RESEARCH ARTICLE

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Effect of irrigation scheduling on some characteristics of Barley under water deficit conditions

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ABSTRACT
A field experiment was conducted during 2016-2017 to investigate the effect of irrigation scheduling on three barley cultivars (viz Nosrat, Roudasht and Behrokh) under water deficit stress conditions. Irrigation treatment was applied based on the maximum allowable depletion of available soil water. Treatment levels comprised of irrigation scheduled at: (I1) 30%; (I2) 60%; and (I3) 90% depletion of available soil water which was applied after flowering stage. Studied traits included: plant height, shoot fresh weight, shoot dry weight, the number of spikes per plant, the number of grains per spike, 1000-grain weight, awn length, harvest index, biological yield, grain yield, and total protein content of grain. Results showed that all traits were significantly reduced with an increase in the severity of stress due to a reduction in the availability of water. However, no significant reduction was observed for cultivar Nosrat regarding grain yield, biological yield and the number of spikes per plant between I2 and I3 treatment levels. Estimation of production functions with respect to yield contributing traits revealed that, at a severe drought stress, the order of the importance of yield-contributing traits was as: harvest index>biomass>spikes per plant>grains per spike. Based on the results, to achieve the highest grain yield and grain total protein content, irrigation should be scheduled at a maximum allowable depletion equal to 30% of available soil water. Nevertheless, an economic production can be achieved with a delayed irrigation.

Key words: drought stress, grain yield, production function, standardized regression

Introduction

Barley is the second most important cereal after wheat which has a significant cultivation area in Iran. According to its relative resistance to water shortage, this plant is generally cultivated in semi-arid regions with scarce, irregular and variable rainfall. However, the occurrence of drought stress during reproductive stage has an adverse impact on its yield (S Nezar H, 2005).

Irrigation scheduling generally determines the time and the amount of water needs to be applied for the next event. Such a method of irrigation leads to attaining the best crop yield at a limited water condition (TA Howell, Meron M, 2007). The goal is to achieve an economic production with the limited use of water. For this purpose, identifying the response of the plant under cultivation to different amounts of water shortage is a prerequisite for an optimal irrigation scheduling. Such research studies have recently been carried out on some plants such as: Jatropha (A Kumar et al., 2017); pomegranate (R Marathe, Babu KD, 2017); sunflower (C Patanè et al., 2017); strawberries (RG Perea et al., 2017) and wheat (H Verma et al., 2017).

In this study, we evaluated the response of barley to irrigation scheduling at different severities of drought stress during the reproductive stage.

Materials and Methods

Field experiment was carried out at the Medicinal Plant Research Center of Shahed University (longitude 51° 20' 22.46" E, latitude 35° 33' 13.96" N, Altitude 1190 m) in 2016-17. The Average annual temperature and rainfall of the experimental field were 17.1° C and 216 mm, respectively. Physicochemical properties of the soil of the site have been presented in Table 1. Seeds were sown on November 20, 2016. Twenty-seven experimental plots of 3×2 m were used. Each plot consisted of 6 rows 3 m in length and 50 cm apart. Seeds were sown on the rows at a distance of 25 cm apart at a depth of 1-2 cm.

Table 1. *Physicochemical properties of the soil of the experimental field.*

Salinity	PH	organic carbon	total nitrogen %	available phosphorus (ppm)	available potassium (ppm)	permanent wilting point %	Field capacity %	sand	Silt %	Clay %	Texture %
2	7.59	0.972	0.1	20	583.2	8	13.9	57	23	20	Sandy loam

The study was conducted on three barley cultivars viz. Rodasht (a mutant line); Behrokh and Nosrat. Plots were arranged in the form of a split-plot experiment based on a complete randomized block statistical design with 3 replications. The main-plots included irrigation treatment levels and barley cultivars were assigned to sub-plots.

Irrigation treatment levels

The irrigation treatments consisted of irrigation scheduling based on maximum allowable depletion of available soil water criteria as:

I1: maximum allowable depletion equal to30% of available soil water (low stress)

I2: maximum allowable depletion equal to 60% of available soil water (moderate stress)

I3: maximum allowable depletion equal to 90% of available soil water (severe stress)

No water stress was applied during the vegetative growth stage.

Irrigation scheduling

The available soil water was calculated as the difference between root zone water storage at field capacity and permanent wilting point. For estimating water storage, the effective root zone of barley crop was considered as 30 cm, regardless of growth stages.

Soil moisture content was measured by the oven drying method. For this purpose, soil samples were taken from the effective root depths (0-30 cm). Samples were immediately weighed and transferred to the oven at 105 ° C to determine the moisture content. This procedure was performed on a daily basis to reach the predefined moisture content of each treatment. The percentage depletion of available soil water in the effective root zone was estimated by the equation proposed by Martin et al. (1990),

$$\text{Depletion } (\%) = 100\frac{FC-\theta}{FC-WP} \quad (1)$$

where FC; is the soil moisture at field capacity, θ; is the soil moisture and WP is the soil moisture at permanent wilting point. The amount of water applied after the attainment of predefined MAD was calculated as:

$$V_d = \frac{MAD(FC-WP)R_zA}{100} \quad (2)$$

Where Vd is the volume of irrigation water (m3), Rz the effective rooting depth (m), A the surface area of the plot (m2). The surface area of each plot was 6 m2 while the effective root zone depth was taken at 30 cm in all treatments. Irrigation water was applied as soon as the depletion of available soil water reached to the predefined level.

Studied traits

Studied traits included: plant height (PH), shoot fresh weight (FW), shoot dry weight (DW), the number of spikes per plant (SPP), the number of grains per spike (GPS), 1000-grain weight (TGW), awn length (AL), harvest index (HI), biological yield (BY), grain yield (GY) and total protein content of grain (PCG). The traits were measured on 5 plants selected randomly from each plot. To determine the grain yield, an area equal to one square meter was harvested from each experimental plot and the total amount of grain was weighted and turned into tons per hectare. To estimate PCG, the nitrogen content of grain was firstly measured at the Nuclear Science and Technology Research Center, Nuclear Agriculture Research Center, Karaj, Iran, by Kjeldahl method (SS Nielsen, 2017). Afterward, the total protein content of grain was calculated by multiplying the nitrogen content of grain by 6.25.

Statistical analysis

Data analysis was done using SAS software version 9.0, 2002, SAS Institute Inc., Cary, NC, USA. Mean comparison using Duncan's multi-range test. Graphs were drawn in the Microsoft Excel software environment version 2013.

Results

Yield and Yield related traits

Measured yield and some yield-related traits for different levels of irrigation have been presented in Figure 1. The results show that, there was a significant decrease in the traits when the irrigation was scheduled at a maximum allowable depletion (MAD) equal to 90% of available soil water (ASW).

This trend was observed for each of the three studied cultivars. As shown in Figure 1, at all levels of stress, Nosrat cultivar had higher values of the traits compared to those observed for the two other cultivars. However, the maximum values of the traits were obtained under a MAD equal to 30% of ASW. At the MAD of 90%, Roudhasht showed the lowest

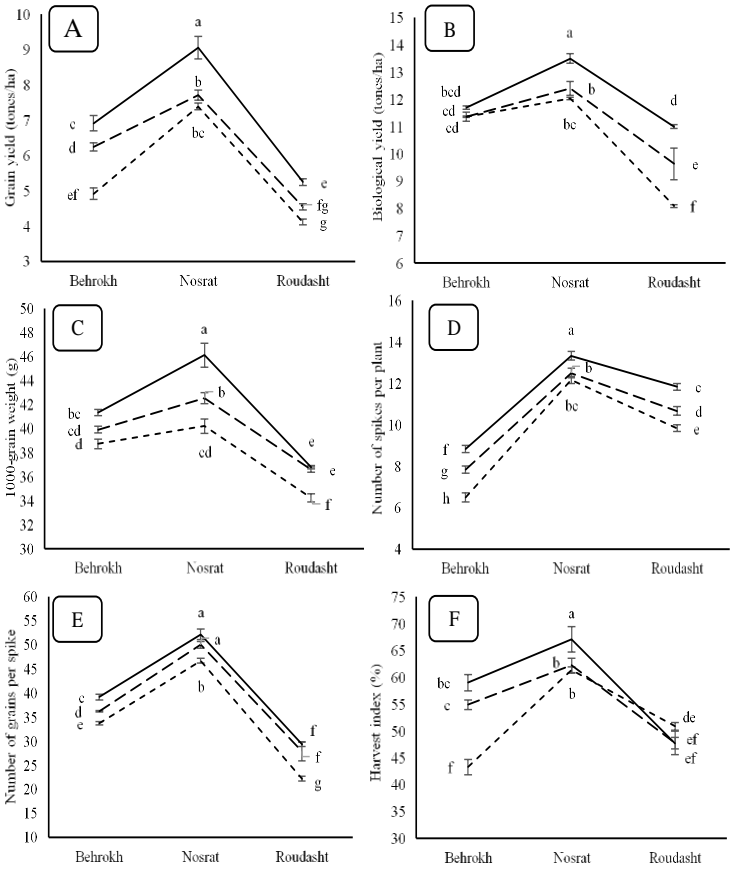

Figure 1. *Measured yield and yield related traits of barley cultivars under different irrigation levels including: irrigation at a maximum allowable depletion equal to 30 (solid line), 60 (long dash line) and 90% (dotted line) of available soil water.*

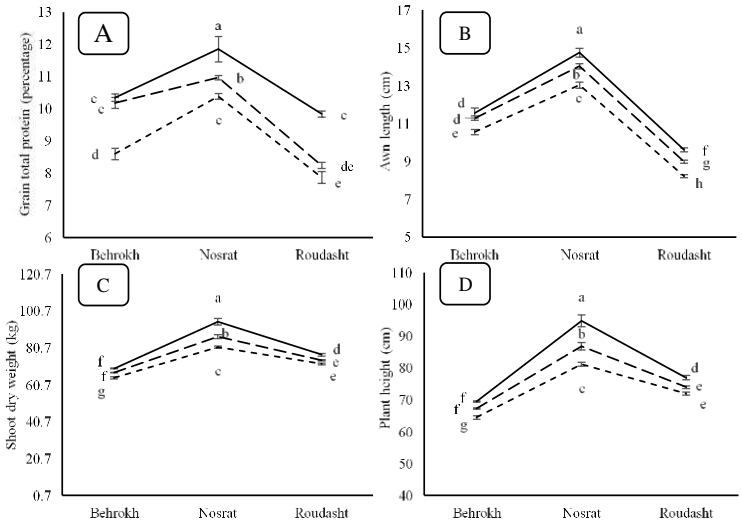

Figure 2. *Measured traits of barley cultivars under different irrigation levels including:irrigation at a maximum allowable depletion equal to 30 (solid line), 60 (long dash line) and 90% (dotted line) of available soil water.*

values for traits: GY, BY, TGW and GPS while, Behrokh had the lowest values for SPP and HI. No significant difference was observed between low and moderate drought stress levels for GPS in Nosrat cultivar (Figure 1E). Likewise, for Roudasht cultivar, the TGW obtained at the MAD equal to 30% of ASW was not significantly different from that found at the MAD of 60% (Fig .1C). Moreover, no significant difference was observed between moderate and severe stress for GY, BY, SPP and HI.

Awn length and total protein content of grain

Figure 2 shows the values of awn length and total protein content of grain measured at the different levels of irrigation. With increase in stress severity, the PCG and AL values were considerably reduced. Like other measured traits, cultivar Nosrat had the highest values of PCG and AL at all irrigation treatments. Also, the lowest values of these traits belonged to cultivar Roudasht.

Production function

Measured values of studied traits comprising PH, TGW, SPP, GPS, AL, FW, DW and HI obtained under different scheduling of irrigations were used for the development of production function. For all the treatments, the measured traits were included in a stepwise linear regression procedure as independent variables against GY as dependent variable.

The resulting regression relationships are presented as equations 3a-3c. The relationships between the grain yield and other studied yield-related traits were found to be:

$$GY\ (MAD = 30\%\ of\ ASW) = -5.13 + 0.02GPS + 0.11HI + 4.17\ DW \quad (3a)$$

$$GY\ (MD = 60\%\ of\ ASW) = -4.42 + 0.48AL + 0.16TGW - 0.016PH \quad (3b)$$

$$GY\ (MAD = 90\%\ of\ ASW) = -8.20 + 0.13HI + 6.68DW + 0.03SPP - 0.02\ GPS \quad (3c)$$

where: the GY denotes barley grain yield in tones/ha and the MAD, ASW, GPS, HI, DW, AL, GW and SPP are as defined earlier in materials and method section. The adjusted coefficient of determinations (AdjR2) for the three equations were found to be 0.999, 0.985 and 0.999, respectively showing that the studied traits were generally responsible for more than 98% of the variation in the GY. The difference between the regression models as well as the coefficients for each of the traits entered in the models indicated that, the relationships between the traits were affected by different levels of drought stress. Calculation of standardized regression coefficients showed that, at a low drought stress, the order of the importance of the yield-contributing traits was as HI>DW>GPS. As the drought severity increased to a moderate stress, the order of the importance of the yield-contributors was changed to AL>TGW>PH. Furthermore, at a severe drought stress, the order of the traits was as HI>DW>SPP>GPS. These equations can be used to estimate barley grain yield at the different severity of drought stress under similar agro-climatic conditions.

Discussion

The phenomenon of global warming caused by climate change can increase environmental stresses on crop production in many parts of the world (DB Lobell et al., 2011). On the other hand, the prevailing weather of Iran is an arid and semi-arid climate with an average annual precipitation of 250 mm which is less than one third of global average precipitation (M Bannayan et al., 2010). Therefore, water scarcity in many areas is a major cause of reduced crop yield. Under such conditions, managing irrigation and exploring ways to save irrigation water is of great importance.

According to the results of this study, the GY obtained for Nosrat and Roudasht cultivars exposed to a MAD of 60% were slightly lower than those obtained with MAD of 30%. However, this difference was not statistically significant. In fact, the significant decrease occurred when the severity of drought increased to a MAD of 90%. Thus, for the two mentioned cultivars, deficit irrigation means reduction of irrigation water without a significant effect on grain yield. Hence, under conditions of water shortage, the irrigation of the two cultivars can be reduced up to a MAD of 60% after flowering stage. However, such irrigation regime cannot be recommended for cultivar Behrokh whose performance decreased significantly with increase in the drought stress severity. The same trend was observed for the total protein content of the seed.

In small grain cereals like barley, the number of spikes per plant, grains per spike and 1000-grain weight are of most important yield contributing traits (S Afshari-Behbahanizadeh et al., 2016). Given that our estimated production function equations confirmed this, the study of these traits under water deficit conditions would be important. Results of the present study revealed that the GPS obtained for Nosrat and Roudasht cultivars exposed to a MAD of 30% was not statistically different than those obtained with MAD of 60%. This means that irrigation scheduling at a MAD equal to 60% would be adequate to gain an economic GPS.

Previous studies have revealed that the additive gene action was the main type controlling inheritance of yield and yield contributing traits in barley under water stressed conditions (E Moustafa, 2014). Therefore, the Nosrat cultivar has a good potential for utilization in plant breeding programs aimed at improving barley grain yield under drought stress conditions.

Conclusion

Results of our study suggested that the Nosrat cultivar could produce the best grain yield as well as grain protein content under a mild stress level as compared to the two other cultivars. Moreover, at a moderate to severe stress levels, the mentioned cultivar had a relatively better situation and produced an acceptable GY and PCG. Furthermore, to achieve the highest GY and PCG, irrigation should be scheduled at a maximum allowable depletion equal to 30% of available soil water. Nevertheless, an economic production can be achieved even with an irrigation scheduled at a MAD of 60% to 90%.

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