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Water Productivity and Virtual Water of Barley Cultivars under Different Irrigation Regimes

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ABSTRACT

To remain viable in facing with increasing costs, farmers need to increase irrigation Water Productivity (WP) and save Virtual Water (VW). To evaluate the WP and VW for five barley cultivars (Reyhan, Nimrooz, Valfajr, Zehak, and Yusof) under different irrigation regimes [well-watered (100% Field Capacity; FC), mild water stress (75% FC), severe water stress (50% FC), and extremely severe water stress (25% FC)], a two-year field experiment was laid out in Darab, Fars Province, Iran, during 2014 and 2015 growing seasons. Results showed that change in moisture stress from well-watered to extremely severe water stress, was associated with a significant increase in WP and Economic Water Productivity (EWP) for straw and biological yield. A positive linear relationship was found between grain yield and VW, and the lowest VW was found in the range of 3,314 to 3,451 kg ha^{-1} of grain yield. Interestingly, for all irrigation regimes, Zehak and Yusof cultivars had greater WP for the grain yield. Furthermore, VW for biological yield of Yusof cultivar sharply decreased from 0.410 m^3 kg^{-1} in well-watered treatment to 0.164 m^3 kg^{-1} under extremely water stress conditions in both years. Comparison of Zehak and Yusof cultivars with Reyhan, Nimrooz and Valfajr showed that under water stress conditions, the first two cultivars showed significantly lower VW for the grain yield than the other cultivars. Indeed, Yusof and Zehak cultivars showed the lowest Economic Virtual Water (EVW), which was in the range of 0.054 to 0.091 m^3 1,000 Rials^{-1}, under extremely water stress conditions. Thus, to achieve optimum EWP and EVW and attaining stable yields under semi-arid conditions, suitable barley cultivars such as Zehak and Yusof could be irrigated with less water (i.e. 25 to 50% FC).

Keywords: Biological yield, Economic virtual water, Water productivity of grain yield, cv. Yusof, cv. Zehak.

INTRODUCTION

In Iran, agricultural sector, as the biggest water user, consumes about 90% of the total water withdrawal of the country (Mirzaei *et al.*, 2019; Barati *et al*., 2020), while 73% of lands in Iran are under arid and semi-arid conditions (Maghsoudi *et al.*, 2018). Therefore, agricultural production greatly depends on water resources and is significantly influenced by water scarcity (Emam and Bijanzadeh, 2012). Given this state of scarcity, climate change, long run drought, non-uniform rainfall distribution, and increasing demand for fresh-water by the growing population, economic development, urbanization, and industrial water use put additional pressure on the water resources (Allan, 1993; Bijanzadeh and Emam, 2012; Najafi Alamdarlo *et al.*, 2018).

Barley (*Hordeum vulgare* L.) is cultivated

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in arid and semiarid areas of the Middle East, such as Iran, with limited precipitations, especially under late season water stress conditions (Emam and Seghatoleslami, 2005). Therefore, Iranian agricultural sector faces a growing water resource scarcity and an access to the sufficient irrigation water is the major challenge for barley production (Bijanzadeh and Naderi, 2015).

These countries face water scarcity and any production policy or international trade pattern that could produce or export commodities with higher Water Productivity (WP) or lower Virtual Water (VW) might be attractive. On the other hand, importing goods that have high VW or a low WP can help to solve the water scarcity problems. Therefore, it is essential to measure the WP and VW for strategic agricultural products in these areas (Baghestani *et al.*, 2010; Alamdarlo *et al.*, 2018). Increasing the WP does not essentially lead to decreased water use or to higher farmers' income (Pereira *et al.*, 2012). On the other hand, the objective of most farmers is to achieve the maximum income and profit (Rodrigues and Pereira, 2009). Therefore, in some studies, Economic Water Productivity (EWP) is taken into consideration.

In 1990s, Allan by introducing the term Virtual Water (VW) aimed to consider water as an economic good (Allan, 1993 and 1994). Since producing each good or service needs water as the main input for production, water is one of the most essential and scarce inputs in the agricultural production, especially in arid and semi-arid areas. Furthermore, globally, more than 80% of water resources are being consumed in the agricultural sector (Brindha, 2017). The Virtual Water (VW) is an indicator of the crop water productivity and opposite of that. Hence, a high VW value shows a low water productivity, while the low VW value shows high water productivity (Zhao *et al.*, 2014). Estimating the VW content of a product must consider the place and period of production, the point of measurement, the production method, and associated efficiency of water use, as they influence the amount of water used in the production chain (Hoekstra, 2003).

There are two approaches for quantifying the VW, including the consumption based and the production based (Hoekstra, 2003). In consumption based approach, the quantity of saved water from importing the products is measured by VW (e.g. Alamdarlo *et al.*, 2018; Tian *et al.*, 2018; Chouchane *et al.*, 2018). However, in the second approach, the quantity of real water that is used in production of the commodity is measured. There are many factors including period of production, irrigation technology and production methods which influence the VW in the production based approach (Hoekstra, 2003) and it has a direct empirical basis (Chapagain and Hoekstra, 2003). Indeed, the VW for various products including agricultural products has been studied in many parts of the world. For instance, Zhang *et al.*, (2014) determined VW for rice in China. Tiwari *et al.* (2017) mapped the VW for rice and wheat in India. In addition, Darzi-Naftchali and Karandish (2017) measured the rice VW under different climatic scenarios in North of Iran. With respect to the important role of water for crop production in semi-arid areas and the point that more than 90% of water resources are consumed in agriculture, VW assessment in the field to reach sustainable development and optimize use of water resources in agriculture in necessary. On the other hand, VW evaluation could be a useful tool to save water resources and achieve water security in south of Iran (Ahmadali, 2013). In the present study, the second approach of VW is used for barely cultivars. The main contribution of this study is determination of the interaction effect of irrigation regime and cultivar on WP and VW of straw, biological yield and grain yield for barely cultivars. This is one of the few attempts that compare the results of WP and VW in two years. Also, this study introduces the Economic Virtual Water (EVW) for the first time. The results of this study could be helpful for agricultural planning to

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recommend the appropriate barely cultivar to the farmers who seek high WP and low VW.

MATERIALS AND METHODS

A 2-year field experiment was laid out to evaluate the Water Productivity (WP) and Virtual Water (VW) consumption for five barley cultivars under different irrigation regimes during two consecutive growing seasons of 2014 and 2015, in Darab region (28° 29′ N, 54° 55′ E), Fars Province, Iran. The soil type was loam (fine, loamy, carbonatic, hyperthermic, typic Torriorthents) with pH of 8.1 and 0.8% organic matter. The experimental design was a randomized complete block, and the treatments were arranged as split-plot, with three replicates. Four irrigation regimes were assigned to the main plots and five barley cultivars to sub plots. The physical and chemical properties of soil in experimental site is given in Table 1. Also, the weather data during 2014 and 2015 growing seasons are presented in Table 2. There were four levels of irrigation regimes including well-watered [soil moisture content in root depth kept at 100% Field Capacity (FC)], mild water stress (75% FC), severe water stress (50% FC), and extremely severe water stress (25% FC) as the main plot (Bijanzadeh and Emam, 2012). The soil water content was monitored in each plot by auger sampling and using the gravimetric method in 30 cm intervals down to depth of 120 cm. Irrigation regimes were started from booting stage [stage 40 of the Zadoks's Scale (ZGS); Zadoks *et al.,* (1974)] to the end of the growing season. The amount of water applied was measured using a time–volume technique (Grimes *et al.,* 1987). In this technique, irrigation water is applied by polyethylene pipes set in each plot and the time of each plot irrigation is calibrated by a timer and a standard container. Then, irrigation water amount of each plot

Table 1. Physical and chemical properties of soil in experimental site (data is average of 2014 and 2015).

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Organic carbon (%)	Nitrogen (%)	Phosphorus (mg kg^{-1})	Potassium (mg kg^{-1})	Electrical conductivity (dS m^{-1})	pH
0-15	38.12	44.70	17.18	0.91	0.083	50	301	1.091	7.4
15-30	38.16	44.58	17.26	0.89	0.081	56	298	1.088	7.1

Table 2. Climatic data of the experimental site during 2014 and 2015 growing seasons.

Month	Temperature (ºC)						Precipitation (mm)		Pan evaporation (mm)	
	2014			2015			2014	2015	2014	2015
	Min	Max	Mean	Min	Max	Mean				
November	8.6	25.1	15.3	11.9	24.4	18.2	0.5	71.3	221.4	235.7
December	5.6	20.3	12.9	5.1	20.1	12.6	34.7	2.2	176.0	203.7
January	3.9	19.1	11.5	4.4	19.2	11.8	99.5	86.4	150.0	168.5
February	5.7	20.9	13.3	8.6	21.4	15.0	0.2	0	175.1	190.3
March	6.8	20.3	13.5	10.5	25.4	17.9	30.9	0	202.2	242.1
April	13.2	27.3	20.1	12.9	29.8	21.3	22.3	47.8	271.0	313.5
May	17.6	34.7	26.1	17.9	34.4	26.2	5.8	0	303.6	316.8
Jun	16.8	38.9	27.8	22.4	39.7	31.1	0	0	310.1	343.2
July	17.1	40.9	29.1	17.3	42.7	30.0	0	0	350.8	383.7
August	21.9	39.2	30.5	21.8	39.8	30.8	0	0	299.2	336.9
September	18.1	30.1	24.1	19.2	31.3	25.3	0	0	264.9	310.3
October	16.2	27.8	22.0	16.8	27.9	22.4	0.3	0	244.9	280.9
Total							193.9	207.7	2969.3	3325.5

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(measured by gravimetric method) was converted to time (min) and the data was applied in analysis.

Five barley cultivars including Reyhan, Nimrooz, Valfajr, Zehak, and Yusof were assigned to subplots. Uniform barley seeds were hand-sown on 25 and 26 November in 2014 and 2015, respectively, in rows 30 cm apart, giving 250 plants m^{-2} in plots of 2×5 m. The field was fertilized based on soil test recommendations with 120 kg nitrogen ha^{-1} (as urea) and 60 kg phosphorus (as triple superphosphate). Half of nitrogen fertilizer was hand-broadcasted at planting, and the remaining was applied at the end of tillering. At physiological maturity, plants in the area of 1 m^2 from center rows of each plot were hand harvested on 5 June 2015 and 4 June 2016. The samples were oven-dried (72˚C for 48 hours) and straw weight, biological yield, and grain yield were measured.

Water Productivity and Economic Water Productivity

Mathematically, water productivity in agriculture and landscape irrigation is calculated by dividing actual crop yield by total consumptive water use of a crop, expressed in kg/m^3 (Rodrigues and Pereira, 2009; Araya *et al.*, 2011; Pereira *et al.*, 2012). The WP can be expressed by equation (1):

$$WP = \frac{Y_a}{IWU_{farm}} \quad (1)$$

Where, Y_a: Is the actual Yield of crop in kg, IWU_{farm}: Is Irrigation Water Used in m^3. The EWP might be expressed by the ratio between value of the agricultural product or gross income to the total irrigation water used, presented in monetary unit (e.g. Rials) to m^3 (Rodrigues and Pereira 2009; Araya *et al.*, 2011). One dollar (USD) is equal to 34500 and 36400 Rials in 2014 and 2015, respectively. The EWP was obtained using Equation (2):

$$EIWP = \frac{Value\ (Y_a)}{IWU_{farm}} \quad (2)$$

Where, *Value* (Y_a) is calculated by multiplying unit price of crop by the actual yield (kg):

$$Value(Y_a) = P.Y_a \quad (3)$$

Where, *P* is the unit Price of agricultural production (in Rials)

Virtual Water and Economic Virtual Water

The VW is the ratio between the irrigation water volume and achieved yield (Zhao *et al.*, 2014) that can be calculated by Equation (4):

$$VW = \frac{IWU_{farm}}{Y_a} \quad (4)$$

Where, VW is the Virtual Water content of a crop (m^3 kg^{-1})

Hoekstra and Chapagain (2007) presented the new index in VW concept. These researchers introduce average virtual water content per value added in the industrial sector. Also, Hokstra *et al*. (2009) believe that VW can be expressed in terms of m^3 to monetary unit (e.g. m3 US $\$^{-1}$) in industrial products. Accordingly, in this study, the new concept of VW is introduced for agricultural products as the EVW. The EVW is calculated by the ratio of the irrigation water applied to the value of the agricultural product in each year. The EVW is expressed in m^3 per monetary unit (e.g. Rials) and is calculated by equation (5).

$$EVW = \frac{IWU_{farm}}{Value(Y_a)} \quad (5)$$

Statistical Analysis

The data were subjected to analysis of variance using SAS software (Version 9.2). The means were separated using Fisher's LSD protected test at 5% probability level.

RESULTS

Climatic Description

The experimental farm of Darab has typically arid Mediterranean climate, which is characterized by long-term mean annual rainfall of 257.5 mm, mostly occurring in fall and winter seasons. Furthermore, its maximum summer air temperature is

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46.5°C. The annual rainfall for 2014 and 2015 were 193.9 and 207.7 mm, respectively (Table 2). These annual rainfall amounts were not only insufficient for normal plant growth but also not well distributed. Since climatic conditions of the two years were not similar, Total Water Use (TWU) was different between 2014 and 2015 growing seasons, depending on irrigation regimes and barley cultivars (Figure 1). Overall, for all irrigation regimes and barley cultivars, TWU in 2015 was greater than 2014, which might be attributed to higher mean temperature and evaporation, especially from February to April, in the second year. Indeed, evaporation in 2014 was 11% less than 2015 (Table 2).

Water Productivity (WP) and Economic Water Productivity (EWP)

By imposing water stress from well-watered (100% FC) to extremely severe water stress conditions (25% FC), the straw WP was increased significantly ($P \leq 0.05$) during 2014 and 2015 growing seasons (Table 3). In both years, the highest WP of straw was observed in Zehak and Yusof compared to other barley cultivars under extremely severe water stress, while under well-watered and mild water stress conditions no significant difference ($P \leq 0.05$) was observed among the barley cultivars. During 2014 and 2015 growing seasons, WP for biological yield was affected by interaction of irrigation regime and barley cultivars, such that in Yusof cultivar, WP of 2.527 and 2.442 kg m^{-3} under well-watered treatment reached 6.104 and 5.487 kg m^{-3} under extremely severe water stress, in 2014 and 2015, respectively (Table 3). In both years, in all barley cultivars, WP for grain yield was also affected by water stress level and in Zehak and Yusof cultivars, it increased significantly ($P \leq 0.05$) from well-watered to extremely severe water stress conditions (Figure 2). Interestingly, in each irrigation regime, Zehak and Yusof cultivars had greater WP for the grain yield in both growing seasons.

During 2014 and 2015, in well-watered and mild water stress conditions, no significant difference ($P \leq 0.05$) was observed among five barley cultivars for EWP of straw. On the other hand, by increasing water stress level from 50 to 25% FC, EWP of straw for Zehak and Yusof cultivars was increased significantly (Table 4). Results of both years showed that by decreasing water application from 50 to 25% FC, EWP for biological yield in all cultivars was increased sharply, however, the increased percentages for Zehak and Yusof was greater than those for Nimrooz, Valfajr and Reyhan cultivars (Table 4). Similar trend was obtained for the grain yield such that, in the second year, under extremely severe water stress conditions, Zahak and Yusof cultivars had the highest EWP for the grain yield, with 17.34 and 18.38 (1,000 Rial m^{-3}), respectively (Table 4). Overall, results showed that the values of WP and EWP for biological yield were more than that of straw as well as the grain yield in all barley cultivars and irrigation regimes during both years.

Virtual Water (VW) and Economic Virtual Water (EVW)

During both of the growing seasons, in well-watered condition, VW for straw ranged from 0.701 to 0.871 m^3 kg^{-1} and declined by increase in water stress: from 0.631 m^3 kg^{-1} under mild water stress to 0.283 m^3 kg^{-1} under extremely severe water stress conditions (Table 5). Yusof and Zehak cultivars had the lower virtual water for straw and the difference was significant with Reyhan under extremely severe water stress conditions. Similar trend was observed for VW of biological yield. In Yusof cultivar, VW for biological yield ranged from 0.410 m^3 kg^{-1} under 75% FC to 0.164 m^3 kg^{-1} under 25% FC treatment. In 2014, no significant difference in VW was observed

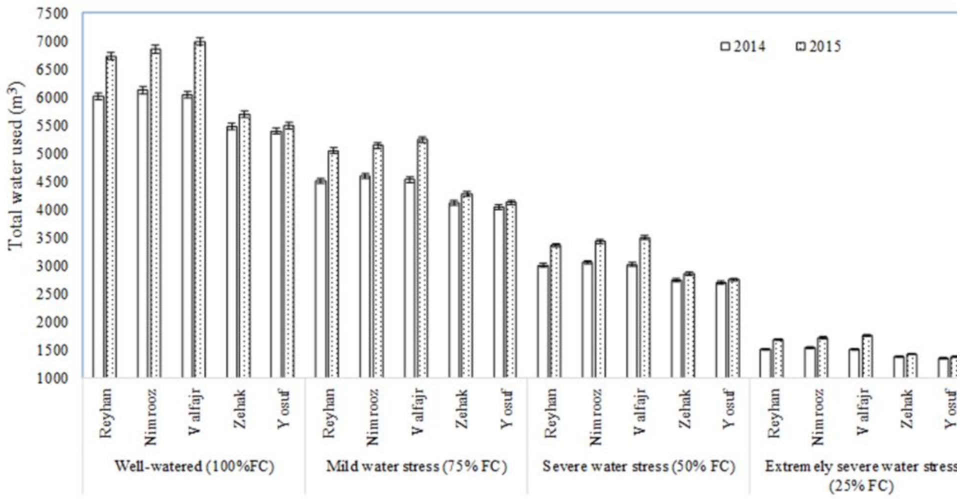

Figure 1. Total water used (m^3) in each irrigation regime and barley cultivar during 2014 and 2015 growing seasons. Vertical bar represent ±SE.

Table 3. Interaction effect of irrigation regime and cultivar on water productivity (kg m^{-3}) for straw and biological y of barley in 2014 and 2015 growing seasons.[a]

Irrigation regime (According to field capacity)	Barley cultivar	Water productivity (kg m^{-3})			
		Straw		Biological yield	
		2014	2015	2014	2015
Well–watered (100% FC)	Reyhan	1.427f	1.252h	2.426jk	2.144f
	Nimrooz	1.319f	1.149h	2.286k	1.998f
	Valfajr	1.337f	1.150h	2.351jk	2.007f
	Zehak	1.387f	1.334gh	2.518j	2.403e
	Yosuf	1.382f	1.348fgh	2.527j	2.442e
Mild water stress (75% FC)	Reyhan	1.801e	1.629e	3.044gh	2.683e
	Nimrooz	1.791e	1.568efg	2.996gh	2.567e
	Valfajr	1.808e	1.585ef	3.010ghi	2.560e
	Zehak	1.760e	1.734e	3.188g	3.086cd
	Yosuf	1.756e	1.712e	3.192g	3.095cd
Severe water stress (50% FC)	Reyhan	1.797e	1.703e	2.842i	2.665e
	Nimrooz	2.171d	1.796e	2.928h	2.714de
	Valfajr	2.033d	1.614 e	3.085gh	2.491e
	Zehak	2.219d	2.081d	3.831e	3.616b
	Yosuf	2.198d	2.111cd	3.877e	3.711b
Extremely severe water stress (25% FC)	Reyhan	2.066d	2.338bc	3.480 f	3.537b
	Nimrooz	2.643c	2.310bcd	4.024d	3.465bc
	Valfajr	2.979b	2.378b	4.514c	3.596b
	Zehak	3.359a	3.082a	5.781b	5.295a
	Yosuf	3.540a	3.141a	6.104a	5.487a

[a] Means followed by the same letter in each column are not significantly different at 5% probability using Fisher's Least Significant Difference (LSD) test.

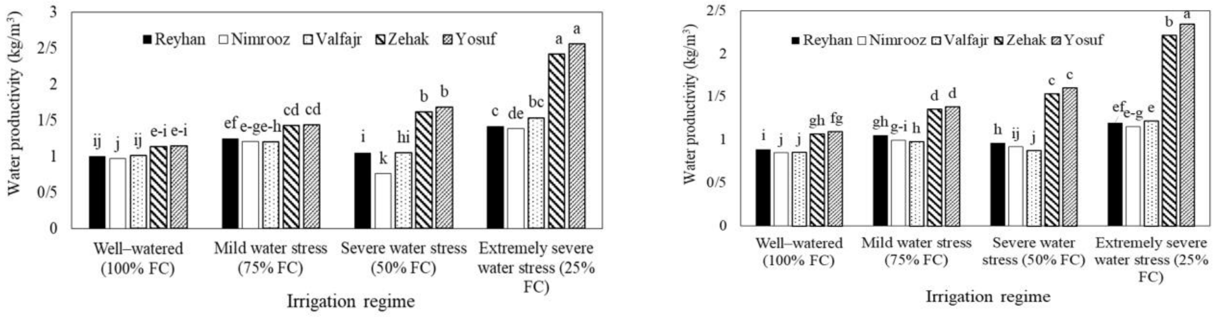

Figure 2. Interaction effect of irrigation regime and cultivar on water productivity (kg m^{-3}) for grain yield of barley in 2014 and 2015growing seasons. Columns with the same letter are not significantly different at 5% probability using Fisher's Least Significant Difference LSD) test.

Table 4. Interaction effect of irrigation regime and cultivar on economic water productivity (1000 Rials^{-1} m^{3}) for straw, biological yield, and grain yield of barley in 2014 and 2015 growing seasons. [a]

Irrigation regime (According to field capacity)	Barley cultivar	Economic water productivity (1000 Rials m^{-3})					
		Straw		Biological yield		Grain yield	
		2014	2015	2014	2015	2014	**2015**
Well–watered (100% FC)	Reyhan	2.28e	2.58f	6.78g	9.53fg	4.50e	6.96f
	Nimrooz	2.11e	2.37f	6.46g	8.99g	4.35ef	6.62f
	Valfajr	2.14e	2.37f	6.70g	9.05fg	4.56d	6.68f
	Zehak	2.22e	2.75f	7.31fg	11.08ef	5.42d	7.79def
	Yosuf	2.21e	2.78f	7.36fg	11.31ef	5.15d	8.53def
Mild water stress (75% FC)	Reyhan	2.88d	3.36de	8.47e	11.58e	6.43c	10.55bcd
	Nimrooz	2.87d	3.23e	8.29e	11.02ef	6.46c	10.79bc
	Valfajr	2.89d	3.26e	8.30e	10.87efg	5.59d	8.23def
	Zehak	2.82d	3.57de	9.24de	14.12d	5.09d	8.34def
	Yosuf	2.81d	3.53de	9.27de	14.32cd	4.76d	6.87f
Severe water stress (50% FC)	Reyhan	2.88d	3.51de	7.60f	11.05ef	4.72d	7.54def
	Nimrooz	3.47c	3.70d	6.89fg	10.89efg	3.42f	7.19ef
	Valfajr	3.25cd	3.33de	8.01ef	10.20efg	5.41d	7.61def
	Zehak	3.55c	4.29c	10.84bc	16.32bc	7.29b	12.03b
	Yosuf	3.52c	4.35c	11.11b	16.88b	7.59b	12.53b
Extremely severe water stress (25% FC)	Reyhan	3.31c	4.82b	9.70cd	14.21d	6.39cd	9.39cd
	Nimrooz	4.23b	4.76b	10.47bc	13.81d	6.24c	9.05cde
	Valfajr	4.77b	4.90b	11.70b	14.44cd	6.94bc	9.54cd
	Zehak	5.37a	6.35a	16.32a	23.69a	10.95a	17.34a
	Yosuf	5.66a	6.47a	17.25a	24.85a	11.59a	18.38a

[a] Means followed by the same letter in each column are not significantly different at 5% probability using Fisher's Least Significant Difference (LSD) test.

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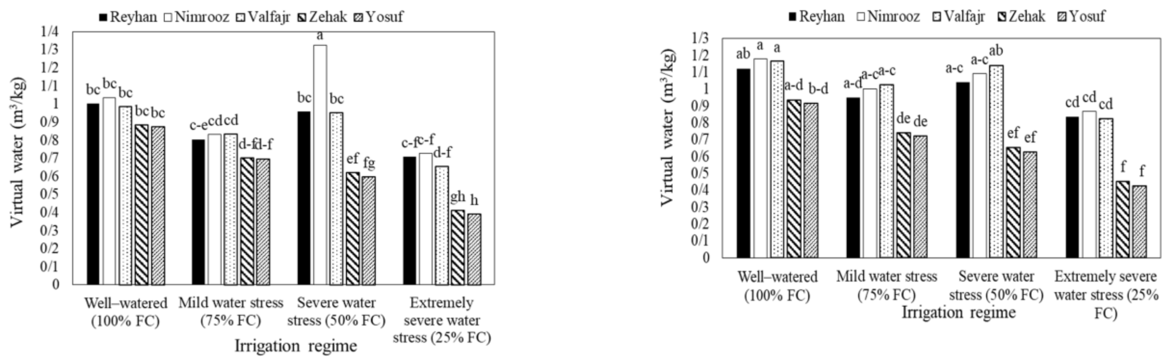
Table 5. Interaction effect of irrigation regime and cultivar on virtual water ($m^3 kg^{-1}$) for straw and biological y of barley in 2014 and 2015 growing seasons.[a]

Irrigation regime (according to field capacity)	Barley cultivar	Virtual Water ($m^3 kg^{-1}$) Straw 2014	Straw 2015	Biological yield 2014	Biological yield 2015
Well–watered (100% FC)	Reyhan	0.701a	0.799ab	0.412ab	0.467ab
	Nimrooz	0.758a	0.871a	0.437a	0.500a
	Valfajr	0.748a	0.870a	0.425ab	0.498ab
	Zehak	0.721a	0.750bc	0.397abc	0.416abc
	Yosuf	0.724a	0.742bc	0.396abc	0.410ab
Mild water stress (75% FC)	Reyhan	0.555b	0.614 d	0.328bcd	0.373bcd
	Nimrooz	0.558b	0.638d	0.334bcd	0.390bc
	Valfajr	0.553b	0.631cd	0.332bcd	0.391bc
	Zehak	0.568b	0.577de	0.314cde	0.324cde
	Yosuf	0.570b	0.584d	0.313cde	0.323cde
Severe water stress (50% FC)	Reyhan	0.557b	0.428g	0.352bcd	0.375bc
	Nimrooz	0.461b	0.433g	0.342bcd	0.369bc
	Valfajr	0.492b	0.421gh	0.324bcd	0.401a
	Zehak	0.451b	0.325hi	0.261def	0.277def
	Yosuf	0.455b	0.319i	0.258def	0.270ef
Extremely severe water stress (25% FC)	Reyhan	0.485b	0.587d	0.287de	0.283de
	Nimrooz	0.379c	0.557def	0.249def	0.289de
	Valfajr	0.336c	0.620d	0.222def	0.278def
	Zehak	0.298c	0.481efg	0.173f	0.189f
	Yosuf	0.283c	0.474efg	0.164f	0.182f

[a] Means followed by the same letter in each column are not significantly different at 5% probability using Fisher's Least Significant Difference (LSD) test.



2014 2015

Figure 3. Interaction effect of irrigation regime and cultivar on virtual water ($m^3 kg^{-1}$) for grain yield of barley in 2014 and 2015 growing seasons. Columns with the same letter are not significantly different at 5% probability using Fisher's Least Significant Difference (LSD) test.

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among five barley cultivars for the grain yield under well-watered and mild water stress conditions (Figure 3). Interestingly, the highest VW for the grain yield was obtained in Nimrooz (1.326 m^3 kg^{-1}) under 25% FC. Zehak and Yusof cultivars had significantly ($P \leq 0.05$) lower VW for the grain yield in both years. Results showed that by increasing water stress, EVW for straw was increased significantly and the highest EVW was obtained in Zehak and Yusof under 25% FC conditions in 2014 and 2015 (Table 6). Likewise, in all cultivars, going from well-watered to extremely severe water stress conditions, EVW for biological yield decreased sharply, especially in Zehak and Yusof cultivars (Table 6). Similar trend was observed in EVW for the grain yield, such that under extremely severe water stress conditions, Yusof and Zehak had the lowest EVW in the range of 0.054 to 0.091 (m^3 1,000 $Rials^{-1}$) in both years, respectively (Table 6).

Relationship between Grain Yield with WP and VW

Grain yield decreased linearly and negatively by increasing WP, such that the higher grain yields from 6,003 to 6,187 kg ha^{-1} resulted in WP in the range of 0.99 to 1.13 kg m^{-3} (Figure 4a). In contrast, a positive linear relationship was observed between grain yield and VW and the lower

Table 6. Interaction effect of irrigation regime and cultivar on economic virtual water (m^3 1000 $Rials^{-1}$) for straw, biological yield, and grain yield of barley in 2014 and 2015 growing seasons.[a]

Irrigation regime (According to field capacity)	Barley cultivar	Economic virtual water (m^3 1000 $Rials^{-1}$)					
		Straw		Biological yield		Grain yield	
		2014	2015	2014	2015	2014	2015
Well–watered (100% FC)	Reyhan	0.438b	0.388b	0.147a	0.105ab	0.222bc	0.144a
	Nimrooz	0.474a	0.423a	0.155a	0.111a	0.230b	0.151a
	Valfajr	0.468a	0.422a	0.149a	0.110a	0.219bc	0.150a
	Zehak	0.451a	0.364c	0.137bc	0.090cd	0.197bcd	0.120ef
	Yosuf	0.452a	0.360c	0.136bc	0.088cd	0.194bcd	0.117ef
Mild water stress (75% FC)	Reyhan	0.347c	0.298ef	0.118ef	0.086d	0.179cdef	0.122de
	Nimrooz	0.349c	0.310e	0.121ef	0.091cd	0.185bcde	0.128d
	Valfajr	0.346c	0.306e	0.120ef	0.092cd	0.185bcde	0.131cd
	Zehak	0.355c	0.280fg	0.108g	0.071e	0.156def	0.095i
	Yosuf	0.356c	0.284fg	0.108g	0.070e	0.155def	0.093i
Severe water stress (50% FC)	Reyhan	0.303d	0.208j	0.132cd	0.091cd	0.212bc	0.133cd
	Nimrooz	0.237f	0.210ij	0.145ab	0.092cd	0.293a	0.139bc
	Valfajr	0.210g	0.204j	0.125de	0.098bc	0.211bc	0.146ab
	Zehak	0.186h	0.158k	0.092i	0.061f	0.137ef	0.083j
	Yosuf	0.177h	0.155k	0.090i	0.059f	0.132f	0.080j
Extremely severe water stress (25% FC)	Reyhan	0.348c	0.285fg	0.103gh	0.070e	0.157def	0.107g
	Nimrooz	0.288e	0.270g	0.096hi	0.072e	0.161def	0.111fg
	Valfajr	0.308d	0.301e	0.085i	0.069e	0.145ef	0.105h
	Zehak	0.282e	0.233h	0.061j	0.042g	0.091g	0.058k
	Yosuf	0.284e	0.230hi	0.058j	0.040g	0.086g	0.054k

[a] Means followed by the same letter in each column are not significantly different at 5% probability using Fisher's Least Significant Difference (LSD) test.

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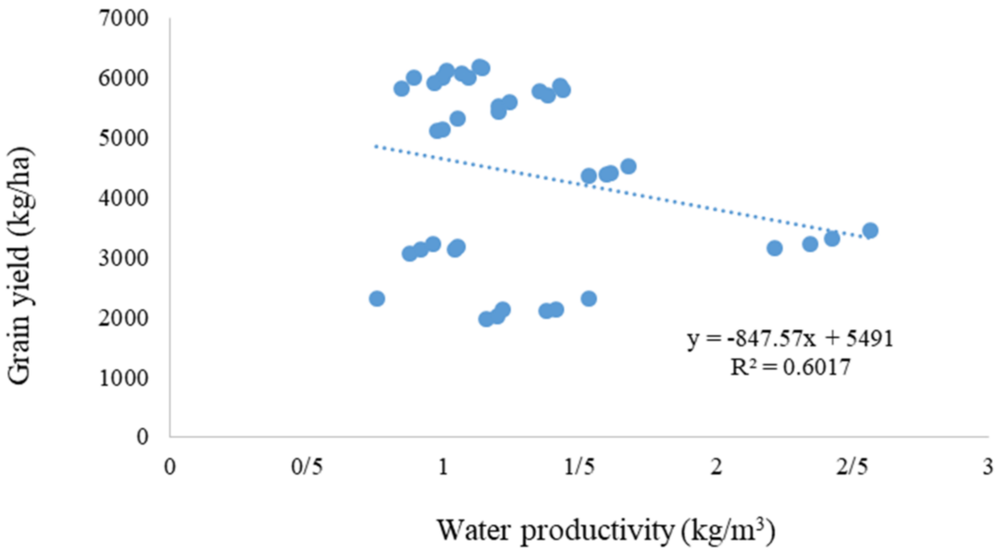
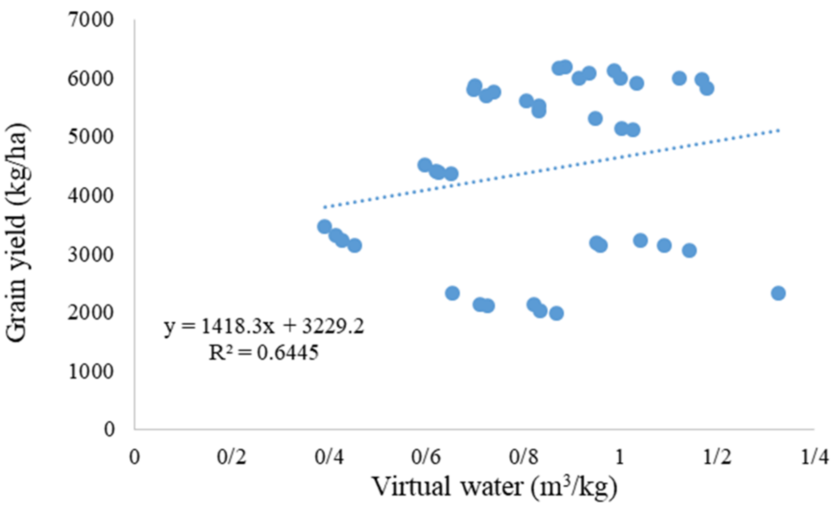


(a)



(b)

Figure 4. Relationship between (a) grain yield and water productivity, (b) grain yield and virtual water, for barley in 2014 and 2015 growing seasons.

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VW were obtained in the range of 3,314 to 3,451 kg ha^{-1} grain yield (Figure 4-b).

DISCUSSION

Increasing Water Productivity (WP) may be the best way to achieve efficient water use (Rodrigues and Pereira, 2009). In agreement with our results, Prieto and Angueira (1999) declared that mild water stress during yield formation did not affect the final yield, but reduced vegetative growth and thus improved WP. In China, Jin *et al.* (1999) reported that application of manure led to higher production and straw mulching improved soil water and soil temperature conditions, consequently, WP for the experiment with straw mulching was 2.67 kg m^{-3}. In a case study in 142 locations in the world, Zwart and Bastiaanssen (2004) declared that the range of WP for the grain yield in irrigated wheat was as large as 0.6 to 1.7 kg m^{-3}. Alizadeh Dizaj and Ebrahimian (2017) reported that the highest amount of WP for rainfed wheat (0.61 kg m^{-3}) and barley 0.44 kg $m^{-3}$was obtained in supplementary irrigation treatment in Urmia dryland conditions. They found that the EWP values were 4.580 and 8.052 1000 Rials m^{-3} for wheat and barley, respectively. In our study, WP for the grain yield depended on interaction of irrigation regime and cultivar type and was in the range of 0.757 to 2.564 kg m^{-3} (Figure 2). In addition, EWP was affected by interaction of irrigation regime and cultivar type and ranged from 4.35 to 18.38 1000 Rials m^{-3} (Table 4). In accordance with Tadayon *et al.* (2012) study, variation in WP and EWP were affected by TWU (Figure 1), barley cultivar, irrigation regime, as well as climatic conditions during the years of the study (Table 2).

In a case study on wheat in Fars Province of Iran, Rojhani Shirazi *et al.* (2016) reported that VW during 2013 was in the range of 2 to 6 m^3 kg^{-1} for irrigated wheat and 2 to 14 m^3 kg^{-1} for dry land, while standard VW for irrigated wheat has been reported to be 1 m^3 kg^{-1} in the world. In addition, they declared that in Darab region, VW for irrigated wheat was between 3.9 to 4.2 m^3 kg^{-1}. Zare Abiane *et al.* (2015) reported that the mean water demands for alfalfa, potato, and sugar beet were 6232 m^3 ha^{-1} and mean VW for these crops was less than 0.46 m^3 kg^{-1}, while mean water demand for wheat and barley was less than 5,900 m^3 ha^{-1}, however, mean VW was 3.53 m^3 kg^{-1}. Likewise, Baghestani *et al.* (2010) reported that the lower grain and biological yield in dry land farming of wheat and barley increased the amount of VW, compared to irrigated potato and sugar beet. Rohani *et al.* (2008) stated that barley and wheat had higher VW ($\geq$ 1) compared to potato, garlic and sugar beet ($\leq$ 0.5). Our results showed that VW for grain yield depended on irrigation regime and cultivar and was in the range of 0.391 to 1.326 m^3 kg^{-1} (Figure 3).

Our findings are in agreement with those of Zwart and Bastiaanssen (2007) who in a case study reported a negative relationship between grain yield and WP for the wheat crop. In addition, similar to our results, Rohani *et al.* (2008) reported a linear and positive relationship between grain yield and VW for barley and wheat crops. Maximum WP will often not coincide with farmers' interests, whose aim is to maximize land productivity or economic profitability. It requires a shift in irrigation science, irrigation water management and basin water allocation to move away from 'maximum irrigation-maximum yield' strategies to 'less irrigation-maximum EWP and minimum EVW' policies.

CONCLUSIONS

It is concluded that water stress during different growth stages affects WP and VW of straw, biological yield, and grain yield of barley cultivars differently depending on cultivar type, irrigation regime level, and TWU. The results of WP and VW of barley cultivars were not similar for straw, biological yield, and grain yield in different irrigation regimes. Generally, water stress in late season was found to improve EWP and reduce EVW, especially in suitable barely cultivars such as Zehak and Yusof. Based on the results, to achieve optimum WP and VW in areas facing water shortage, it is wise to irrigate barley drought tolerant cultivars such as Zehak and Yusof with less irrigation water (50 to 25% FC) to attain stable yields.

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بهره وری آب وآب مجازی ارقام جو در رژیم های متفاوت آبیاری

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چکیده

کشاورزان برای بقاء در مواجهه با افزایش هزینه‌ها نیازمند افزایش بهره‌وری آب و ذخیره آب مجازی می‌باشند. به منظور ارزیابی بهره وری آب و آب مجازی پنج رقم جو (ریحان، نیمروز، والفجر، زهک و یوسف) در شرایط رژیم های متفاوت رطوبتی شامل آبیاری مطلوب (۱۰۰ درصد ظرفیت مزرعه)، تنش آبی ملایم (۷۵ درصد ظرفیت مزرعه)، تنش آبی شدید (۵۰ درصد ظرفیت مزرعه) و تنش آبی خیلی شدید (۲۵درصد ظرفیت مزرعه)، آزمایشی دو ساله و مزرعه ای در جنوب ایران در طول فصول رشد ۱۳۹۵و ۱۳۹۶ در منطقه داراب استان فارس اجرا شد. نتایج نشان داد تغییرات در تنش آبی از آبیاری مطلوب تا تنش آبی خیلی شدید به طور معنی داری با افزایش بهره وری آب و بهره وری آب اقتصادی برای کاه و عملکرد زیست توده همراه است. یک رابطه مثبت خطی و معنی داری بین عملکرد دانه و آب مجازی یافت شد و کمترین میزان آب مجازی در دامنه عملکرد بین ۳۳۱۴ و ۳۴۵۱ کیلوگرم در هکتار مشاهده گردید. جالب آن که برای همه رژیم های رطوبتی ارقام زهک و یوسف دارای بیشترین بهره وری آب برای عملکرد دانه بودند. علاوه بر این در هر دو سال آب مجازی برای عملکرد زیست توده رقم یوسف به سرعت از ۰/۴۱۰ متر مکعب در کیلوگرم در آبیاری مطلوب به ۰/۱۶۴ متر مکعب در کیلوگرم در تنش خیلی شدید کاهش یافت. مقایسه ارقام زهک و یوسف با ریحان، نیمروز و والفجر نشان داد که در شرایط تنش آبی، دو رقم اول به طور معنی داری دارای میزان آب مجازی کمتری نسبت به سایر ارقام بودند. در حقیقت ارقام یوسف و زهک کمترین میزان آب مجازی اقتصادی را در دامنه ای از ۰/۰۵۴ تا ۰/۰۹۱ متر مکعب در هر هزار ریال نشان دادند. می توان توصیه کرد که برای رسیدن به بهینه بهره وری آب اقتصادی و آب مجازی اقتصادی و بدست آوردن عملکرد پایدار در شرایط نیمه خشک، ارقام مناسبی از جو مانند زهک و یوسف می توانند با مقدار آب کمتری (۲۵ تا ۵۰ درصد ظرفیت مزرعه) آبیاری شوند.

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