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ORIGINAL PAPER

Strategies to increase barley production and water use efficiency by combining deficit irrigation and nitrogen fertilizer

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Abstract

Iran imported around 1.3 million tons of barley in 2017. Accordingly, conducting researches under low organic matter soils and limited water resources is important to enhance barley products and improve economic conditions. Field experiments were performed to evaluate the effect of different levels of irrigation water (0, 50, 75 and 100% of crop water requirement as main plot) and nitrogen fertilizer (0, 70, 140 and 210 kg ha^{-1}; as subplot) on barley (Reyhane 0–3 cv.) growth, agronomic indices and water and nitrogen use efficiency. The results revealed that the barley grain yield dropped by lowering applied water, as the grain yield in 50% irrigation water was around 44% of full irrigation, in both years. Increasing the nitrogen fertilizer to 140 kg ha^{-1} significantly increased grain yield, while no significant difference was detected between grain yield of 140 kg ha^{-1} and the highest nitrogen application rate. The maximum water use efficiency was obtained at 75% of full irrigation showing that application of full irrigation did not agronomically increased the grain yield. Nitrogen use efficiency increased by applying more water, while application of nitrogen more than 140 kg ha^{-1} reduced the nitrogen use efficiency. Furthermore, nitrogen harvest index of 75% indicated that Reyhane 0–3 barley cultivar had the ability to accumulate higher portion of applied N in grain than in straw. Application of 25% deficit irrigation with 140 kg ha^{-1} nitrogen fertilizer is suggested to obtain the maximum barley production and water use efficiency under semi-arid conditions.

Introduction

Agricultural crop productions need to be increased by 60–110% worldwide by 2050, due to predicted increases in the human population and its diet (Ray et al. 2013). Cereals, due to high essential calories and protein content for human's diets, are among the most extensively agricultural crops grown worldwide (Lafiandra et al. 2014). Barley (*Hordeum vulgare* L.) is a major cereal grain, whose cultivation area and production ranked fourth in the world following wheat, rice, and maize (Baik and Ullrich 2008). Barley is grown annually on 46.9 million hectares in the world producing 141.3 million tons (FAO 2017). Barley is typically cultivated in arid and semi-arid regions for pasture and grain production (Talame et al. 2007; Oueslati et al. 2005), where drought is a limiting factor for agricultural production. Cereal production has been reduced by 10% globally under drought conditions (Lesk et al. 2016) due to its adverse effects on plant growth, physiology, and yield production (Farooq et al. 2014). Groundwater in semi-arid regions, as a valuable resource for irrigation during drought, is continuously declining due to low rainfall, high evaporation, and over-application of irrigation water (Balugani et al. 2017). Thus, finding an appropriate solution to enhancing crop production through using less water is of utmost importance for water resources management in semi-arid regions (Oweis et al. 2004).

Deficit irrigation involves applying less water with almost minimum yield reduction, which hence increases the water use efficiency (Geerts and Raes 2009). Under deficit irrigation condition, the total soil water potential declines (Ayers and Westcot 1985) followed by water absorption reduction by plants, which thus reduces the crop growth, negatively affects the stomatal conductance and photosynthesis rate, and finally reduces the crop yield (Chaves et al. 2010; Farouk and Amany 2012). In barley, drought during the grain-filling stage lowered the grain yield by reducing grain weight and number of grains per ear (Andersen et al. 1992). Similarly, González et al. (2007) studied the effect of terminal soil

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moisture stress on 12 genotypes of barley in Spain and showed that drought accelerated leaf senescence, reduced grain-filling period, and lowered the mean grain weight and, as a consequence, decreased grain yield. In another study, Samarah (2005) showed that drought stress treatments (60% field capacity and 20% field capacity) curtailed the barley grain yield through reduction in the number of tillers, spikes, grains per plant and grain weight, and finally suggested not to apply drought stress at the post-anthesis stage.

Nitrogen (N) is the key limiting nutrient for most crops as well as many aquatic and terrestrial ecosystems (Good and Beatty 2011), where inappropriate application of nitrogen resulted in environmental pollution (Udvardi et al. 2015). Worldwide N fertilizer application was 112.5 million tons in 2015 and is predicted to be around 118.2 million tonnes in 2019 (Sharma and Bali 2017). Regardless of large amounts of consumed global N fertilizers, the nitrogen efficiency is very low, varying between 25 and 50% of applied nitrogen (Chien et al. 2016). Due to over-application of N and its adverse on the environment, determining the optimum level of nitrogen under different climate conditions is important.

The interaction effects of nitrogen against sowing date (Reddy et al. 2018; Pankaj et al. 2016), mulch (Hingonia et al. 2016) and irrigation water (Naghdyzadegan Jahromi et al. 2020; Kumar et al. 2019; Kouzegaran et al. 2015; Cossani et al. 2012, 2010; Albrizio et al. 2010; Lopes et al. 2004) were investigated in various studies whose results showed the importance of these variables on barley growth and production. In this regard, Ghasemi-Aghbolaghi and Sepaskhah (2018) conducted a research to investigate the effect of different nitrogen levels (0, 90, and 180 kg ha^{-1}), different methods of partial root-zone drying irrigation, and two sowing dates on barley. They found that the maximum water productivity as well as water use efficiency was observed in variable alternate furrow irrigation with in-furrow sowing and nitrogen application of 180 kg ha^{-1}. In another study, Kouzegaran et al. (2015) studied the effect of irrigation water (full irrigation and irrigation withdrawal at flowering, at grain-setting and at both flowering and grain-setting) and nitrogen fertilizer (0, 75, 150 and 225 kg ha^{-1}) on barley (cv. Karoun in Kavir). They recommended applying 150 kg N ha^{-1} and full irrigation to produce barley in regions with climates similar to Birjand. Given low rainfall events and drought occurrence in arid as well as semi-arid regions, such as Iran and lack of soil organic matters (Mesgaran et al. 2017), the current study aimed to explore the effect of lowering applied irrigation water and nitrogen fertilizer on barley grain protein content and yield (Reyhane 0–3 cv.) in a semi-arid region.

Materials and methods

A 2-year field experiment (2013–2014 and 2014–2015) was performed at the experimental research station of Agricultural School, Shiraz University, I.R. Iran (52º 32' E, 29º 36' N and 1810 m a.m.s.l.). The mean daily air temperature and daily air relative humidity changed from − 9 °C to 24.5 °C (− 1.7 to 22.2 °C) and 24.5–78% (15.5–79%) in the 1st (2nd) year, respectively. The amounts of rainfall during the growing season were 259 and 222 mm in the 1st and 2nd years, respectively. Physical and chemical soil characteristics in the study site are provided in Table 1.

Irrigation water (I) treatments (0%, 50%, 75%, and 100% of crop water requirement; named as $I_{0\%}$, $I_{50\%}$, $I_{75\%,}$ and $I_{100\%}$, respectively) and nitrogen fertilizer (N) treatments (0, 70, 140, and 210 kg ha^{-1}; named as N_0, N_{70}, $N_{140,}$ and N_{210}, respectively) were arranged in a factorial experiment with split-plot design. The main plot and subplot were irrigation water and nitrogen fertilizer treatment, respectively, where three replications were considered for each treatment (Fig. 1). Irrigation water of $I_{0\%}$ (0% of full irrigation (100% of crop water requirement)) was considered due to the climate condition of the study region and farmers interest to cultivate this crop under rainfed conditions. Reyhane 0–3 cultivar of barley was sown at the rate of 150 kg ha^{-1}. The seeds were located manually at 4 cm depth beneath the soil surface in 10.5 m^2 plots (3 × 3.5 m^2) with 20 cm row spacing in November 2013 and October 2014. Prior to sowing, 150 kg ha^{-1} phosphorus fertilizer (in the form of triple superphosphate) was applied to soil in both years.

After sowing, the treatments of $I_{50\%}$, $I_{75\%,}$ and $I_{100\%}$ were irrigated with 100 mm (irrigation water depth) to ensure full crop establishment. Application of irrigation water treatments was initiated in 133 and 140 days after sowing (DAS) in the 1st and 2nd year, respectively. Before each irrigation, the crop water requirement ($ETc = ET_0 \times K_c$, mm day^{-1}) was calculated. Reference crop evapotranspiration (ET_0, mm day^{-1}) was estimated using meteorological data

Table 1 Physical and chemical properties of the experimental site soil

	Soil depth				
Properties	0–10	10–30	30–60	60–90	90–120
θ_{FC} (cm^3 cm^{-3})	0.30	0.32	0.33	0.33	0.33
θ_{PWP} (cm^3 cm^{-3})	0.16	0.16	0.19	0.19	0.19
ρ_b (g cm^{-3})	1.3	1.43	1.43	1.43	1.43
Clay (%)	35	31	39	34	29
Silt (%)	55	57	51	50	53
Sand (%)	10	12	10	16	18
Soil texture	Loam silty clay				
EC (dS m^{-1})	0.65	0.63	0.6	0.57	0.53

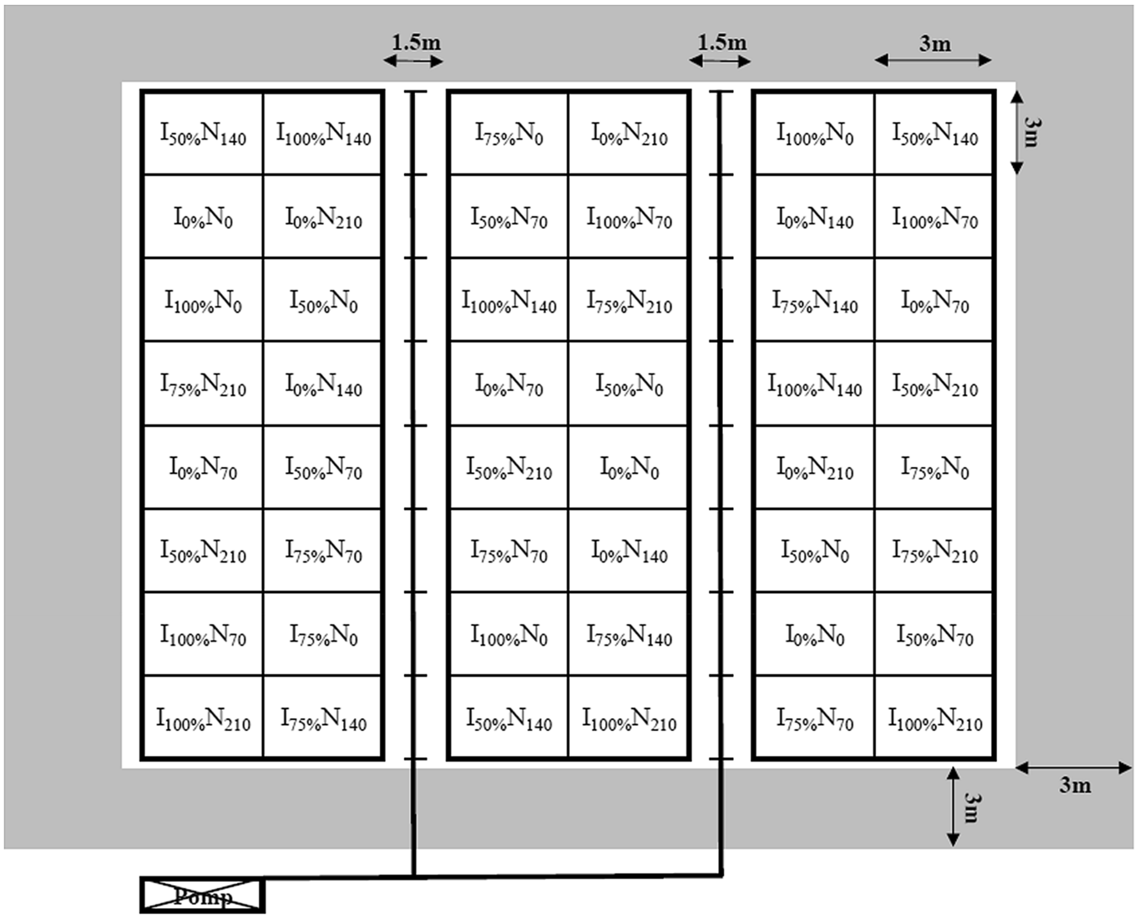


Fig. 1 Schematic of experimental design. The grey color indicates the border area. $I_{0\%}$, $I_{50\%}$, $I_{75\%,}$ and $I_{100\%}$ denote 0%, 50%, 75%, and 100% of crop water requirement, respectively, and N_0, N_{70}, $N_{140,}$ and N_{210} represent 0, 70, 140, and 210 kg N ha^{-1}, respectively

of synoptic weather station located close to the experimental field and the modified FAO–Penman–Montieth equation (Razzaghi and Sepaskhah, 2012). The single crop coefficients (K_c) for initial, mid-, and late-season stages were estimated as 0.61, 1.16, and 0.22, respectively (Allen et al. 1998). The Kc values were adjusted according to the climatic conditions of the study region (Allen et al. 1998). The full irrigation treatment ($I_{100\%}$) received 100% of ETc at each irrigation and the irrigation water was applied by considering the plot area and volumetric counter in surface irrigation system. The volume of irrigation water for $I_{75\%}$ and $I_{50\%}$ was then calculated and applied based on 75% and 50% of the volume of $I_{100\%}$, respectively. Irrigation frequency was 10 days and irrigation efficiency was considered as 100% according to the following reasons: (1) water was transferred by pipe to each plot (without wasting water to the farm and plot), (2) size of the plots was small (10.5 square meters), (3) no cracks and crevices were observed on the soil surface, and 4) the depth of irrigation was less than or equal to the crop standard evapotranspiration. Two additional irrigation water in the 2nd year were applied on 52 (40 mm) and 80 (50 mm) DAS, due to higher air temperature. The total amount of irrigation water in $I_{100\%,}$ $I_{75\%,}$ and $I_{50\%}$ treatments were 442 (534), 331.5 (400.5), and 221 (267) mm in the 1st (2nd) year, respectively. The amounts of irrigation water, rainfall, soil water content and readily available water (RAW) in root zone are shown in Fig. 2. The RAW (mm) was calculated as follows:

$$\text{RAW} = p \times \text{TAW}, \tag{1}$$

where TAW is total available water (mm) and p is fraction of TAW which can be depleted from the root zone before water stress and calculated as follows:

$$\text{TAW} = \left(\theta_{FC\_}\theta_{PWP}\right) \times \text{RD}, \tag{2}$$

$$P = 0.55 + 0.04 \times \left(5 - ET_c\right), \tag{3}$$

where θ_{FC} and θ_{PWP} are the water content at field capacity and wilting point (m^3 m^{-3}), respectively, RD is root depth (mm), and ET_c is crop evapotranspiration (mm d^{-1}).

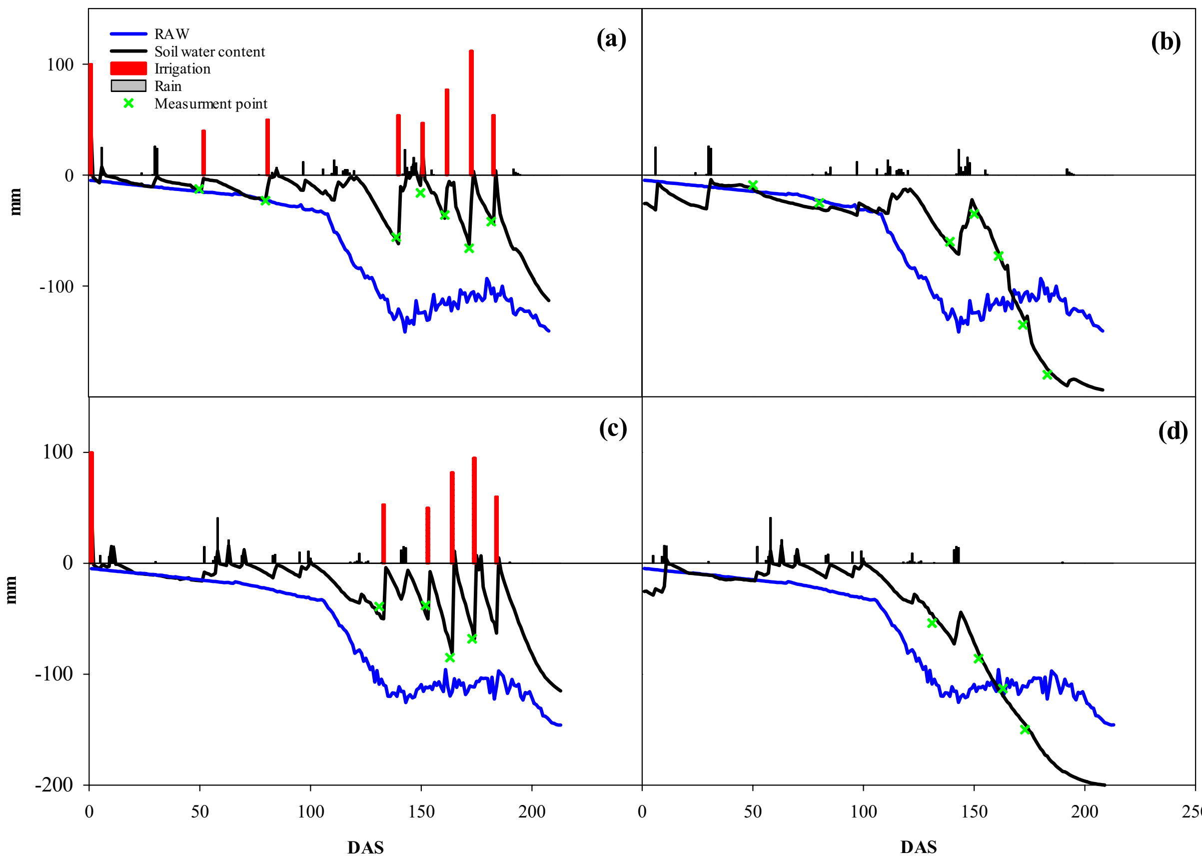


Fig. 2 Soil water content, readily available water (RAW), rainfall and irrigation in $I_{100}N_{210}$ (**a**: second year and **c**: first year) and I_0N_{210} (**b**: second year and **d**: first year). ** $I_{0\%}$ and $I_{100\%}$ denote 0%, and 100% of crop water requirement, respectively, and N_{210} represents 210 kg N ha^{-1}, respectively

Thirty percent of nitrogen fertilizer treatment in the form of urea (46% N) was applied after sowing in both years and 70% of nitrogen fertilizer was applied on 6th of March 2014 (120 DAS) and 2nd of March 2015 (127 DAS) upon the initiation of the rapid growth of barley in spring. The nitrogen fertilizers (urea) were weighed according to nitrogen treatments and were then distributed manually on the soil before the irrigation. The soil residual nitrogen content (before sowing determined by the Kjeldahl method (Bremner 1965)) was 38 and 23 kg NO_3 ha^{-1} in the 1st and 2nd years of the experiment, respectively.

Measurements and calculations

Barley's phenological stages were recorded by regular observations during the growing season, where the results were calculated based on the days after sowing. For this purpose, four important stages of the barley plant growth period (initial, development, mid-season, late season stages) were recorded when 50% of plants reached that stage (Allen et al. 1998).

The plant height (H, m) was measured at harvest in the 1st (2nd) year. The grain yield (GY, Mg ha^{-1}), straw yield (SY, Mg ha^{-1}), dry matter (DM, Mg ha^{-1}), 1000 grain weight (1000-GW, g), grain numbers per spike (GPS, $spike^{-1}$), spike number per unit area (SN, m^{-2}), and grain (GP, %) and straw (SP, %) protein content at harvest were measured in 2 m^2 at the middle of each plot to prevent border effects. The straw yield and grain yield were dried in an oven (80 °C). The protein content of dried grain and straw was calculated through multiplying nitrogen content by 5.7 (Lopez-Bellido et al. 2004). The nitrogen content of grain and straw was determined by the Kjeldahl method (Bremner 1965) at harvest.

The water use efficiency of grain yield (WUE_{GY}, kg m^{-3}) and aboveground dry matter (WUE_{DM}, kg m^{-3}) were calculated as follows:

$$WUE_{GY} = \frac{GY}{10 \times ETa}, \quad (4)$$

$$WUE_{DM} = \frac{DM}{10 \times ETa}, \quad (5)$$

where GY and DM are the grain yield and aboveground dry matter (kg ha^{-1}), respectively, the number 10 is conversion factor and ETa is actual evapotranspiration (mm), which was estimated using the soil water balance method (Ram et al. 2013) as follows:

$$ETa = R + I + \Delta W - \mathrm{RO} - D + \mathrm{CR}, \quad (6)$$

where R, I, ΔW, RO, D, and CR are precipitation, irrigation depth, soil moisture change between sowing and harvesting, surface runoff, deep percolation, and capillary rise (mm), respectively. Surface runoff (RO) was not observed during barley growth. In addition, as the amount of soil moisture at the sowing and harvesting was almost the same, ΔW has been neglected in calculating the total evapotranspiration. In addition, the capillary rise was neglected as the depth of groundwater table was deep (50 m). Furthermore, the irrigation water could minimize deep percolation. In this regard, irrigation was applied when root zone soil water content in full-irrigation treatment (I_{100}) reduced about 50% of the available soil water content, and the amount of applied irrigation water was considered to refill the root zone depth to field capacity without any deep percolation. Deep percolation was also assumed as negligible for the irrigation treatments of $I_{75\%}$ and $I_{50\%}$ as they received a lower amount of irrigation water compared to $I_{100\%}$

Thus, Eq. (3) was reduced to Eq. (4) as follows:

$$ETa = R + I, \quad (7)$$

Nitrogen use efficiency (NUE, kg kg^{-1}) was calculated as follows:

$$\mathrm{NUE} = \frac{GY_x - GY_c}{N_x - N_c}, \quad (8)$$

where GY_x and GY_c are the grain yield (kg ha^{-1}) in different nitrogen treatments and control (N_0), respectively. N_x and N_c are the amounts of applied nitrogen in different nitrogen treatments (kg ha^{-1}) and control, respectively.

The ratio of grain nitrogen uptake (GNU, kg ha^{-1}) to aboveground biomass nitrogen uptake (TNU, kg ha^{-1}) was defined as nitrogen harvest index (NHI) as follows:

$$\mathrm{NHI} = \frac{\mathrm{GNU}}{\mathrm{TNU}}. \quad (9)$$

The analysis of barley growth stage was calculated based on growing degree days (GDD) as follows:

$$\mathrm{GDD} = \sum_{0}^{n} T_a - T_b, \quad (10)$$

where T_a is the daily average air temperature (°C), T_b denotes the base temperature (°C) assumed as 3.5 °C for barley (Eshraghi-Nejad et al. 2015) and n is the number of days. If T_a was lower than T_b, it was taken as T_b and if it was greater than upper threshold temperature (T_u, assumed as 30 °C for barley), it was taken equal to T_u (Tribouillois et al. 2016).

Statistical analysis

The PROC GLM of SAS (SAS Institute Inc. 2007) was used for statistical analyses. All data satisfied the normality and homogeneity of variance tests. The interaction effects between irrigation and nitrogen treatments were evaluated using analysis of variance test. The means were compared using Duncan's Multiple Range Test (DMRT) at the 5% level of probability. The results of 2 years for different traits were considered separately in the analysis as the effect of year was significant on the measured traits.

Results and discussion

Crop development stages

Durations of barley seeding emergence, vegetation, anthesis, maturity, and harvest stage in 2013–2014 and 2014–2015 are shown in Fig. 3. Duration of growing season were 213 and 208 days in first and second years, respectively, for all irrigation treatments except $I_{0\%}$. Rainfed treatments ($I_{0\%}$) harvested sooner (18 and 21 days in first and second years, respectively) than other irrigated treatments due to lower soil moisture content. Furthermore, seeding emergence period took longer for $I_{0\%}$, as it did not receive initial irrigation in both years. Similarly, Cakir (2004) reported that the length of the growth period in rain-fed treatment was shorter than in irrigated treatments. Applying nitrogen fertilizer increased the duration of the vegetation stage at all irrigation levels (except in $I_{50\%}N_{210}$ in the 2nd year). Similarly, Shafi et al. (2011) indicated that application of nitrogen (0, 20, 40, 60, 80, and 100 kg ha^{-1}) did not significantly affect the days to emergence; however, nitrogen levels had a significant influence on days to anthesis (Kernich and Halloran 1996).

Crop height

The results of the analysis of variance indicated that the crop height was influenced significantly by applied irrigation water and nitrogen (Table 2). The maximum crop height of 103 and 107 cm was obtained in $I_{100\%}$ treatment on 213 and 208 DAS (at harvest) in the 1st and 2nd years, respectively. At harvest, the maximum crop heights of $I_{100\%}$, $I_{75\%}$, and $I_{50\%}$ treatments were 2.46 (2.36), 1.77 (2.33), and 2.15 (1.67) times, respectively, more than that obtained in $I_{0\%}$ treatment in the 1st (2nd) year. In addition, due to the shorter duration of the growing season in $I_{0\%}$ treatment (Fig. 3), the maximum crop height was observed earlier

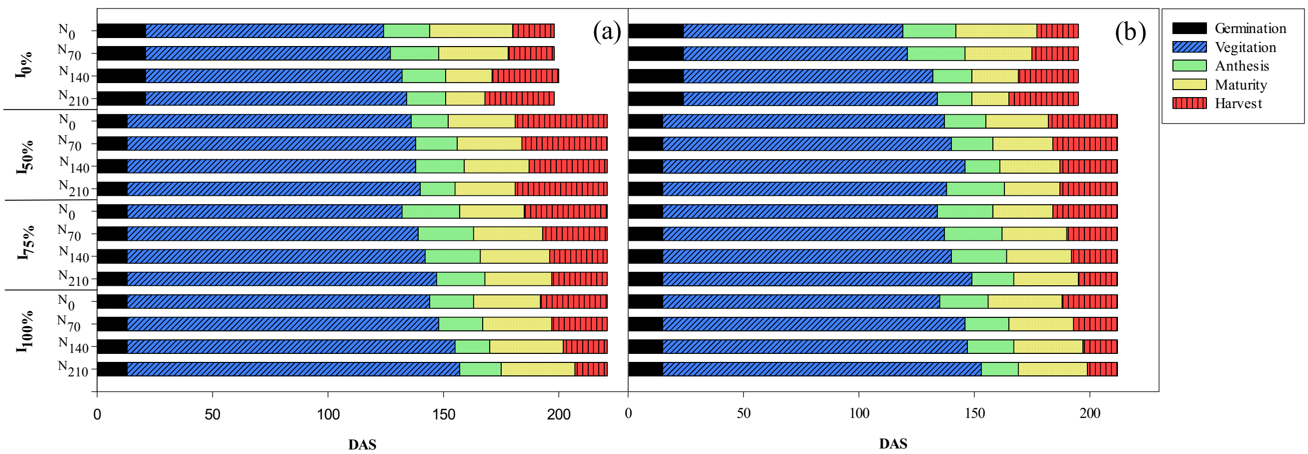


Fig. 3 Duration of seeding emergence, vegetation, anthesis, maturity stages, and harvest time of barley under different treatments of irrigation water and nitrogen treatments in 2013–2014 (**a**) and 2014–2015 (**b**) growing season. $I_{0\%}$, $I_{50\%}$, $I_{75\%}$, and $I_{100\%}$ denote 0%, 50%, 75%, and 100% of crop water requirement, respectively, and N_0, N_{70}, N_{140}, and N_{210} represent 0, 70, 140, and 210 kg N ha^{-1}, respectively

Table 2 Main and interaction effects of different irrigation water and nitrogen treatments on barley height (*H*, cm) on 213 DAS and 208 DAS in 2013–2014 and 2014–2015, respectively

Irrigation level	Nitrogen application rate (kg ha^{-1})				
	N_0**	N_{70}	N_{140}	N_{210}	Mean
	2013–2014				
$I_{0\%}$**	43.59 ± 2.84 ^{g*}	53.65 ± 4.18 ^{f}	37.56 ± 3.06 ^{gh}	33.42 ± 2.70 ^{h}	41.92 ± 2.56 $^{\gamma}$
$I_{50\%}$	68.13 ± 5.48 ^{e}	69.61 ± 5.57 ^{e}	68.24 ± 5.51 ^{e}	90.51 ± 6.22 ^{dc}	74.12 ± 5.83 $^{\beta}$
$I_{75\%}$	92.98 ± 5.50 ^{dc}	96.93 ± 5.46 ^{bcd}	102.87 ± 5.92 ^{b}	103.03 ± 6.01 ^{b}	98.95 ± 5.75 $^{\alpha}$
$I_{100\%}$	87.79 ± 4.24 ^{d}	97.42 ± 5.57 ^{bc}	114.46 ± 6.02 ^{a}	112.26 ± 5.67 ^{a}	102.98 ± 5.43 $^{\alpha}$
Mean	75.81 ± 4.98 ^{C}	79.40 ± 5.31 ^{BC}	80.78 ± 5.02 ^{B}	84.81 ± 6.38 ^{A}	
Year	Year < 0.001				
I	$P < 0.001$				
N	$P < 0.01$				
I*N	$P < 0.001$				
	2014–2015				
$I_{0\%}$	38.84 ± 2.10 ^{i}	49.46 ± 3.79 ^{h}	44.37 ± 2.16 ^{ih}	50.31 ± 1.33 ^{h}	45.75 ± 2.45 $^{\delta}$
$I_{50\%}$	70.98 ± 2.12 ^{g}	77.65 ± 1.73 ^{gf}	75.33 ± 1.62 ^{gf}	81.84 ± 2.42 ^{fe}	76.45 ± 1.96 $^{\gamma}$
$I_{75\%}$	87.14 ± 3.34 ^{cd}	90.84 ± 2.80 ^{de}	104.84 ± 3.46 ^{bc}	110.61 ± 3.00 ^{b}	98.59 ± 3.11 $^{\beta}$
$I_{100\%}$	96.29 ± 3.15 ^{dc}	101.28 ± 3.27 ^{bc}	108.81 ± 4.23 ^{b}	119.97 ± 5.21 ^{a}	106.59 ± 4.14 $^{\alpha}$
Mean	64.26 ± 2.85 ^{C}	71.62 ± 2.95 ^{B}	72.14± 3.17 ^{B}	76.62 ± 3.98 ^{A}	
I	$P < 0.001$				
N	$P < 0.001$				
I*N	P < 0.001				

*In each year, different lower case, capital case and Greek alphabets indicate the significant difference at 5% probability using Duncan's multiple range test for interaction effect of treatments, main effect of nitrogen and main effect of irrigation water, respectively

**$I_{0\%}$, $I_{50\%}$, $I_{75\%}$, and $I_{100\%}$ denote 0%, 50%, 75%, and 100% of crop water requirement, respectively, and N_0, N_{70}, N_{140}, and N_{210} represent 0, 70, 140, and 210 kg N ha^{-1}, respectively

than other irrigation treatments (Table 2). In addition, the maximum values of crop height were in $I_{100\%}N_{140}$ (which had no significant difference with $I_{100\%}N_{210}$) in the first year and in $I_{100\%}N_{210}$ in the second year, respectively. The minimum height was observed in $I_{0\%}N_{210}$ (which had no significant difference with $I_{0\%}N_{140}$) in the first year and $I_{0\%}N_0$ (which had no significant difference with $I_{0\%}N_{140}$) in the second year. Applying irrigation level raised the height at all nitrogen levels (except in N_0 in the 1st year). In all nitrogen treatments, the crop height was enhanced by increasing the amount of irrigation in both years. These results are in contrast with Kouzegaran et al. (2015), as no significant effect of irrigation treatments on barley (cv. Karoun in Kavir) height was detected. Similar to Dubey et al. (2018) and Barati et al. (2015), increasing the nitrogen application enhanced the maximum crop height except in $I_{0\%}$. In addition, Shafi et al. (2011) reported that the maximum barley height (107.4 cm) was observed at 100 kg N ha^{-1} rate. Emam et al. (2009) indicated that increase in nitrogen treatments boosted the ability of plants to uptake more N and improved plant height as well as growth. Similar to other studies, increasing in nitrogen application augmented barley height under irrigated treatments (Mohammadi Aghdam and Samadiyan 2014; Dubey et al. 2018); however, no lodging was observed during the growing period due to (1) timing of nitrogen application and (2) splitting the nitrogen application into two times (Hussain and Leitch 2007; Dahiya et al. 2018).

Grain yield and aboveground dry matter

The interaction and main effects of applied irrigation water and nitrogen on grain yield (GY) and aboveground dry matter (DM) are shown in Tables 3 and 4, respectively. No significant difference was seen between grain yield in the 1st and 2nd years (p value = 0.063), while there was a significant difference between dry matter of 2 years of study (p value < 0.0001). According to Tables 3 and 4, the interaction effects of irrigation and nitrogen on DM and GY were significant in both years. Considering the main effect of irrigation water treatment, the amounts of GY and DM rose with increasing total amounts of applied water in both years. There was no significant difference between the amounts of GY of $I_{75\%}$ and $I_{100\%}$ in both years, which indicated that by reducing 25% of irrigation water (from $I_{100\%}$ to $I_{75\%}$ treatments), the value of *GY* did not decrease. Hence, the application of 25% deficit irrigation could be considered as a sustainable irrigation strategy in on-farm irrigation management. According to the results, the amount of GY was reduced by 8%, 45%, and 87% in the 1st year and by 2%, 43%, and 89% in the 2nd year for $I_{75\%}$, $I_{50\%}$ and $I_{0\%}$ treatments, respectively, relative to full irrigation treatment ($I_{100\%}$). Similarly, the amount of DM dropped by 14%, 44%, and 86% in the 1st year and 5%, 38%, and 84% in the 2nd year in $I_{75\%}$, $I_{50\%,}$ and $I_{0\%}$ treatments, respectively, relative to full irrigation treatment ($I_{100\%}$). Barati et al. (2018) indicated that Nimrouz cultivar of barley obtained 5.34 Mg ha^{-1} GY under full irrigation conditions in semi-arid region and in comparison with full irrigation treatment, around 8% and 29% grain yield reductions were observed in $I_{75\%}$ and $I_{50\%}$, respectively.

Increasing the nitrogen application up to 140 kg ha^{-1} significantly elevated the GY and DM values, but no significant

Table 3 Main and interaction effects of different irrigation water and nitrogen treatments on barley grain yield (GY, Mg ha^{-1}) in 2013–2014 and 2014–2015

Irrigation level	Nitrogen application rate (kg ha^{-1})				
	N_0**	N_{70}	N_{140}	N_{210}	Mean
	2013–2014				
$I_{0\%}$**	0.41 ± 0.07 ^{h*}	0.62 ± 0.08 ^{h}	0.75 ± 0.17 ^{gh}	0.53 ± 0.08 ^{h}	0.58 ± 0.16 $^{\gamma}$
$I_{50\%}$	1.75 ± 0.74 ^{fg}	2.52 ± 0.15 ^{ef}	3.14 ± 0.29 ^{de}	3.20 ± 0.18 ^{de}	2.65 ± 0.70 $^{\beta}$
$I_{75\%}$	2.38 ± 1.15 ^{ef}	3.88 ± 0.18 ^{cd}	5.63 ± 0.26 ^{ab}	5.77 ± 0.65 ^{a}	4.42 ± 1.56 $^{\alpha}$
$I_{100\%}$	2.72 ± 1.35 ^{ef}	4.67 ± 0.53 ^{bc}	6.02 ± 0.89 ^{a}	5.88 ± 0.70 ^{a}	4.82 ± 1.59 $^{\alpha}$
Mean	1.82 ± 1.24 ^{C}	2.92 ± 1.62 ^{B}	3.89 ± 2.25 ^{A}	3.85 ± 2.33 ^{A}	
Year	$P = 0.063$				
I	$P < 0.0001$				
N	$P < 0.0001$				
I*N	$P = 0.005$				
	2014–2015				
$I_{0\%}$	0.37 ± 0.03 ^{h}	0.57 ± 0.13 ^{h}	0.67 ± 0.15 ^{h}	0.60 ± 0.15 ^{h}	0.55 ± 0.15 $^{\gamma}$
$I_{50\%}$	1.91 ± 0.13 ^{g}	2.74 ± 0.26 ^{f}	3.36 ± 0.34 ^{e}	3.48 ± 0.10 ^{e}	2.87 ± 0.68 $^{\beta}$
$I_{75\%}$	3.33 ± 0.33 ^{e}	4.34 ± 0.20 ^{ed}	6.22 ± 0.38 ^{a}	6.03 ± 0.51 ^{ab}	4.98 ± 1.29 $^{\alpha}$
$I_{100\%}$	3.02 ± 0.14 ^{ef}	5.24 ± 0.62 ^{c}	6.40 ± 0.36 ^{a}	5.57 ± 0.54 ^{bc}	5.06 ± 1.36 $^{\alpha}$
Mean	2.16 ± 1.22 ^{C}	3.22 ± 1.87 ^{B}	4.16 ± 2.47 ^{A}	3.92 ± 2.26 ^{A}	
I	$P < 0.0001$				
N	$P < 0.0001$				
I*N	$P < 0.0001$				

*In each year, different lower case, capital case and Greek alphabets indicate the significant difference at 5% probability using Duncan's multiple range test for interaction effect of treatments, main effect of nitrogen and main effect of irrigation water, respectively

**$I_{0\%}$, $I_{50\%}$, $I_{75\%,}$ and $I_{100\%}$ denote 0%, 50%, 75%, and 100% of crop water requirement, respectively, and N_0, N_{70}, $N_{140,}$ and N_{210} represent 0, 70, 140, and 210 kg N ha^{-1}, respectively

Table 4 Main and interaction effects of different irrigation water and nitrogen treatments on barley dry matter (*DM*, Mg ha^{-1}) in 2013–2014 and 2014–2015

Irrigation level	Nitrogen application rate (kg ha^{-1})				
	N_0**	N_{70}	N_{140}	N_{210}	Mean
	2013–2014				
$I_{0\%}$**	1.69 ± 0.37 ^{f*}	2.46 ± 0.39 ^{f}	2.67 ± 0.41 ^{f}	2.15 ± 0.69 ^{f}	2.24 ± 0.56 $^{\delta}$
$I_{50\%}$	7.75 ± 0.96 ^{e}	7.83 ± 1.07 ^{e}	9.44 ± 0.74 ^{de}	10.47 ± 0.93 ^{d}	8.87 ± 1.43 $^{\gamma}$
$I_{75\%}$	10.65 ± 2.09 ^{d}	11.4 ± 1.74 ^{d}	16.49 ± 0.74 ^{bc}	17.67 ± 2.07 ^{b}	13.99 ± 3.65 $^{\beta}$
$I_{100\%}$	11.1 ± 1.95 ^{d}	15.27 ± 0.98 ^{c}	18.42 ± 0.53 ^{b}	20.33 ± 1.52 ^{a}	16.15 ± 4.03 $^{\alpha}$
Mean	7.58 ± 3.95 ^{C}	9.24 ± 5.02 ^{B}	11.76 ± 6.52 ^{A}	12.68 ± 7.49 ^{A}	
Year	$P < 0.0001$				
I	$P < 0.0001$				
N	$P < 0.0001$				
I*N	$P < 0.0001$				
	2014–2015				
$I_{0\%}$	1.93 ± 0.13 ^{g}	2.76 ± 0.63 ^{g}	3.05 ± 0.69 ^{g}	2.84 ± 0.73 ^{g}	2.65 ± 0.67 $^{\gamma}$
$I_{50\%}$	8.96 ± 0.59 ^{f}	9.90 ± 0.94 ^{ef}	11.25 ± 1.16 ^{ed}	11.79 ± 0.30 ^{cd}	10.47 ± 0.72 $^{\beta}$
$I_{75\%}$	12.81 ± 1.26 ^{cd}	13.22 ± 0.61 ^{c}	18.47 ± 1.12 ^{ab}	19.57 ± 1,64 ^{a}	16.02 ± 1.39 $^{\alpha}$
$I_{100\%}$	10.01 ± 0.47 ^{ef}	17.32 ± 2.05 ^{b}	19.90 ± 1.11 ^{a}	19.48 ± 1.89 ^{a}	16.68 ± 1.44 $^{\alpha}$
Mean	8.43 ± 4.23 ^{C}	10.80 ± 5.67 ^{B}	13.17 ± 7.05 ^{A}	13.42 ± 7.27 ^{A}	
I	$P < 0.0001$				
N	$P < 0.0001$				
I*N	$P < 0.0001$				

*In each year, different lower case, capital case and Greek alphabets indicate the significant difference at 5% probability using Duncan's multiple range test for interaction effect of treatments, main effect of nitrogen and main effect of irrigation water, respectively

**$I_{0\%}$, $I_{50\%}$, $I_{75\%}$, and $I_{100\%}$ denote 0%, 50%, 75%, and 100% of crop water requirement, respectively, and N_0, N_{70}, N_{140}, and N_{210} represent 0, 70, 140, and 210 kg N ha^{-1}, respectively

difference was observed between the values of GY and DM in N_{140} and N_{210} treatments, in both years. The *GY* and DM under N_{140} treatment increased by 114% and 55% in 2013–2014 and 92% and 56% in 2014–2015 compared to that in N_0, respectively (Dubey et al. 2018; Ghasemi-Aghbolaghi and Sepaskhah 2018; Barati et al. 2015). Ali et al. (2021) studied the effect of nitrogen fertilizer levels and irrigation water types on barley yield and showed that the highest grain yield was recorded under 60 kg N fed^{-1}. In another study, Yuan et al. (2022) reported that the highest wheat grain yield was obtained at 200 kg N ha^{-1}, and further application of N (300 kg N ha^{-1}) decreased the grain yields, indicating that crop failure under excessive N application. Considering variations of GY and DM, harvest index (data not shown) was augmented by increasing nitrogen level from N_0 to N_{140}, but it declined with further increase in nitrogen (N_{210}), at each level of irrigation and in 2 years of study (Pirzado et al. 2021). In addition, similar to Liben et al. (2011), a positive correlation was observed between barley height and the grain and straw yield (Fig. 4).

The interaction effect between irrigation treatment and nitrogen application rate on GY was significant. The maximum GY in both years was observed in $I_{100\%}N_{140}$ treatment (6.02 and 6.40 Mg ha^{-1}), though *GY* of this treatment was not significantly different with that in $I_{75\%}N_{140}$, $I_{75\%}N_{210}$ and $I_{100\%}N_{210}$ in the 1st year and with $I_{75\%}N_{140}$ and $I_{75\%}N_{210}$ in the 2nd year and the minimum *GY* was observed in $I_{0\%}N_0$ in both years. As a result, 25% deficit irrigation with nitrogen fertilizer of 140 kg ha^{-1} is the proper management for barley production in the study region. Sharafi et al. (2011) examined the effect of different levels of irrigation water on the potential yield of some genotypes of winter barley. They indicated that Reyhane 0–3 cultivar of barley obtained 6.22 and 3.72 Mg ha^{-1} grain yield under full irrigation and water stress (watered only at pre-flowering) conditions, respectively, with 100 kg N ha^{-1}.

Grain protein

The maximum grain protein (GP) of 13.85 and 12.03% and the maximum straw protein (SP) of 4.67 and 5.24% were observed under rainfed treatment ($I_{0\%}$) in the 1st and 2nd years, respectively (Table 5). No significant difference was found between the values of *GP* in $I_{50\%}$, $I_{75\%}$, and $I_{100\%}$, between *SP* in $I_{100\%}$ and $I_{75\%}$, as well as between $I_{50\%}$ and $I_{75\%}$, in both years. Shrief and El-Mohsen (2014) showed that deficit irrigation in barley resulted in grain yield reduction and grain protein enhancement. The amounts of GP and SP enhanced by increasing the nitrogen fertilizer application (Barati et al. 2015; Montemurro et al. 2006). Grain protein in

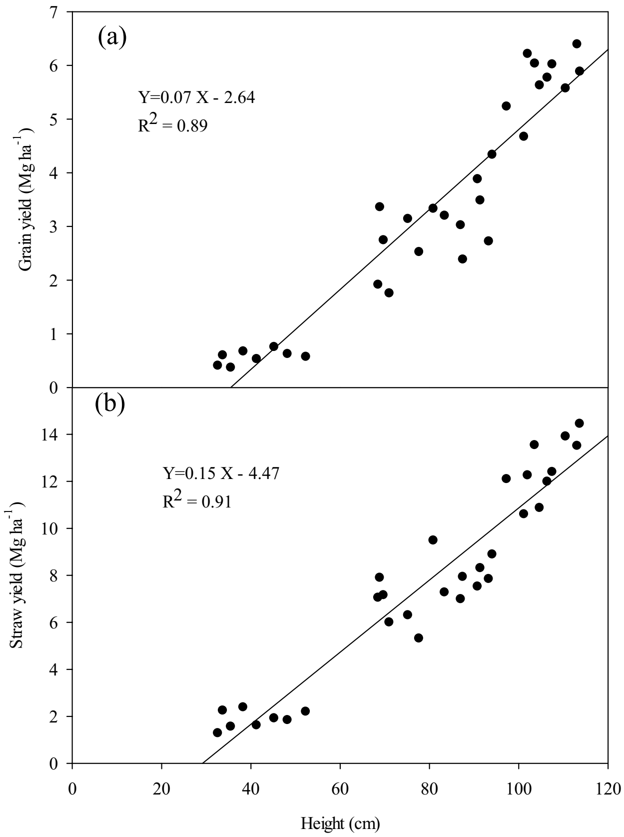


Fig. 4 Relationship between barley grain yield (GY) and height (H) (**a**) and between straw yield (SY) and *H* (**b**)

the N_0 treatment was significantly lower than that obtained in other nitrogen fertilizer application treatments. Considering the main effect of nitrogen on GPS, the maximum measured GP (14.14% and 14.54% in the 1st and 2nd years, respectively) and SP (3.02% and 3.99% in the 1st and 2nd years, respectively) were observed in N_{210} treatment. The amounts of *GP* in N_{140}, N_{70}, and N_0 treatments were reduced to 8, 10, and 22% in the 1st year and 15, 22, and 36% in the 2nd year, compared to that obtained in N_{210}. In this regard, Ghasemi-Aghbolaghi and Sepaskhah (2018) reported that the protein content of barley (Bahman cultivar) was 8.36%, 10.03%, and 12.20% for of 0, 90, and 180 kg ha^{-1} of applied nitrogen fertilizer, respectively. In addition, the maximum grain and straw protein in both years were observed in $I_{0\%}N_{210}$ (6.5 and 7.7% for straw protein as well as 15.4 and 14.0% for grain protein in 1st and 2nd years, respectively). The minimum straw protein was observed in $I_{75\%}N_0$ as 0.20 and 0.23% in 1st and 2nd years, respectively, while the minimum value for grain protein was obtained in $I_{100\%}N_0$ as 10.27 and 7.85% in 1st and 2nd years, respectively.

Yield components

As the effects of year on 1000 grain weight (1000-GW, *P* value = 0.9391) and grain number per spike (GPS, *P* value = 0.84) were not significant, the average values of each variable were considered for statistical analysis with the results shown in Table 6. However, the effect of year on spike number per unit area (SN, m^{-2}) was significant (Table 7). The 1000-Grain weight, grain number per spike, and spike number per unit area increased significantly with increase in irrigation water levels, in both years. Although increasing N fertilizer elevated the 1000-GW, no significant difference was observed between the N treatments. The maximum and minimum of 1000-GW was observed in $I_{100\%}N_{210}$ (48.12 g) and in $I_{0\%}N_0$ (35.87 g), respectively. The

Table 5 Effects of different irrigation water and nitrogen treatments on grain and straw protein content for barley in 2013–2014 and 2014–2015

Year	2013–2014		2014–2015	
Treatment	Straw protein content (%)	Grain protein content (%)	Straw protein content (%)	Grain protein content (%)
Irrigation				
$I_{0\%}$**	4.67 ± 1.59 ^{a*}	13.85 ± 1.94 ^{a}	5.24 ± 1.70 ^{a}	12.03 ± 1.93 ^{a}
$I_{50\%}$	1.77 ± 1.04 ^{b}	12.43 ± 1.65 ^{ab}	2.05 ± 1.25 ^{b}	10.83 ± 2.05 ^{ab}
$I_{75\%}$	1.25 ± 0.84 ^{bc}	12.37 ± 2.11 ^{ab}	1.48 ± 1.01 ^{bc}	10.43 ± 1.92 ^{b}
$I_{100\%}$	0.97 ± 0.84 ^{c}	12.14 ± 2.06 ^{b}	1.2 ± 1.05 ^{c}	9.98 ± 2.54 ^{b}
Nitrogen				
N_0**	1.03 ± 1.27 ^{c}	10.94 ± 1.28 ^{b}	1.48 ± 1.53 ^{c}	9.29 ± 1.49 ^{c}
N_{70}	2.05 ± 1.74 ^{bc}	12.65 ± 1.62 ^{a}	2.51 ± 1.85 ^{b}	11.29 ± 1.69 ^{b}
N_{140}	2.62 ± 1.55 ^{b}	13.00 ± 1.45 ^{a}	2.96 ± 1.57 ^{b}	12.37 ± 1.43 ^{b}
N_{210}	3.02 ± 2.20 ^{a}	14.14 ± 2.22 ^{a}	3.99 ± 2.60 ^{a}	14.54 ± 1.99 ^{a}

*In each year and each treatment, means followed by same letters for each parameter are not significantly different at 5% level of using Duncan's multiple range test

**$I_{0\%}$, $I_{50\%}$, $I_{75\%}$, and $I_{100\%}$ denote 0%, 50%, 75%, and 100% of crop water requirement, respectively, and N_0, N_{70}, N_{140}, and N_{210} represent 0, 70, 140, and 210 kg N ha^{-1}, respectively

Table 6 Effects of different irrigation water and nitrogen treatments on mean values of 1000 grain weight (1000-GW, g) and Grain number (GPS, Spike^{-1})

Irrigation level	Nitrogen application rate (kg ha^{-1})				
	N_0**	N_{70}	N_{140}	N_{210}	Mean
	1000-GW				
$I_{0\%}$**	35.87 ^{d}	37.43 ^{cd}	38.00 ^{bcd}	39.92 ^{abcd}	37.80 $^{\beta}$
$I_{50\%}$	37.55 ^{cd}	43.20 ^{abcd}	43.78 ^{abcd}	45.09 ^{abc}	42.40 $^{\alpha}$
$I_{75\%}$	42.45 ^{abcd}	43.02 ^{abcd}	47.52 ^{a}	44.93 ^{abc}	44.48 $^{\alpha}$
$I_{100\%}$	45.22 ^{abc}	46.13 ^{abc}	46.83 ^{ab}	48.12 ^{a}	46.57 $^{\alpha}$
Mean	40.27 ^{A}	42.445 ^{A}	44.03 ^{A}	44.52 ^{A}	
Year	$P=0.9391$				
I	$P=0.0009$				
N	$P=0.1412$				
I*N	$P=0.9762$				
	GPS				
$I_{0\%}$	16.00 ^{e}	17.47 ^{e}	19.96 ^{de}	19.35 ^{de}	18.20 $^{\gamma}$
$I_{50\%}$	23.01 ^{cd}	27.15 ^{bc}	28.16 ^{ab}	30.13 ^{ab}	27.11 $^{\beta}$
$I_{75\%}$	27.56 ^{abc}	27.74 ^{abc}	29.24 ^{ab}	31.28 ^{ab}	28.95 $^{\alpha\beta}$
$I_{100\%}$	30.18 ^{ab}	29.87 ^{ab}	32.74 ^{a}	32.68 ^{a}	31.36 $^{\alpha}$
Mean	28.36 ^{A}	24.19 ^{C}	25.56 ^{CB}	27.524 ^{AB}	
Year	*P* value = 0.8402				
I	*P* value < 0.0001				
N	*P* value = 0.0029				
I*N	*P* value = 0.8669				

*For each variable, different lower case, capital case and Greek alphabets indicate the significant difference at 5% probability using Duncan's multiple range test for interaction effect of treatments, main effect of nitrogen and main effect of irrigation water, respectively

**$I_{0\%}$, $I_{50\%}$, $I_{75\%}$, and $I_{100\%}$ denote 0%, 50%, 75%, and 100% of crop water requirement, respectively, and N_0, N_{70}, N_{140}, and N_{210} represent 0, 70, 140, and 210 kg N ha^{-1}, respectively

GPS increased by enhancing irrigation application in each nitrogen treatment. Elevation of the nitrogen level from 0 to 210 kg ha^{-1}increased *GPS*, significantly. Moselhy and Zahran (2002) stated that the increase in nitrogen had resulted in GPS reduction. The maximum and minimum amount of GPS were observed in $I_{100\%}N_{140}$ (32.74 Spike^{-1}) and $I_{0\%}N_0$ (16.00 Spike^{-1}), respectively.

Furthermore, elevation of the nitrogen rate to N_{140} significantly increased *SN* compared to that in N_0 in both years. Considering interaction effects on *SN*, the minimum amount of *SN* was observed in $I_{0\%}N_0$ (105 and 130 m^{-2} in the 1st and 2nd years, respectively) and maximum amount of *SN* was found in $I_{100\%}N_{140}$ (570 m^{-2}) and $I_{100\%}N_{210}$ (598 m^{-2}) in the 1st and 2nd years, respectively (Table 7).

Water use efficiency

Table 8 reports the mean values of WUE_{DM} (kg m^{-3}) and WUE_{GY} (kg m^{-3}) in different irrigation water regimes and nitrogen application rates. Among irrigation treatments, the maximum values of WUE_{DM} were 4.00 and 4.24 kg m^{-3} in the 1st and 2nd years, respectively, and the maximum values of WUE_{GY} were 1.34 and 1.27 kg m^{-3} in the 1st and 2nd years, respectively, obtained in $I_{75\%}$. The results revealed that WUE_{DM} and WUE_{GY} increased with augmenting the applied irrigation water up to $I_{75\%}$ in both years, and further increase in irrigation water significantly reduced WUE_{GY} and WUE_{DM} of both years. Twenty-five percent reduction in irrigation water relative to full irrigation water was increased the values of WUE_{DM} and WUE_{GY}.

The results indicated that no significant difference was observed between WUE_{DM} and WUE_{GY} of N_{140} and N_{210}, in both years. In addition, WUE_{DM} and WUE_{GY} under the treatments of N_{140} were significantly higher than those obtained in N_{70} and N_0 treatments. The maximum values of WUE_{DM} were 3.95 and 4.23 kg m^{-3}, in the treatment of N_{210} in the 1st and 2nd years, respectively, and no significant difference was observed between WUE_{DM} of N_{140} and N_{210} in both years. Similarly, Al-Menaie et al. (2021) indicated water use efficiency of barley increased with increased nitrogen application rates under arid climate condition. The maximum value of WUE_{GY} (1.31 and 1.17 kg m^{-3} in the 1st and 2nd years, respectively) was obtained in N_{140} treatment. It is noticeable that because of no irrigation application and minimum obtained grain yield (Table 3) under the treatment of $I_{0\%}$, WUE_{DM} and WUE_{GY} had high differences with those in the other irrigation treatments. Barati et al. (2018) sowed barley (cv. Nimroz) under the basin irrigation and three irrigation

Table 7 Effects of different irrigation water and nitrogen treatments on spikes number (SN, m^{-2}) for barley in 2013–2014 and 2014–2015

Irrigation level	Nitrogen application rate (kg ha^{-1})				
	N_0**	N_{70}	N_{140}	N_{210}	Mean
	2013–2014				
$I_{0\%}$**	105.41 ^{g}	117.80 ^{fg}	164.54 ^{efg}	118.41 ^{fg}	126.54 $^{\delta}$
$I_{50\%}$	233.74 ^{ef}	280.18 ^{de}	364.00 ^{cd}	280.94 ^{de}	289.71 $^{\gamma}$
$I_{75\%}$	228.15 ^{ef}	472.52 ^{abc}	442.90 ^{bc}	530.48 ^{ab}	418.51 $^{\beta}$
$I_{100\%}$	503.25 ^{ab}	441.49 ^{bc}	569.78 ^{a}	547.95 ^{ab}	515.62 $^{\alpha}$
Mean	267.64 ^{B}	328.00 ^{A}	385.31 ^{A}	369.44 ^{A}	
Year	P value < 0.0001				
I	P value < 0.0001				
N	P value = 0.0018				
I*N	P value = 0.0250				
	2014–2015				
$I_{0\%}$	130.04 ^{e}	138.35 ^{e}	146.24 ^{de}	206.90 ^{d}	155.38 $^{\delta}$
$I_{50\%}$	332.77 ^{c}	335.30 ^{c}	357.00 ^{c}	394.76 ^{c}	354.96 $^{\gamma}$
$I_{75\%}$	382.82 ^{c}	489.16 ^{b}	543.99 ^{ab}	544.99 ^{ab}	490.24 $^{\beta}$
$I_{100\%}$	531.5 ^{ab}	576.36 ^{a}	549.25 ^{ab}	597.66 ^{a}	563.69 $^{\alpha}$
Mean	344.28 ^{C}	384.79 ^{B}	399.12 ^{B}	436.08 ^{A}	
I	P value < 0.0001				
N	P value < 0.0001				
I*N	P value = 0.0872				

*In each year, different lower case, capital case and Greek alphabets indicate the significant difference at 5% probability using Duncan's multiple range test for interaction effect of treatments, main effect of nitrogen and main effect of irrigation water, respectively

**$I_{0\%}$, $I_{50\%}$, $I_{75\%}$, and $I_{100\%}$ denote 0%, 50%, 75%, and 100% of crop water requirement, respectively, and N_0, N_{70}, N_{140}, and N_{210} represent 0, 70, 140, and 210 kg N ha^{-1}, respectively

Table 8 Effects of different irrigation water and nitrogen treatments on water use efficiency for aboveground dry matter (WUE_{DM}, kg m^{-3}) and for grain yield (WUE_{GY}, kg m^{-3}) of Barley in 2013–2014 and 2014–2015

Treatments	2013–2014		2014–2015	
	WUE_{GY} (kg m^{-3})	WUE_{DM} (kg m^{-3})	WUE_{GY} (kg m^{-3})	WUE_{DM} (kg m^{-3})
Irrigation				
$I_{0\%}$**	0.58 ± 0.16 ^{c*}	2.65 ± 0.56 ^{c}	0.58 ± 0.16 ^{d}	2.24 ± 0.68 ^{c}
$I_{50\%}$	1.21 ± 0.32 ^{ab}	3.92 ± 0.65 ^{a}	1.08 ± 0.25 ^{b}	4.03 ± 0.51 ^{ab}
$I_{75\%}$	1.34 ± 0.47 ^{a}	4.00 ± 1.10 ^{a}	1.27 ± 0.32 ^{a}	4.24 ± 0.83 ^{a}
$I_{100\%}$	1.09 ± 0.36 ^{b}	3.12 ± 0.91 ^{b}	0.96 ± 0.25 ^{c}	3.67 ± 0.81 ^{b}
Nitrogen				
N_0**	0.64 ± 0.29 ^{c}	2.59 ± 0.84 ^{c}	0.65 ± 0.19 ^{c}	2.68 ± 0.74 ^{c}
N_{70}	1.00 ± 0.24 ^{b}	3.25 ± 0.59 ^{b}	0.95 ± 0.23 ^{b}	3.23 ± 0.50 ^{b}
N_{140}	1.31 ± 0.38 ^{a}	3.90 ± 0.91 ^{a}	1.17 ± 0.35 ^{a}	4.03 ± 0.72 ^{a}
N_{210}	1.27 ± 0.48 ^{a}	3.95 ± 1.36 ^{a}	1.11 ± 0.37 ^{a}	4.23 ± 0.90 ^{a}

*In each year and each treatment, means followed by same letters for each parameter are not significantly different at 5% level of probability using Duncan's multiple range test

**$I_{0\%}$, $I_{50\%}$, $I_{75\%}$, and $I_{100\%}$ denote 0%, 50%, 75%, and 100% of crop water requirement, respectively, and N_0, N_{70}, N_{140}, and N_{210} represent 0, 70, 140, and 210 kg N ha^{-1}, respectively

treatments of 50%, 75%, and 100% of full irrigation and indicated that the values of WUE_{GY} were maximized under the treatment of $I_{75\%}$.

Nitrogen use efficiency

The main effect of irrigation water and nitrogen fertilizer on nitrogen use efficiency (NUE) is presented in Fig. 5. The results indicated that increasing the irrigation water from $I_{0\%}$ to $I_{100\%}$ treatments enhanced the amount of nitrogen uptake per unit of applied nitrogen (Fig. 5). The values of NUE of $I_{50\%}$, $I_{75\%}$ and $I_{100\%}$ treatments increased by 2.8, 6.9, and 7.8 (4.9, 7.86, and 11.1) times more than the values obtained at $I_{0\%}$ in 1st (and 2nd) year, respectively. No significant difference was observed between the *NUE* of $I_{100\%}$ and $I_{75\%}$ treatments in the 1st year.

The results of this study showed that increasing nitrogen application to 210 kg ha^{-1} reduced NUE in both years. While no significant difference was observed between NUE of N_{70} and N_{140} in both years, NUE of N_{140} was greater than that in N_{70} in the 1st year, and NUE of N_{70} was higher than that in N_{140} in the 2nd year. Huggins and Pan (2003), Albrizio et al. (2010), and Barati et al. (2015) showed that elevation of the nitrogen application level led to decreased *NUE*, while Latiri-Souki et al. (1998)

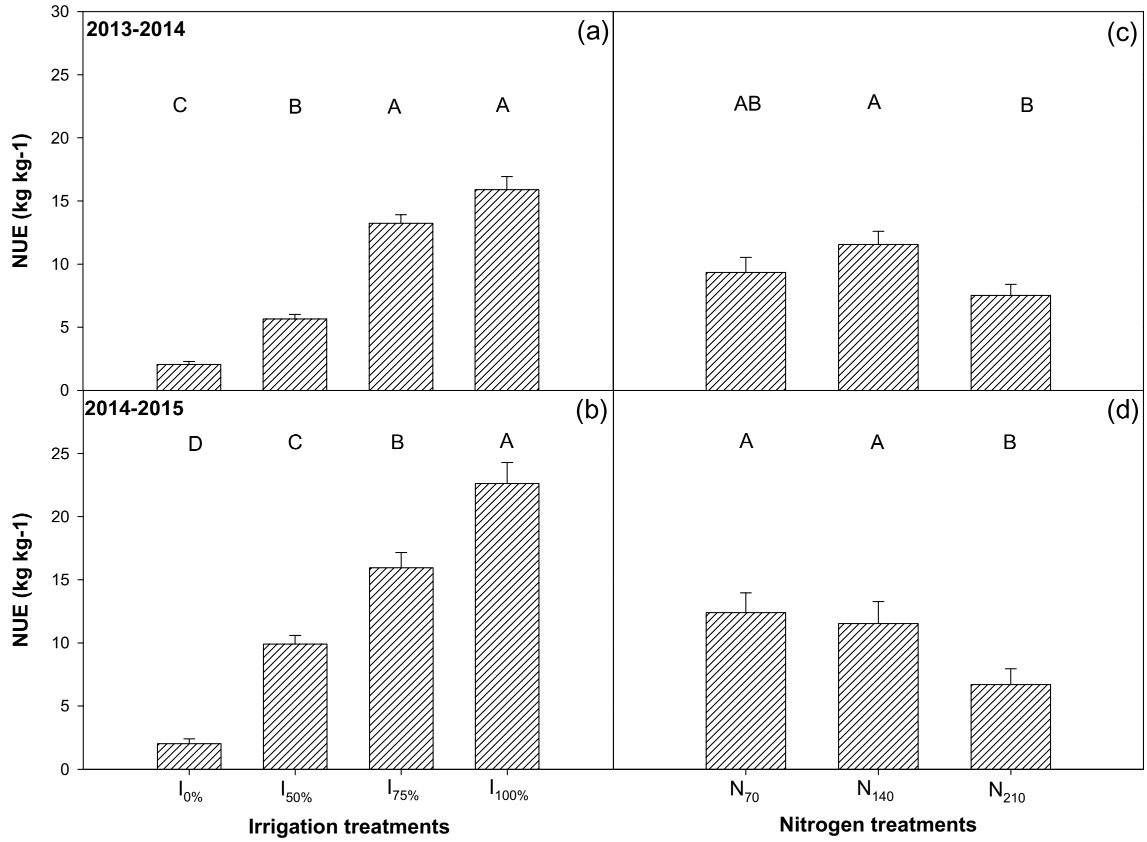


Fig. 5 Effects of different irrigation water (**a**, **b**) and nitrogen (**c**, **d**) treatments on nitrogen use efficiency (NUE) in 2013–2014 and 2014–2015. Capital letters indicate significant difference between main effect of irrigation water as well as nitrogen fertilizer treatments. $I_{0\%}$, $I_{50\%}$, $I_{75\%}$, and $I_{100\%}$ denote 0%, 50%, 75%, and 100% of crop water requirement, respectively, and N_0, N_{70}, N_{140}, and N_{210} represent 0, 70, 140, and 210 kg N ha^{-1}, respectively

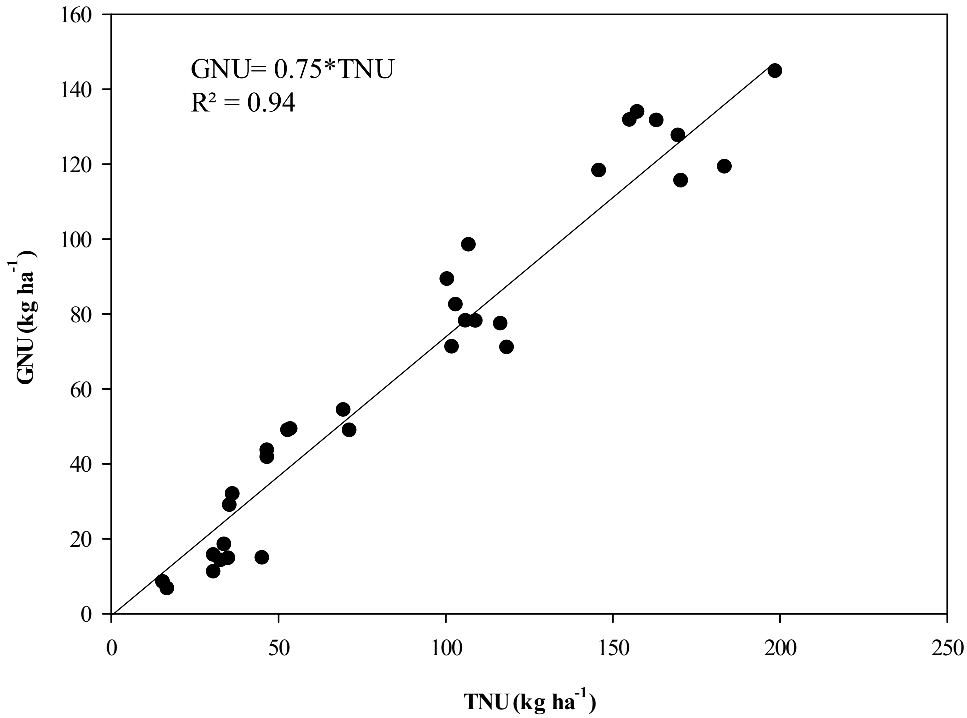
and Raun and Johnson (1999) reported that augmentation of the nitrogen application rate enhanced *NUE*. In addition, higher *NUE* achievement might be because of N loss reduction and N uptake increase at lower nitrogen applied rates. Note that capability of yield-increasing per unit of nitrogen declined remarkably by increasing nitrogen fertilizer, as confirmed by Sinebo et al. (2004).

Similar to our results, the value of *NUE* diminished with increasing water stress in Yusef variety of barley, as 33.7, 31.2, 24.3, and 14.5 kg kg^{-1} *NUE* were obtained in $I_{100\%}$, $I_{75\%}$, $I_{50\%}$, and $I_{0\%}$, treatments, respectively (Barati et al. 2015). They further indicated that NUE dropped with increasing nitrogen application, although because of high residual nitrogen (130 kg ha^{-1}), their calculated NUE (32.3, 25.9 and 20.5 kg kg^{-1} in 0, 60 and 120 kg ha^{-1}, respectively) was larger than NUE of this study. Hoseinlou et al. (2013) indicated that application of 120 kg N ha^{-1}under severe drought condition (no irrigation water) resulted in minimum spring barley NUE among other treatments.

Relationship between grain and aboveground nitrogen uptake

Nitrogen harvest index (NHI) indicates how efficiently the plant converts absorbed N into grain. The relationship between the measured nitrogen uptake by grain and aboveground biomass for all treatments is shown in Fig. 6. The NHI value of barley (cv, Reyhane 0–3) was equal to 75%, which is higher than that obtained in wheat (66%; Mahbod et al. 2015) and maize (66%; Majnooni-Heris et al. 2011), indicating that barley (cv. Reyhane 0–3) had the ability to accumulate higher portion of applied N in grain than in straw. Comparison of NHI value of Reyhane 0–3 cultivar of barley with other barley's cultivar showed greater NHI in cv. Reyhane 0–3, as the NHI values for Yousef, Nimrouz, and Holker cultivars were 68.3% (Barati 2014), 68.5% (Barati 2014), and 69.8% (Kassie and Fanataye 2019), respectively. The NHI values for Reyhane 0–3 (75%) and Miskal-21 (75.7%) cultivars were almost the same (Kassie and Fanataye 2019). Since the effect of year was not significant on GNU and TNU, the average values of variable were considered

Fig. 6 Relationship between grain (GNU) and aboveground biomass (TNU) nitrogen uptake



for statistical analysis (Table 9). The results indicated that GNU and TNU rose by increasing irrigation water. Furthermore, increasing applied nitrogen augmented both GNU and TNU, though no significant difference was observed between GNU and TNU of N_{140} and N_{210} (Table 9). In addition, NHI increased by elevating the irrigation level from $I_{0\%}$ to $I_{75\%}$, while 25% increase in irrigation ($I_{100\%}$) did not improve NHI. On the other hand, NHI dropped by increasing nitrogen application to 140 kg ha^{-1} and there was no difference in NHI values of N_{140} and N_{210}.

Conclusions

Reyhane 0–3 cultivar of barley produced higher amounts of grain yield under 75% of full irrigation and nitrogen fertilizer treatments of 140 and 210 kg ha^{-1} compared with the average amount of barley production (irrigated cultivation) in Iran (3.07 Mg ha^{-1}) during the study period. Furthermore, 25% deficit irrigation yielded to the maximum water use efficiency, and nitrogen fertilizer of 140 kg ha^{-1} had significantly similar NUE as 70 kg ha^{-1}. Considering the NHI values, the result showed that Reyhane 0–3 cultivar of barley accumulated more nitrogen in grain rather than in straw in comparison with other common barley cultivars used in the study region. It is recommended to consider 25% deficit irrigation with 140 kg N ha^{-1} as a sustainable agriculture management for barley production, especially under semi-arid regions.

Table 9 Effects of different irrigation water and nitrogen treatments on grain and total nitrogen uptake for barley

Treatments	GNU (kg ha^{-1})	TNU (kg ha^{-1})	NHI
Irrigation			
$I_{0\%}$**	13.00 ± 4.43 ^{c*}	30.03 ± 12.45 ^{c}	0.41
$I_{50\%}$	57.70 ± 20.62 ^{b}	82.27 ± 35.98 ^{b}	0.67
$I_{75\%}$	95.22 ± 37.09 ^{a}	121.14 ± 53.19 ^{a}	0.77
$I_{100\%}$	99.10 ± 42.57 ^{a}	123.85 ± 61.74 ^{a}	0.78
Nitrogen			
N_0**	32.44 ± 18.48 ^{c}	37.97 ± 20.45 ^{c}	0.85
N_{70}	59.78 ± 34.98 ^{b}	77.30 ± 33.41 ^{b}	0.80
N_{140}	83.58 ± 46.95 ^{a}	116.27 ± 57.27 ^{a}	0.73
N_{210}	89.24 ± 54.13 ^{a}	125.75 ± 65.55 ^{a}	0.73
Year	P value = 0.1512	P value = 0.8214	
I	P < 0.0001	P < 0.0001	
N	P < 0.0001	P < 0.0001	
I*N	P = 0.0132	P = 0.0143	

*In each year and each treatment, means followed by same letters for each parameter are not significantly different at 5% level of probability using Duncan's multiple range test

**$I_{0\%}$, $I_{50\%}$, $I_{75\%}$, and $I_{100\%}$ denote 0%, 50%, 75%, and 100% of crop water requirement, respectively, and N_0, N_{70}, N_{140}, and N_{210} represent 0, 70, 140, and 210 kg N ha^{-1}, respectively

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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