare new wheat cultivars and lines, an experiment was implemented in the form of split plots (randomized complete blocks) with three replications for two years at the Chahartakhte research station, Shahrekord, located in the agricultural and natural resources research center of Chaharmahal and Bakhtiari Province. The main treatments included three levels of irrigation, corresponding to (FI) 100%, (I80) 80%, and (I65) 65% soil moisture deficiency, while the subplots featured six wheat cultivars (Mihan, Heydari, line CD-94-9, line CD-94-8, Oroom, and Pishgam). The results of analysis of variance showed that the effect of irrigation levels on grain yield, total yield, plant height, harvest index, 1000 grams grain weight, spike length, water use efficiency and water productivity were significant at 1% level. The highest amount of grain yield was obtained from the Mihan cultivar with FI treatment with 7.85 tons/ha, which was placed in the same statistical group with the yield of two cultivars, Heydari and Pishgam. The lowest amount of grain yield was obtained from the Heidari cultivar treatment with the I65 irrigation level with 2.81 tons per hectare. The highest water use efficiency and water productivity were 2.06 and 1.83 kg/m^3, respectively, obtained from the Mihan cultivar treatment in FI irrigation management. The lowest water

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use efficiency and water productivity were 1.13 and 1.01 kg/m^3, respectively, obtained from the Heydari cultivar and I65 treatments. Therefore, in order to improve water efficiency with the aim of producing more for less water used, using cultivars with high yield potential and drought tolerance (the cultivars used in the present research), including the Mihan cultivar, can be some of the most important saving solutions for water used.

Introduction

In recent years, the demand for food has increased, through increasing the of world population. However, climate change has created many challenges, like pests, environmental pollution, etc. These factors can affect agricultural production and grain quality. Wheat (*Triticum aestivum* L.) is one of the most important food crops in the world (Asseng *et al*., 2020) and is a source of energy for more than half of the world's population (Lian *et al*., 2020). The area under wheat cultivation in 2020 in Iran and the world was six million hectares and 219 million hectares, respectively. The average wheat yield in the world is 3.68 tons per hectare, but in Iran, it is 1.66 tons per hectare (FAO, 2022). Abiotic stresses such as salinity, ultraviolet rays, high and low temperatures, drought and heavy metals can affect different stages of the plant's life cycle. These stresses have a significant impact on plant morphology, growth and production (AL-Quraan *et al*., 2019). Wheat production is seriously affected by global climate changes and rainfall patterns. With the decrease of rainfall, evapotranspiration and air temperature increase, as a result, the water requirement of wheat increases. So far, extensive studies have been conducted to investigate the effect of drought stress on the yield of crops, especially wheat, worldwide, including in Iran. Among environmental stresses, drought stress is the most important factor that leads to a significant decrease in wheat grain yield through closing the stomata and as a result, reducing the amount of photosynthesis. In short, this stress often occurs during the reproductive period of wheat (Rebetzke *et al*., 2008). Less irrigation or water saving can be an effective method of water management in the field, increasing the area under cultivation and helping determine optimal cultivation patterns. The results of many researchers showed that moisture stress in different stages of wheat development has caused a decrease in biological yield, grain yield, harvest index, and yield components of wheat grain, inside and outside the country (Emam *et al*., 2007; Gooding *et al*., 2003). Akbari Moghaddam *et al*. (2002) showed that the interruption of irrigation at the stage of spike emergence reduced grain yield and biomass yield by 36% and 20%, respectively. Shanazari *et al*. (2021)

conducted an experimented to evaluate the tolerance of drought stress in bread wheat (Tritipyrum and Terticale genotypes) in two regions of Isfahan and Shiraz provinces. The results showed that triticale lines had the highest drought tolerance. Saba et al. (2018) showed that increase in plant height caused to increase in length of the grain filling period and reducing the number of days to spike. Also, Spike length increases the number of spikes per plant and the weight of one thousand grains and reduces the selection criteria for high grains. Hosseinalipour *et al*. (2020) showed that drought stress in soil water potential lower than -5 bar causes a significant decrease in root growth parameters. Also, there was a genetic difference between cultivars regarding root growth and response to drought stress, and drought-tolerant and sensitive cultivars showed different responses to drought stress. Therefore, an important factor in the drought tolerance of the wheat plant is the reaction and development of the root system, which can be affected by drought stress, and the difference between cultivars, in terms of root growth characteristics, may reveal their difference in resistance to drought stress. Additionally, Ahmed et al. (2020) showed that when drought stress is applied to wheat, the photosynthetic pigment content of the crop diminishes, whereas the tolerant genotypes exhibit higher levels of chlorophyll. The basic solution to eliminate or minimize the effects of environmental stresses, including drought stress, is to find genotypes that, by having a set of desirable traits and high heritability, can tolerate such stresses with minimal yield reduction.

Wheat is one of the leading products of Chaharmahal and Bakhtiari Province. However, wheat production is seen as one of the significant obstacles in the province of Chaharmahal and Bakhtiari. Under such conditions, it is essential to explore various methods to enhance production relative to the water used. Different wheat cultivars have been cultivated in the province, with some being studied. However, comprehensive information about their responses to water stress is lacking. Investigating the reactions of suitable cultivars with high yield potential and desirable quality under low irrigation and drought stress management is crucial. This research aims to develop effective and practical management strategies for improving water use efficiency and irrigation water productivity, representing a fundamental and significant challenge in irrigated agriculture. Therefore, in order to make the research comprehensive and to answer the questions raised in this field, the practical and affected factors of deficit irrigation and drought stress should be considered, which play a decisive role in choosing the best option. For this reason, the present study was conducted to

Optimize water use for wheat production under drought conditions in Shahrekord province, Iran.

Materials and Methods

Study Area

The current research was carried out for two years (2018-2019) at the Chahartakhte research station of Shahrekord, located in the agricultural and natural resources research center of Chaharmahal and Bakhtiari province, (32°N latitude and 55°E longitude). It was implemented at altitude of 2090 meters above sea level and with a semi-humid regional climate with a mild summer and a very cold winter. Figure 1 shows the location of the intended research farm.

Fig 1. Studied location

Soil characteristics of the study area

To determine some physical and chemical characteristics of the soil, compound samples of the soil of the project were prepared from the depths of 0-30 and 30-60 cm, before soil preparation stages, at the beginning of October for two years. The samples were transferred to the soil and water research department laboratory and their various characteristics were measured. The results of these measurements are presented in Tables 1 and 2.

Table 1. Physical soil properties

Year	Soil depth (cm)	Texture	Bulk density ($g.cm^{-3}$)	F.C (θ_m%)	P.W.P (θ_m%)
2018	0-30	Loam	1.36	24.01	9.3
	30-60	Silt Loam	1.41	25.20	8.3
2019	0-30	Loam	1.34	26.8	9.1
	30-60	Silt Loam	1.39	23.5	8.2

Table 2. Chemical soil properties

Year	Soil depth (cm)	E.C ($dS.m^{-1}$)	pH	O.C (%)	P ava. ($mg.kg^{-1}$)	K ava. ($mg.kg^{-1}$)	N (%)
2018	0-30	0.709	7.73	0.838	6.3	265	0.081
2019	0-30	0.801	7.77	0.912	9.1	284	0.086

Characteristics of irrigation water

The water used in the research farm was supplied from a well. In order to determine the quality of irrigation water, water sample was taken from the outlet of the well and transported to the laboratory to measure its chemical properties. The results of chemical analysis of water are shown in Table 3.

Table 3. Some chemical properties of water used in this study

pH	EC	Na^{+}	K^{+}	Ca^{2+}	Mg^{2}	Cl^{-}	HCO_3^{-}	CO_3^{2-}	SO_4^{2-}	Cd	Fe^{2+}	Cu^{+}	Zn^{+}
	µS/cm	(meq/L)								(mg/L)			
7.20	325	0.17	0.05	5.01	2.81	0.52	7.35	0	0.01	0	0.03	0.01	0.01

Stages of preparation and implementation of the plan

In order to prepare the soil, plowing and disc harrowing were carried out, in early October, for two years. Land leveling was carried out to prepare the soil, before planting. Based on the results of soil compound samples, the required amount of fertilizers was determined according to the soil test method, in each year. The required phosphorus and potassium fertilizers were from triple superphosphate and potassium sulfate sources, given to the soil respectively, before cultivation. The required nitrogen was supplied to the plant from the urea source in four stages: before cultivation, tillering stage, stem growth and before spike emergence. Iron, zinc, copper and manganese micronutrient elements were obtained from iron sulfate, zinc sulfate, copper sulfate and manganese sulfate, respectively, and used before planting. Wheat grains were disinfected before sowing (Table 4). Planting operations were carried out in the first decade of November every year. Following planting, pipes and drip irrigation equipment were installed in the field. Planting operations were carried out in the first decade of November and harvesting in early June.

Experimental design

An experiment was conducted using a split-plot design within a randomized complete block framework, with three replications, to compare wheat cultivars and lines under different irrigation levels. The study was carried out on a 1,000 square-meter plot over two consecutive cropping years. The main plots included treatments for drought stress and deficit irrigation, which were as

Table 4. Types and amounts of fertilizers used in the two years of the experiment (kg/hec)

year	Fertilization time	Nitrogen	Phosphorus	Potassium	Iron	zinc	copper	Manganese
2018	Before planting	100	150	0	40	30	15	20
	Soiling stage	100	0	0	0	0	0	0
	Before flowering	100	0	0	0	0	0	0
2019	Before planting	100	150	150	40	30	15	20
	Soiling stage	100	0	0	0	0	0	0
	Before flowering	100	0	0	0	0	0	0

follows:

FI = full irrigation (without stress)

I80 = providing 80% of the soil moisture deficiency of the complete irrigation treatment for this treatment in each irrigation (mild tension)

I65 = providing 65% of the soil moisture deficiency of the full irrigation treatment for this treatment in each irrigation (severe stress)

The treatments in this research included: 1- six cultivars and lines of wheat 2- three levels of irrigation and moisture drainage. Sub-treatments include new cultivars and lines of wheat, which include: V1 =Mihan, V2 = Heydari (New cultivar), V3 = promising line CD-94-9 is expected to have more tolerance to drought stress, V4 = promising line CD-94-8 is expected to be more tolerant to drought stress, V5 = Oroom, V6= Pishgam.

In this research, the number of treatments was 18 (3 * 6) with three replications, which formed 54 experimental plots. The dimensions of the sub-plots were considered to be 2 * 5 meters. The sub-plots were separated by 1 meter, the main plots by 1 meter and the replications by 3 meters. Grains (with a density of 450 grains per square meter) after disinfection were planted in plots with an area of 10 square meters in a line with a distance of 15 cm, In the first decade of November every year. All the operations of land preparation, planting, were carried out uniformly according to the practice of the region. The irrigation method in this research was drip tape which was installed on the soil at a distance of 50 cm. In the strip drip irrigation method, drip tapes 36 meters long with a diameter of 16 mm and a distance of water outlet channels of 20 cm were used for each crop row. The amount of irrigation water in each treatment was measured and controlled by shut-off valves and a volume meter installed on polyethylene pipes for water transfer. In this research, the amount of irrigation water in each irrigation interval was calculated by measuring the soil moisture during irrigation (Using a portable moisture measuring device) and in the full irrigation treatment according to the area of each plot and applying the irrigation efficiency of the volume of water used for each method. The amount of water used for the deficit irrigation management treatments was set as a coefficient of its amount in the full irrigation treatment. The irrigation interval for all treatments was considered constant in the full irrigation treatment and the maximum daily evaporation and transpiration rate of the experimental site was considered for 7 days so that no stress is applied to the plant in the full irrigation treatment. In this way, in the full irrigation treatment, the amount of soil moisture was always higher than the amount of easily accessible moisture during irrigation. The studied traits included spike length, grain yield, biological yield, harvest index, and thousand grain weight. In the end, the obtained data were subjected to simple and compound variance analysis based on the statistical design using SAS software, and Tukey's test was used to compare the means of the treatments, and finally, the most tolerant genotype to water stress conditions during the season was the basis of grain yield, grain protein and water use efficiency for use in Shahrekord city and similar areas were identified and introduced. The total water used was calculated based on the National Water in Agriculture Document. Equations 1, 2 and 3 calculate water use efficiency, water productivity and harvest index.

$$WUE = \frac{Yield}{ET_c} \quad (1)$$

$$WP = \frac{amount\ of\ product\ produced}{amount\ of\ water\ used} \quad (2)$$

$$\text{harvest index} = \frac{grain\ Yield}{total\ Yield} \quad (3)$$

Water use efficiency (Kg.mm^{-1}), Yield (Kg. ha^{-1}), Plant evapotranspiration (mm. ha^{-1}) and : Water Productivity.

Results and discussion

The amount of applied water

The net irrigation water requirement for the treatment of maintaining 100% of soil moisture deficiency was calculated and applied during each irrigation interval. The goal was to replenish soil moisture in the root development zone up to field capacity. To calculate the gross requirement of irrigation water, the application efficiency was obtained on average for two years of research during the growing season of the plant in the drip tapes irrigation method, according to the uniformity coefficient of water distribution and the efficiency reduction factor, the water application efficiency was 89%. The average values of the net and gross requirement of irrigation water used for the experimental treatments in the two years of the research are presented in Table 5.

Yield and yield components

The summary of the results of the compound variance analysis of the effect of cultivar and irrigation levels on the yield and yield components of wheat in two years of the research is presented in Table 6.

Table 5. Water volume required and consumed for different drought stress treatments during the wheat growing season

Levels of irrigation	FI	I_{80}	I_{65}
Water volume required (m^3/ha)	3814	3051	2479
Water volume consumed (m^3/ha)	4285	3428	2785

Table 6. Results of the combined analysis of variance of measure properties of wheat crop under irrigation treatment in two crop years

Source of variation	df	Mean of squares					
		Grain yield	Biological performance	Plant height	Harvest index	Weight of a thousand grains	Spike length
Year (y)	1	2832^{ns}	13125^{ns}	156^{ns}	33699^{ns}	681^{ns}	12.07^{ns}
Error y	4	1840	2220	5.34	0.32	1.08	0.2
Levels of irrigation	2	1429560^{**}	3566431^{**}	95.21^{**}	502^{**}	951.38^{**}	16.63^{**}
Year ×Levels of irrigation	2	8601^{**}	1798^{ns}	4.25^{ns}	487^{**}	8.86^{**}	0.01^{ns}
Error a	8	530	1701	2.41	2.19	0.49	0.1
Cultivar	5	24839^{**}	270952^{**}	106.15^{**}	5.33^{**}	19.07^{**}	10.59^{**}
Year ×Cultivar	5	2866^{**}	4633^{**}	0.86	5.39^{ns}	10.52^{**}	0.34^{**}
Levels of irrigation × Cultivar	10	11071^{**}	49847^{**}	33.11^{**}	17.96^{**}	9.90^{**}	0.37^{**}
Year ×Levels of irrigation× Cultivar	10	2653^{**}	8742^{**}	2.32^{ns}	17.99^{**}	5.60^{**}	0.02^{ns}
Error b	60	744	1319	2.94	1.86	0.74	0.1
CV		5.02	2.38	2.03	7.57	2.63	3.05

ns, * and **: not significant, significant at 5% and 1% probability levels, respectively.

Grain yield

In general, the results of compound variance analysis (Table 6) showed that the effect of year was not significant on grain yield. The effect of irrigation levels was significant at level of 1% level on grain yield. The maximum and minimum grain yields were obtained at 7.05 and 3.30 tons per hectare for FI and I65 treatments, respectively (Table 7). The effect of cultivar on grain yield was significant at the level of 1%, so that the maximum and minimum grain yield per unit area was 5.75 and 4.82 tons per hectare, respectively, for Mihan cultivar and line CD-94-8 (Table 7). The interaction effect of cultivar and irrigation levels on grain yield was significant (Table 6). The mean comparison of grain yield in wheat cultivars under different irrigation levels showed the highest grain yield in Mihan cultivar with FI treatment (7.85 tons per hectare) and the lowest grain yield in Heydari cultivar with I65 irrigation level (2.81 tons per hectare) (Figure 2). In this study, the I_{80} treatment decreased the grain yield by 20%, but the I_{65} treatment decreased the grain yield by 56%. This reduction in yield can be attributed to the long-term stress applied to the plant, which reduces the photosynthetic level of the plant, thereby reducing plant growth and ultimately reducing yield. Ahmadi Lahijani and Emam (2013) indicated that grain yield under normal irrigation conditions and drought stress had a positive and significant correlation with all traits except for thousand grain weight. The reduction of grain yield due to drought stress has been reported in other studies (Emam *et al*., 2007). Also, results showed that by increasing amount of irrigation water to the full irrigation, grain yield can increase near the production potential and full irrigation treatment had the highest grain yield, but severe stress on the plant caused a significant reduction in the yield. The cultivars used in this research have a high yield. (Table 7), which is due to the high potential and compatibility with the growing environment of these cultivars. The aims of cultivar selection are different in different countries, but in all programs, it is cultivar selection will likely be effective for high yield, and their suitability for specific uses, resistance to living and non-living stresses, less water requirement, better use of nutrients such as nitrogen and phosphorus. In short, new cultivars should have high yield. In this regard, new cultivars should be evaluated for different traits in the country. Therefore, for the optimal use of water and increased production per unit of water used, it is necessary to modify and select suitable plant cultivars according to the environmental conditions of plant growth and apply appropriate management of low irrigation. Also, the grain yield in all drought stress management treatments was higher in Mihan cultivar than other cultivars. Due to the limitation of water resources in arid and semi-arid regions, methods should be adopted to obtain optimal productivity from available water resources and also not to harm the sustainability of the production of this product. One of the possible methods in the optimal use of available water resources is to introduce cultivars that are less sensitive to irrigation reduction and have acceptable yield in low irrigation conditions.

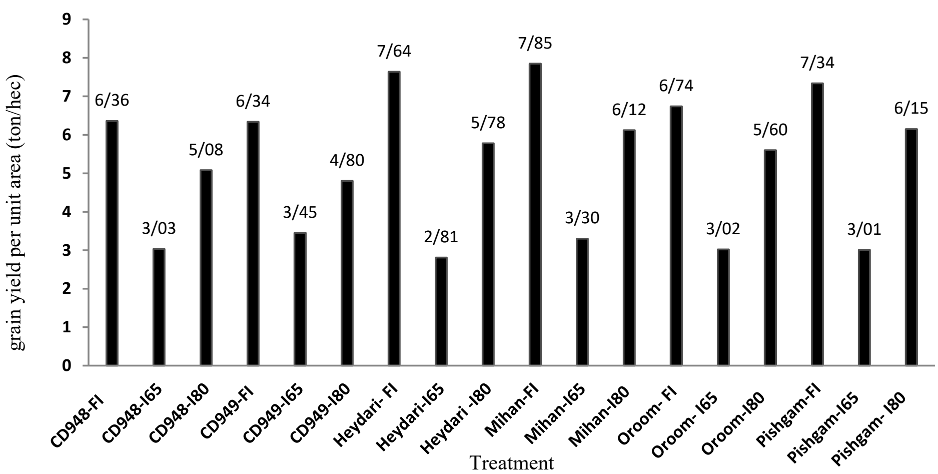

Fig 2. Interaction effect of cultivar and irrigation levels on wheat grain yield

Biological function

In general, the results of compound variance analysis (Table 6) showed that the effect of year on biological yield was insignificant. The effect of irrigation levels on biological yield was significant at the 1% level (Table 6). The maximum and minimum biological yield were obtained at 17.07 and 10.85 tons per hectare for FI and I_{65} treatments, respectively (Table 8). Emam *et al*., (2011) and Pireivatlou *et al*., (2010), also reported similar results of reduced biological yield due to drought stress. The effect of cultivar on biological yield per unit area was significant at the level of 1% (Table 6). The highest amount of biological yield per unit area was obtained for the Mihan cultivar (15.71 tons per hectare). The interaction effect of cultivar and irrigation levels on biological performance was significant (Table 6). Comparison of biological yield in wheat cultivars under different levels of irrigation showed that the highest biological yield per unit area was in the Pishgam cultivar with FI treatment amounting to 18.49 tons per hectare, which was in the same statistical group with Mihan and Heydari cultivars (Figure 3). The lowest amount of biological yield per unit area was obtained in Heydari cultivar with I_{65} irrigation level of 10.25 tons per hectare (Figure 3). The results showed that biological yield reduced with the decrease in the amount of irrigation water. The I_{65} treatment reduced biological yield by 36% compared to FI. In mild drought stress, Mild drought stress primarily reduces transpiration, whereas severe stress significantly impairs photosynthesis, leading to a sharp decline in biological yield. Therefore, for optimal use of water and increase production per unit of water used, it is necessary, modify and select suitable plant cultivars according to the environmental conditions of plant growth.

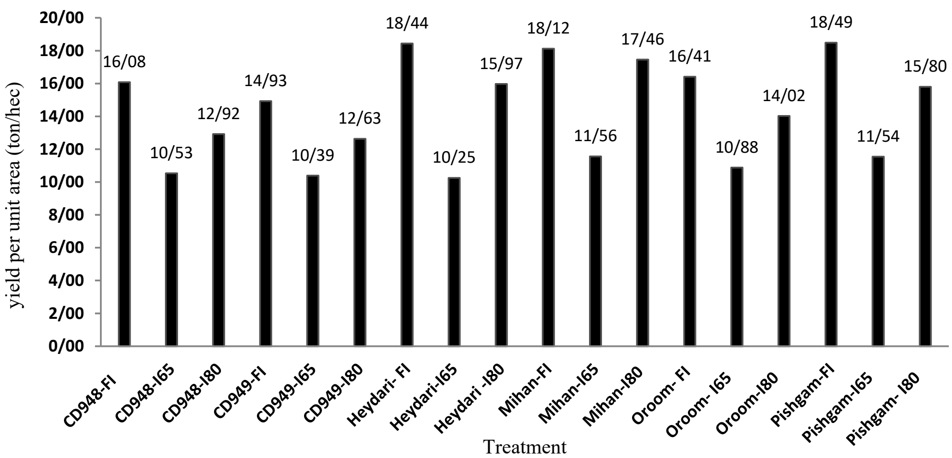

Fig 3. Interaction effect of irrigation levels in cultivar on biological yield of wheat

Plant height

In general, the results of compound variance analysis (Table 6) showed that the effect of year on plant height was insignificant. The effect of irrigation levels on plant height was significant at the 1% level (Table 6). Also, by increasing the amount of irrigation water from 65% to 100%, the height of the plant increased from 82.91 to 86.15 cm (Table 7). Plant height is one of the characteristics that is influenced by genetic and environmental factors. The increase in plant height is usually the most noticeable change caused by plant growth. Height can be considered an advantage in terms of competition with other plants in a plant community. Generally, biological yield is the sum of grain yield and straw yield. The higher the plant height, the higher the straw yield, and thus the higher the total yield.

The effect of the cultivar on plant height was significant at the 1% level (Table 6). The highest height of the plant was obtained for the Oroom cultivar (87.8 cm) (Table 7). The interaction effect of cultivar and irrigation levels on plant height was significant at the 1% level (Table 7). The mean comparison of plant height in wheat cultivars under different irrigation levels showed that the highest plant height was obtained in Oroom cultivar with FI treatment at a height of 90.32 cm and the shortest plant height in Mihan with I_{65} irrigation treatment at height of 77.98 cm. (Figure 4).

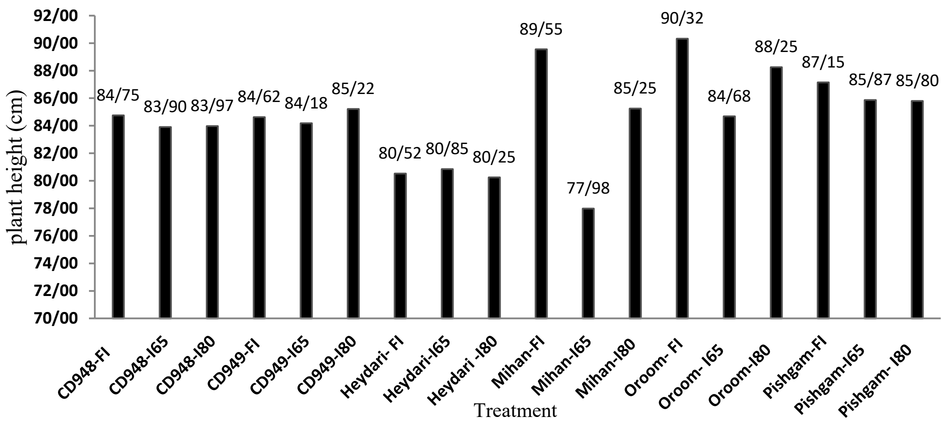

Fig 4. Interaction effect of irrigation levels and cultivar on wheat plant height

Table 7. Comparison of means in different traits of

Treatment		Grain yield (ton/ha)	Biological performance (ton/ha)	Plant height (cm)	Harvest index	Thousand grain weight (gr)	Spike length (cm)
Year	Year 1	5.29a	14.35a	85.81a	0.36a	35.44a	10.67a
	Year 2	5.19a	14.13a	83.41a	0.36a	33.76a	10.00a
Levels of irrigation	FI	7.05a	17.07a	86.15a	0.42 a	38.03a	11.03a
	I_{80}	5.58b	14.8b	84.79b	0.37b	33.01b	10.31b
	I_{65}	103.10c	10.85c	82.91c	0.3c	27.75c	9.67c
Cultivar	Mihan	5.76a	15.71a	384.3c	0.35b	32.2d	10.1c
	Oroom	5.13c	13.77d	87.8a	0.35b	31.6e	11.3a
	CD-94-8	4.82d	13.17e	84.2c	0.36b	33.3bc	10.7b
	CD-94-9	4.86d	12.65f	84.7c	0.4a	32.7acd	10.6b
	Heydari	5.41b	14.89c	80.5d	0.34b	33.41b	10.2c
	Pishgam	5.50b	15.27b	86.3b	0.36b	34.48a	9.0d

Means in each column having at least one similar letter are not significantly different at 5% probability.

Harvesting index

In general, the results of compound variance analysis (Table 6) showed that the effect of year on harvesting index was not significant. The results showed that the effect of irrigation levels on the harvesting index was significant at the 1% level (Table 6). The lowest and highest harvest index at different irrigation levels were 0.30 and 0.42, respectively (Table 8). The effect of cultivar on harvesting index was significant at the level of 1%. The lowest harvesting index (0.34) was obtained from Heydari cultivar and the highest harvesting index (0.40) from CD-94-9 line (Table 7). According to the harvesting index calculation equation (3), when the grain yield is higher, the harvesting index value increases.

Soleimani (2016) indicated that the effect of drought stress treatments on the harvesting index was significant. The interaction effect of cultivar and irrigation levels on harvesting index was significant at the level of 1% (Table 6). The mean comparison of the harvesting index in wheat cultivars under different irrigation levels showed that the highest harvesting index was obtained in Mihan cultivar with FI treatment at the rate of 0.43 and the lowest harvesting index was obtained in Pishgam, Heydari and Oroom cultivars with I_{65} irrigation treatment at the rate of 0.27 (Fig 5).

Thousand grains Weight

In general, the results of compound variance analysis (Table 6) showed that the effect of year on the weight of one thousand grains was insignificant. The results showed that the effect of irrigation levels on the weight of 1000 grains was significant at the level of 1%, so that the maximum weight of 1000 grains (1803 grams) was related to the FI treatment and the minimum weight of 1000 grains (27.75 grams) was related

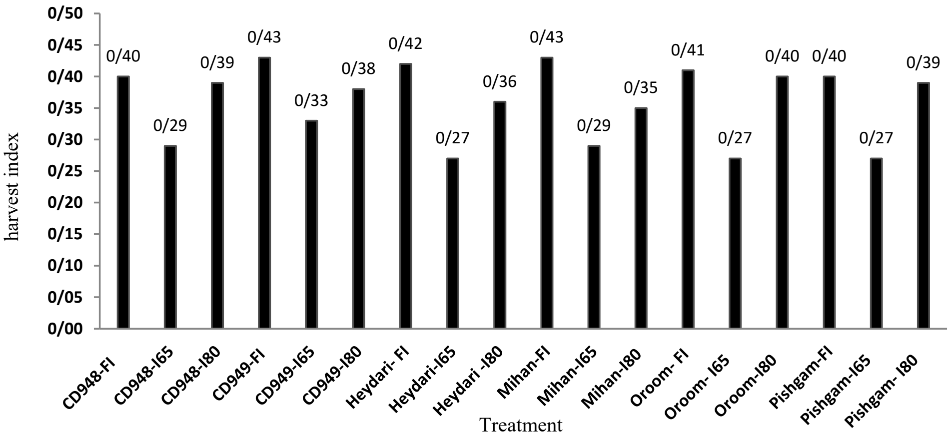

Fig 5. Interaction effect of irrigation levels and cultivar on harvesting index

to the I65 treatment (Table 7). The effect of cultivar on the weight of 1000 grains was significant at the level of 1% (Table 6). The lowest weight of 1000 grains (31.6 grams) were obtained from the Oroom cultivar and the highest weight of 1000 grains (34.48 grams) was obtained from the Pishgam (Table 7). Marc *et al*. (1985) reported that post-flowering drought stress reduced the number of endosperm cells at the base and apex of the spike and ultimately reduced the 1000 grain weight. The interaction effect of cultivar and irrigation levels on the weight of 1000 grains was significant at the 1% level (Table 6). Results of the mean comparison of the weight of 1,000 grains in different wheat cultivars for different irrigation levels showed that the Pishgam cultivar with FI irrigation management treatment had the maximum 1,000 grain weight (41.27 grams) and the Oroom cultivar with I65 irrigation level had the minimum 1,000 grain weight (35. 26 gr) (Figure 6). In general, as grain yield decreases, harvesting index and water use efficiency decrease.

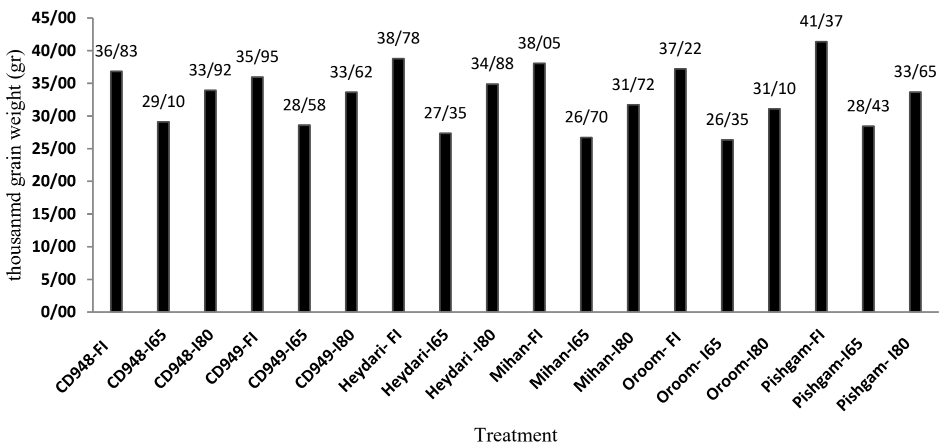

Fig 6. Interaction effect of irrigation levels and cultivar on thousand grain weight

Spike length

In general, the results of compound variance analysis (Table 6) showed that the effect of year on spike length was insignificant. The effect of irrigation levels on spike length was significant at the level of 1% (Table 6), so that by increasing the amount of irrigation water from 65% to 100%, spike length increased from 9.67 to 11.03 cm (Table 7). The effect of cultivar on spike length was significant at the 1% level (Table 6). The longest spike length was obtained from Oroom cultivar (11.30 cm) and the shortest spike length was obtained from Pishgam cultivar (0.9 cm) (Table 7). The interaction effect of the cultivar and irrigation levels on spike length was significant at the 1% level (Table 6). The results of mean comparison of spike length in wheat cultivars under different irrigation levels showed that the longest spike length in Oroom cultivar with FI treatment was 12.07 cm and the shortest spike length was 8.58 cm in Pishgam cultivar with I65 irrigation treatment (Fig 7).

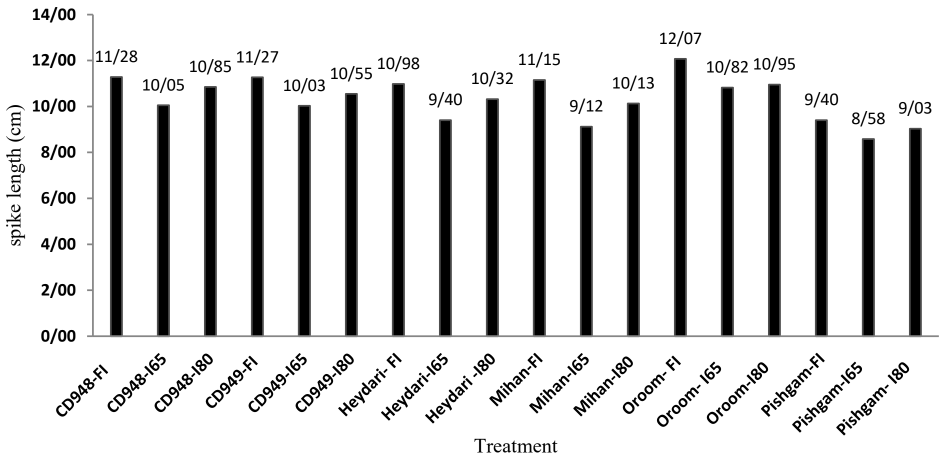

Fig 7. Interaction effect of irrigation levels and cultivar on spike length

Effect of drought stress management on water use efficiency and water productivity

The summary of the results of the compound variance analysis of the effect of cultivar and irrigation levels on the water use efficiency and water productivity in two years of research is presented in Table 7. The results of the analysis of the variance table (Table 8) showed that the effect of irrigation levels on the water use efficiency and water productivity was significant at the level of 1%. In general, the results of the mean comparison showed that the highest water use efficiency and water productivity were 1.85 and 1.64 kg per cubic meter, respectively, which were related to the FI irrigation management treatment, and the lowest water use efficiency and water productivity were 1.25 and 1.12 kg, respectively. per cubic meter in I65 (Table 9). Liu *et al*. (2016)

stated that with the increase in the intensity of drought stress, the water use efficiency for total dry matter and grain yield increases, so that mild stress creates a significant difference compared to the control treatment (no stress). The effect of cultivar on water use efficiency and water productivity was significant at the level of 1% (Table 8). The results of the mean comparison showed that the highest water use efficiency and water productivity were 1.80 and 1.60 kg/m^3, respectively, for Mihan (Table 9). The lowest water use efficiency and water productivity were 1.52 and 1.35 kg/m^3, respectively, in the CD-94-8 line (Table 9). The interaction effect of cultivar and irrigation levels on water use efficiency was significant at the level of 1% (Table 8). The mean comparison of water use efficiency in wheat cultivars under different irrigation levels showed the maximum water use efficiency in Mihan cultivar with FI treatment with 2.06 kg/m^3 and the lowest water use efficiency in Heydari cultivar with I65 treatment 1.13 kg/m^3 (Figure 8). The mean comparison of water productivity in two cultivars under different irrigation levels showed that the maximum water productivity in Mihan cultivar with FI treatment was 1.83 kg/m^3 and the lowest water productivity was obtained in Heydari cultivar with I_{65} treatment at 1.01 kg/m^3 (Fig. 9). In drip irrigation, because water is provided exactly according to the plant's needs and water efficiency is very high, it is recommended that all the water needed be provided for it and deficit irrigation is not recommended.

Table 8. Results of the combined analysis of variance of water use efficiency and water efficiency of wheat crop in two crop years

Source of variation	df	Mean of squares	
		Water Use Efficiency	Water efficiency
Year (y)	1	0.13^{ns}	0.11^{ns}
Error y	4	0.02	0.01
Levels of irrigation	2	4.13**	3.28**
Levels of irrigation× Year	2	0.12^{ns}	0.09^{ns}
Error a	8	0.001	0.001
Cultivar	5	0.21	0.16**
Cultivar× Year	5	0.03^{ns}	0.02^{ns}
Cultivar× Levels of irrigation	10	0.11**	0.09**
Year × Levels of irrigation× Cultivar	10	0.03^{ns}	0.02^{ns}
Error b	60	0.01	0.01
CV		5.41	5.45

ns, * and **: not significant, significant at 5% and 1% probability levels, respectively.

Table 9. Mean of water use efficiency and water efficiency in two crop years

Treatment		Water use efficiency (kg/m^3)	Water efficiency (kg/m^3)
Year	Year 1	1.67a	1.49 a
	Year 2	1.60 a	1.43 a
Levels of irrigation	FI	1.85a	1.64a
	I_{80}	1.83a	1.63a
	I_{65}	1.25b	1.12b
Cultivar	Mihan	1.80a	1.60a
	Oroom	1.61c	1.43b
	CD-94-8	1.52d	1.35d
	CD-94-9	1.54d	1.37d
	Heydari	1.68b	1.49b
	Pishgam	1.72b	1.53b

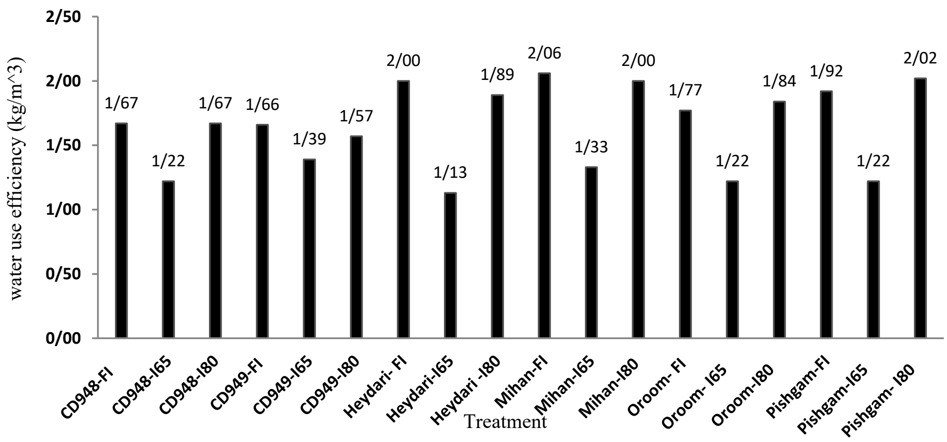

Fig 8. Interaction effect of cultivar and irrigation levels on wheat water use efficiency

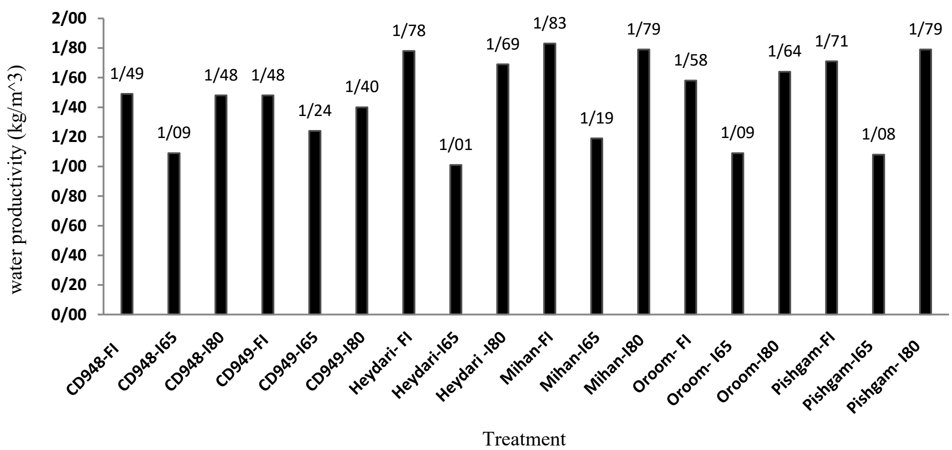

Fig 9. Interaction effect of irrigation levels and cultivar on wheat water productivity

Conclusion

To address the challenge of improving water use efficiency, it is essential to increase crop yield (the numerator of the efficiency index) while simultaneously reducing water used (the denominator). The effectiveness of measures aimed at enhancing water use efficiency is realized when these actions lead to simultaneous improvements—an increase in the numerator and a decrease in the denominator of the efficiency index. In other words, solving the problem of increasing water use efficiency requires a broader perspective that goes beyond focusing solely on the water sector. A special emphasis should also be placed on other areas, such as agriculture and plant nutrition. These findings support national development programs aiming to improve water use efficiency and food security under water-scarce conditions. To optimize water use and increase production per unit of water consumed, it is essential to adapt and using cultivars with high yield potential (cultivars used in the present study), including Mihan cultivar. Also, due to the limited water resources of the country and the need to plant wheat as an agricultural product that creates employment and provides food security and eradicates poverty in the world, it requires that the use of new technologies for the irrigation of this product be taken into consideration, and it seems that the drip tapes irrigation method and cultivars tested in this research, by reducing water used, is one of the ways to fight against water scarcity for the cultivation of this crop in arid and semi-arid regions of Iran.

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