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Research Article
Impact of Different Irrigation and Nitrogen Treatments on Barley Yield, Yield Components and Water Use Efficiency

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Abstract

Background and Objective: Water and nitrogen are the two major agricultural inputs that influence the yield and water use efficiency of barley. Kuwait is an arid country that depends on irrigated agriculture and intense fertilization due to its scarce water resources and less fertile soil. Studies on the interactive effect of water and nitrogen, the two limiting sources, on barley yield and water use efficiency are little. Therefore, the main objective of the study was to investigate the combined effect of different irrigation and nitrogen treatments on the yield, yield components and water use efficiency of fifteen different barley genotypes under an arid environment. **Materials and Methods:** The study determined yield, yield components and water use efficiency in 15 different barley genotypes subjected to three different nitrogen fertilizer application rates (0, 50 and 100 kg N ha^{-1}) with two different irrigation treatments (100 and 75% ET) under arid conditions. **Results:** The nitrogen treatments significantly increased the crop yield and water use efficiency of barley. However, it did not vary significantly between 75 and 100% irrigation treatments. Moreover, 50 and 100 kg N ha^{-1} nitrogen treatments did not present a significant change in the water use efficiency under the deficit irrigation of 75% ET. **Conclusion:** Thus, the study implies feasibility of improving barley yield as well as water use efficiency through reduced water and fertilizer use by employing 75% ET irrigation with 50 kg N ha^{-1} fertilization in arid lands.

Key words: Nitrogen, deficit irrigation, yield, yield components, barley, water use efficiency, pesticides

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Improved sustainable yield under reduced use of agricultural inputs such as water and fertilizers is critical in designing various strategies intended to feed the increasing global population sustainable. Kuwait is an arid country situated on the north-eastern border of the Arab Peninsula with little precipitation. The harsh environmental conditions, less percentage of arable land, less fertile soil with low organic matter content and limited freshwater resources for irrigation drastically affects the crop production in Kuwait. It does not possess any permanent surface water and the continuous pumping of water has deteriorated the quantity and quality of groundwater. The exploitation of aquifers at a rate exceeding that of groundwater recharge and population growth has led to increased pressure on the water resources in Kuwait. A previous study has noted that the gross maximum consumption reached a value of 1440.17×10^3 m^3 d^{-1} (316.8 MIGD) for the year which is above the total capacity of the available distillation units[1]. Improving water productivity is a necessity in arid regions with limited water resources and is defined as the crop yield per unit of water applied during its growth period. Resource-efficient sustainable crop production demands the optimum application of water and nutrients as water and plant nutrients are complementary inputs. Plants under poor soil fertile conditions cannot efficiently use water as the plant response to increasing doses of one of these factors is best when the other factor is not limited. Several previous studies have revealed an increase in yield and water productivity through efficient water and fertilizer management practices in various crops such as rice[2-5]. A previous study conducted in maize has noted a significant increase in maize yield, nitrogen uptake and irrigation water productivity with an increase in soil organic matter content[6].

Irrigation and agricultural chemical application (fertilizers and pesticides) are interrelated and their effects on water productivity are crop as well as specific. Barley (*Hordeum vulgare*), is one of the most drought and salt-tolerant cereal crop and provides the main source of feeds for animals (livestock and poultry)[7]. Globally, it ranks fourth in cereal production after maize, wheat and rice[8] and is included in the list of the priority crops in the Agriculture Master Plan of the State of Kuwait[9]. In Kuwait, the local farming systems account for only about 4-5% of the total livestock feed requirement, therefore the country mainly depended on imported barley grains, straws and other feeds. Kuwait had to import 100% of both barley grains and straws for animals. Previously, several field experiments were conducted to examine the suitability of various barley cultivars in Kuwait. The performance of several barley lines was evaluated under Kuwait's environmental conditions and several promising lines were selected[10-12]. But a sustainable increase in the agricultural output could be achieved only by establishing a resource-efficient cropping system. Improving water productivity could significantly reduce agricultural water consumption to a great extent. In arid regions like Kuwait where both water and nutrients exist as limiting factors, water productivity of crops must be determined under a combined irrigation and fertilization treatments. The studies on water productivity of barley under various irrigation and fertilization treatments are little under Kuwait's environmental conditions. The present study addresses this gap and investigated the water productivity displayed by 15 different barley genotypes subjected to three different fertilization treatments under two different irrigation treatments in Kuwait. The results will provide baseline data to establish efficient irrigation management practices to optimize water productivity for barley production in Kuwait and thus contribute solutions to food security that are both scientifically rigorous and commercially practical.

MATERIALS AND METHODS

Study area: The field experiments were carried out for two growing seasons (2016-2018) at Kuwait Institute for Scientific Research Station for Research and Innovation, Sulaibiya, Kuwait. The selected site was not virgin in nature and barley (*Hordeum vulgare*) was the previous crop. The soil was sandy in texture and was ploughed thrice, before planting to a depth of 50 cm using a cultivator in Table 1. Various chemical soil quality indicators such as pH, electrical conductivity and presence of water-soluble cations and anions were determined to assess the relative risk of soil and crop damage from sodium and other salts in the soil given in Table 2.

Research methodology: Once the soil was prepared for planting, good quality compost (4 t ha^{-1}) was incorporated into the soil before planting to improve the soil structure. In addition, phosphorous was added in the form of triple superphosphate at the rate of 150 kg P_2O_5 ha^{-1} (16% P_2O_5) and potassium at the rate of 120 kg K_2O ha^{-1} (60% K_2O) in the upper 30 cm of soil. The nitrogen fertilizer was added in the

Table 1: Physical properties of the soil

	Sample depth (cm)			
Soil texture (%)	0-30	30-60	60-90	90-120
Sand	98.6	93.6	91.6	91.6
Silt	1	6	6	4
Clay	0.4	0.4	2.4	4.4
Texture	Sandy	Sandy	Sandy	Sandy

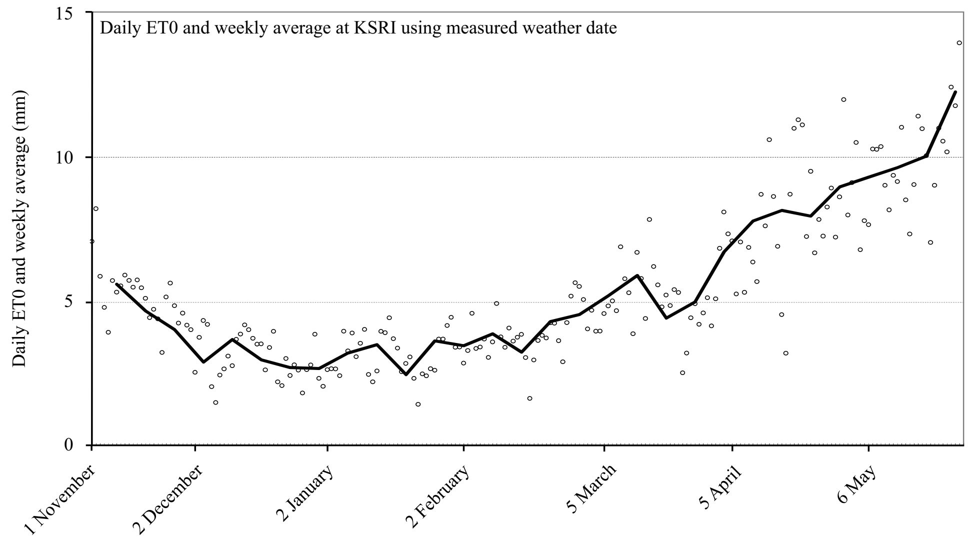

Fig. 1: Average of weekly evapotranspiration

Table 2: Chemical properties of soil

Properties		Sample depth (cm) 0-30	30-60	60-90	90-120
	pH	7.5	7.5	7.6	7.6
	ECe (mS cm^{-1})	3.30	2.13	3.26	3.07
	TDS (ppm)	2112.0	1363.2	2086.4	1964.8
Cations (mg kg^{-1})	Ca^{+2}	107.03	88.18	152.46	119.13
	Mg^{+2}	13.30	13.15	22.51	40.16
	K^+	15.23	17.16	22.42	8.35
	Na^+	74.58	15.87	9.79	9.56
Anions (mg kg^{-1})	Cl^{-1}	154.29	26.28	25.77	18.37
	CO_3^-	<10	<10	<10	<10
	HCO_3^-	98.99	33.59	15.40	12.48
	NO_3^-	1.60	3.60	1.60	1.20
	NO_2^-	0.52	0.84	0.80	0.80
	P	6.5	24.8	5.2	<1

EC_e: Electrical conductivity, TDS: Total dissolved solids, Ca^{+2}: Calcium, Mg^{+2}: Magnesium, K^+: Potassium, Na^+: Sodium, Cl^{-1}: Chloride ion, CO_3^-: Carbonate ion, HCO_3^-:Bicarbonate ion, NO_3^-: Nitrate ion, NO_2^-: Nitrite ion, P: Phosphorous ion

form of urea at the rates of 0, 50 and 100 kg N ha^{-1} as split applications. Two-hand manual weeding was done at tillering stage with a 20 day interval to reduce the competition between weed and barley for light, water and minerals.

Experimental design: The experiment was laid out in a split-split-plot arrangement with three replicates. Two different irrigation treatments equivalent to 75 and 100% of the recommended irrigation were randomly assigned to the main plots and administered by a sprinkler irrigation system. Irrigations were based on reference Evapotranspiration (ET_0) estimated using daily measurements of maximum and minimum air temperature and relative humidity, average wind speed and total solar radiation. The Penman-Monteith method was used to estimate ET_0 and actual Evapotranspiration by the crop (ET_C) using the suggested crop coefficient (k_c) for barley ($ET_C = k_c \times ET_0$).

Replacement of ET_C determined the recommended irrigation amount, while the reduced irrigation amount was 75% of this. Weekly average ET0 based on daily estimates are shown in the chart of Fig. 1. The ET estimates to be used in irrigation scheduling were calculated using data from a nearby automatic weather station. An initial uniformity test was conducted using containers (catch cans) spaced to measure the irrigation application relative to the distance from the risers. The average irrigation depth was measured over a fixed operation time to calibrate the sprinkler system. The uniformity was considered acceptable for a solid set system operating under the bird protective nets covering the plots. The water was supplied by a pump and a storage tank controlled by a timer.

Urea was used as the nitrogen fertilizer and three different nitrogen fertilizer applications at rates of 0, 50 and 100 kg N ha^{-1} served as the subplot factor. The fertilizer was applied on the surface from germination. These fertilizer application rates are consistent with a previous study on barley[13]. The sub-subplots were occupied by the selected mutant barley varieties. The 15 different cultivars constituting four mutant cultivars, Golden Promise (*ari-e.GP*), *ari-e.1*, *ari-e.156* and *ari-e.228*, along with the parental lines Maythorpe, Bonus, Foma, California Marriot, Gustoe and 6 local promising cultivars constituted the sub-sub plot factor. Each experimental plot consisted of one replicate of each genotype under one of the treatments in six rows of 2.5 m in length with 20 cm in-row spacing. Seeds were sown on November, 15 in 2016 and harvested on May, 16 in 2017. No noticeable crop damage was observed due to weeds, insects or diseases. All agronomic practices were performed according to the precise high-yielding cultivation system. The growth and yield of these genotypes under a combination of different irrigation and fertilization treatments were determined under Kuwait environmental conditions. Yield and quality parameters such as number of days to heading and maturity, number of spikes per square meter (m^2), number of kernels per spike, plant height, 1000 kernel weight and grain yield (kg ha^{-1}), flag leaf area and chlorophyll index were measured upon maturity.

RESULTS

This study investigated the effect of two different irrigation regimes (100 and 75% of potential water use) and three levels of nitrogen fertilizer application rates (0, 50 and 100 kg N ha^{-1}) on yield, yield components and WUE responses of 15 barley varieties. The variance of analysis (F-values) on yield, yield components and water use efficiency of barley genotypes shown in Table 3 and have different significant values. Nitrogen has a significant effect.

Plant height: The experimental results revealed a significant effect ($p<0.01$) of nitrogen application rates on the plant height. The mean value of plant height for the fifteen cultivars was highest with N3 treatment (94.93 cm) under T_1 irrigation treatment and the lowest value was noted under N_1 nitrogen treatment (78.36 cm) with T_2 irrigation in Table 4. However, irrigation treatments did not impose a significant effect and an interactive effect was noted between genotype, irrigation and nitrogen factors for the plant height.

Table 3: Variance of analysis (F-values) on yield, yield components and water use efficiency of barley genotypes

	Plant height	Number of spikes m^{-2}	Number of kernels per spike	Thousand kernel weight	Grain yield	Total biomass	Harvest index	Water use efficiency
Variety	0.64^{ns}	0.70^{ns}	2.28**	2.52**	0.70^{ns}	0.32^{ns}	1.29^{ns}	0.34^{ns}
Irrigation	3.11^{ns}	42.03***	5.32*	23.54***	7.78**	0.00^{ns}	4.44*	2.95^{ns}
Nitrogen	36.89**	78.35***	0.28^{ns}	29.91***	67.26***	41.74***	0.27^{ns}	73.49***
Variety*irrigation	0.66^{ns}	0.68^{ns}	0.88^{ns}	0.60^{ns}	0.23^{ns}	0.16^{ns}	0.62^{ns}	0.14^{ns}
Variety*nitrogen	0.50^{ns}	0.64^{ns}	0.93^{ns}	0.55^{ns}	0.26^{ns}	0.14^{ns}	0.73^{ns}	0.17^{ns}
Irrigation*nitrogen	2.29^{ns}	1.01^{ns}	2.99^{ns}	5.45**	2.75^{ns}	0.94^{ns}	0.07^{ns}	2.65^{ns}
Variety*irrigation*nitrogen	0.59^{ns}	0.42^{ns}	0.94^{ns}	0.81^{ns}	0.57^{ns}	0.17^{ns}	1.08^{ns}	0.22^{ns}

ns: Non-significant. *, **, *** showed different significant values ($p \leq 0.05$)

Table 4: Plant height (cm) of 15 barley cultivars under different irrigation and nitrogen treatments

	T_1				T_2				
Genotype	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	Mean
Kuwait 1	72.67	84.67	89.67	82.34	74.33	92.00	86.67	84.33	83.33[a]
Kuwait 2	82.33	89.00	98.33	89.89	77.67	94.00	86.67	86.11	88.00[a]
Kuwait 3	87.00	89.33	95.67	90.67	73.33	94.00	88.00	85.11	87.89[a]
Kuwait 4	86.67	96.00	95.00	92.56	82.67	74.67	85.00	80.78	86.67[a]
Kuwait 5	77.33	78.67	89.67	81.89	75.00	93.33	75.67	81.33	81.61[a]
Kuwait 6	82.33	91.33	90.33	88.00	82.67	94.00	90.33	89.00	88.50[a]
ari-e. GP	77.33	86.33	103.67	89.11	80.00	89.00	88.67	85.89	87.50[a]
ari-e.1	78.33	94.00	96.33	89.55	81.00	92.00	92.00	88.33	88.94[a]
ari-e.156	74.33	94.33	98.67	89.11	74.33	94.33	89.33	86.00	87.56[a]
ari-e.228	74.33	95.33	97.33	89.00	77.67	93.00	87.00	85.89	87.44[a]
Maythorpe	88.00	90.00	96.67	91.56	74.33	84.33	91.67	83.44	87.50[a]
Bonus	72.67	89.33	92.67	84.89	84.67	88.67	95.33	89.56	87.22[a]
Foma	81.00	87.67	95.00	87.89	83.67	84.33	92.00	86.67	86.89[a]
California marriott	78.67	91.00	99.67	89.78	76.00	89.33	90.67	85.33	87.55[a]
Gustoe	71.33	91.33	85.33	82.66	78.00	89.67	87.33	85.00	83.83[a]
Mean	78.95	89.89	94.93	87.93	78.36	89.78	88.42	85.52	86.70

N_1 (Control): 0 kg N ha^{-1}, N_2: 50 kg N ha^{-1}, N_3: 100 kg N ha^{-1}, T_1: 100% irrigation, T_2: 75% irrigation, Mean values with 'a' superscripts in the column were significantly different ($p \leq 0.05$)

Number of spikes m^{-2}: The number of spikes m^{-2} differed significantly ($p<0.01$) between T_1 and T_2 irrigation treatments. The mean number of spikes m^{-2} was highest with 75% irrigation under N3 (167) given in Table 5. All the fifteen cultivars exhibited a higher mean value of the number of spikes m^{-2} under T_2 irrigation in comparison to T_1 (Table 5). Similarly, the three different nitrogen treatments significantly affected the number of spikes m^{-2} where it increased with increasing doses of nitrogen under both the irrigation treatments. With 100% irrigation, the cultivars under N_1 nitrogen treatment produced the least number of spikes m^{-2} (78) in comparison to plants under 50 kg N ha^{-1} (131) and 100 kg N ha^{-1} (147) treatments respectively. Similarly, the plants with N_1 treatment recorded the least number of spikes m^{-2} (107) in comparison to N_2 (163) and N_3 treatments (167) under 75% irrigation.

Number of kernels per spike: The number of kernels per spike differed significantly between the fifteen different cultivars under study ($p<0.01$). The cultivar Kuwait 5 presented the highest mean value with 53 kernels per spike under T_2 irrigation and the cultivar California Marriot exhibited the least value of 28 kernels per spike with T1irrigation given in Table 6. Similarly, the cultivars presented a significant difference in the number of kernels per spike between the two irrigation treatments ($p<0.05$). The mean value obtained by averaging the number of kernels per spike of all the barley cultivars for three nitrogen treatments was highest with T_2 irrigation treatment (39) when compared to the mean value for the three nitrogen treatments under T_1 irrigation treatment (37) (Table 6). The cultivars Kuwait 1 (42), Kuwait 2 (40), Kuwait 3 (35), Kuwait 5 (53), *ari-e.*1 (35), *ari-e.*228 (40), Bonus (39) and California Marriot (40) exhibited a higher mean number of kernels per spike under T_2 irrigation in comparison to its mean California Marriot (40) exhibited a higher mean number of kernels per spike under T_2 irrigation in comparison to its mean value for three nitrogen treatments under T_1 irrigation (Table 6). In contrast, it did not vary significantly between the three different nitrogen treatments and a significant interaction was not noted between the varietal difference, irrigation and nitrogen treatments.

Thousand kernel weight: The thousand kernel weight differed significantly ($p<0.05$) between the fifteen different cultivars under study. The cultivar *ari-e.228* presented the highest mean value for thousand kernel weight (47.68 g) under T_2 irrigation, whereas the lowest value was reported by cultivar *ari-e. GP* (38.05 g) given in Table 7. The thousand kernel weight of the cultivars varied significantly between the two irrigation treatments T_1 and T_2 as well as the three nitrogen treatments N_1, N_2 and N_3 ($p<0.001$). The mean value for thousand kernel weight with T_2 irrigation treatment (45.60 g) was higher than T_1 treatment (43.01) (Table 7). All the fifteen cultivars exhibited a higher mean value of thousand kernel weight under T_2 irrigation in comparison to T_1 (Table 7). The significant interactive effect noted between irrigation and nitrogen treatment revealed the highest mean value for thousand kernel weight (48.08 g) (Table 7) for the cultivars subjected to N_3 treatment under T_2 irrigation treatment.

Table 5: Number of spikes m^{-2} of 15 barley cultivars under different irrigation and nitrogen treatments

	T_1				T_2				
Genotype	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	Mean
Kuwait 1	89	144	138	82	89	156	171	139	131[a]
Kuwait 2	86	130	148	90	130	138	160	143	132[a]
Kuwait 3	85	130	151	91	115	179	172	155	139[a]
Kuwait 4	92	137	145	93	89	153	166	136	130[a]
Kuwait 5	115	118	154	82	125	171	166	154	138[a]
Kuwait 6	75	127	149	88	114	172	181	155	136[a]
ari-e. GP	87	145	161	89	126	172	187	162	146[a]
ari-e.1	84	156	145	90	115	146	158	140	134[a]
ari-e.156	53	159	166	89	85	163	172	140	133[a]
ari-e.228	65	143	154	89	114	169	170	151	123[a]
Maythorpe	101	121	133	92	98	149	168	138	128[a]
Bonus	58	105	145	85	118	155	159	144	123[a]
Foma	67	95	135	88	101	164	170	145	122[a]
California marriott	55	128	154	90	103	169	162	144	128[a]
Gustoe	51	121	122	83	86	190	150	142	120[a]
Mean	78	131	147	88	107	163	167	146	131

N_1 (Control): 0 kg N ha^{-1}, N_2: 50 kg N ha^{-1}, N_3: 100 kg N ha^{-1}, T_1: 100% irrigation, T_2: 75% irrigation, Mean values with 'a' superscripts in the column were significantly different ($p\leq 0.05$)

Table 6: Number of kernels per spike of 15 barley cultivars under different irrigation and nitrogen treatments

	T_1				T_2				
Genotype	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	Mean
Kuwait 1	40	35	41	38	38	46	42	42	38[ab]
Kuwait 2	33	42	35	37	35	38	46	40	40[ab]
Kuwait 3	44	28	30	34	33	36	36	35	34[ab]
Kuwait 4	40	48	30	39	32	36	38	35	37[ab]
Kuwait 5	40	29	48	39	57	50	52	53	48[c]
Kuwait 6	32	42	40	38	33	41	38	37	36[ab]
ari-e. GP	39	36	42	39	34	39	42	38	38[ab]
ari-e.1	30	38	28	32	30	39	36	35	33[a]
ari-e.156	38	48	47	44	39	37	48	41	44[bc]
ari-e.228	31	43	33	36	43	32	45	40	37[ab]
Maythorpe	44	33	38	39	40	32	43	38	38[ab]
Bonus	40	30.	36	36	32	44	40	39	36[ab]
Foma	41	41	31	38	37	35	39	38	37[ab]
California marriott	25	26	33	28	34	46	39	40	33[a]
Gustoe	47	37	40	42	38	44	40	41	38[ab]
Mean	38	37	37	37	37	40	42	39	38

N_1 (Control): 0 kg N ha^{-1}, N_2: 50 kg N ha^{-1}, N_3: 100 kg N ha^{-1}, T_1: 100% irrigation, T_2: 75% irrigation, a, b, c Mean values with different superscripts in each column were significantly different ($p\leq 0.05$)

Grain yield: The grain yield varied significantly between the two irrigation treatments ($p<0.01$). The T_2 irrigation treatment recorded the highest mean grain yield (3.43 kg ha^{-1}) in comparison to T_1 (3.15 kg ha^{-1}) given in Table 8 taking into account the mean value of all barley cultivars and nitrogen treatments. The cultivars Kuwait 1 (3.26 kg ha^{-1}), Kuwait 2 (3.11 kg ha^{-1}), Kuwait 3 (3.44 kg ha^{-1}), Kuwait 5 (3.63 kg ha^{-1}), Kuwait 6 (3.71 kg ha^{-1}), *ari-e.GP* (3.52 kg ha^{-1}), *ari-e*.1 (3.56 kg ha^{-1}), *ari-e*.156 (3.29 kg ha^{-1}), *ari-e*.228 (3.52 kg ha^{-1}), Maythorpe (3.56 kg ha^{-1}), Bonus (3.38 kg ha^{-1}), Foma (3.51 kg ha^{-1}), Gustoe (3.45 kg ha^{-1}) recorded the highest mean grain yield value with T2 irrigation in comparison to T_1 treatment (Table 8). Similarly, the grain yield also varied significantly between the three different nitrogen treatments ($p<0.001$). With T_1 irrigation, N_1 recorded the lowest value (2.14 kg ha^{-1}) whereas the highest value (3.82 kg ha^{-1}) was recorded under N_3 treatment (Table 8). Similarly, T_2 irrigation recorded the lowest grain yield (2.72 kg N ha^{-1}) with N_1 treatment, while N_2 treatment displayed the highest grain yield (3.81 kg ha^{-1}) (Table 8). Furthermore, no significant interaction was observed between varieties, irrigation and nitrogen treatments (Table 8).

Table 7: Thousand kernel weight (g) of 15 barley cultivars under different irrigation and nitrogen treatments

	T_1				T_2				
Genotype	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	Mean
Kuwait 1	37.04^{a}	43.64^{a}	42.62^{ab}	41.10	41.55^{a}	42.42^{a}	47.22^{a}	43.73	42.42
Kuwait 2	37.47^{a}	47.44^{a}	45.37^{b}	43.43	45.89^{a}	47.79^{cde}	49.18^{abc}	47.62	45.52
Kuwait 3	41.04^{a}	44.68^{a}	46.52^{b}	44.08	47.00^{a}	46.36^{bcde}	48.42^{abc}	47.26	45.67
Kuwait 4	41.27^{a}	41.73^{a}	41.89^{ab}	41.63	41.96^{a}	42.57^{ab}	46.74^{abc}	43.76	42.69
Kuwait 5	40.25^{a}	43.11^{a}	40.89^{ab}	41.42	40.84^{a}	43.09^{abc}	49.04^{abc}	44.32	42.86
Kuwait 6	40.50^{s}	45.91^{a}	47.95^{b}	44.79	43.69^{a}	48.00^{de}	50.51^{bc}	47.40	46.09
ari-e. GP	38.05^{s}	45.05^{a}	32.65^{a}	38.58	43.35^{a}	44.79^{abcde}	48.59^{abc}	45.58	42.08
*ari-e.*1	38.51^{s}	46.42^{a}	45.50^{b}	43.48	43.77^{a}	44.25^{abcd}	49.17^{abc}	45.73	44.60
*ari-e.*156	39.70^{a}	47.32^{a}	47.13^{b}	44.72	43.44^{a}	46.72^{bcde}	48.57^{abc}	46.24	45.48
*ari-e.*228	41.12^{a}	48.52^{a}	46.45^{b}	45.36	44.56^{a}	47.08^{bcde}	51.40^{c}	47.68	46.52
Maythorpe	39.36^{a}	43.76^{a}	43.65^{b}	42.26	40.94^{a}	42.45^{ab}	44.89^{ab}	42.76	42.51
Bonus	39.92^{a}	46.35^{a}	43.65^{b}	43.31	43.36^{a}	46.63^{bcde}	46.11^{abc}	45.37	44.34
Foma	41.24^{a}	46.02^{a}	49.42^{b}	45.56	44.50^{a}	49.22^{e}	47.06^{abc}	46.93	46.24
California marriott	38.88^{a}	44.69^{a}	49.44^{b}	44.34	43.69^{a}	45.63^{bcde}	48.01^{abc}	45.78	44.78
Gustoe	38.30^{a}	43.86^{a}	41.16^{ab}	41.11	42.50^{a}	42.91^{ab}	46.35^{abc}	43.92	42.99
Mean	39.51	45.23	44.29	43.01	43.40	45.33	48.08	45.60	44.32

N_1 (Control): 0 kg N ha^{-1}, N_2: 50 kg N ha^{-1}, N_3: 100 kg N ha^{-1}, T_1: 100% irrigation, T_2: 75% irrigation, a, b, c, d, e, f, g: Mean values with different superscripts in each column were significantly different ($p \leq 0.05$)

Table 8: Grain yield (kg ha^{-1}) of 15 barley cultivars under different irrigation and nitrogen treatments

	T_1				T_2				
Genotype	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	Mean
Kuwait 1	2.00	3.67	3.67	3.11	2.43	3.67	3.67	3.26	3.20^{a}
Kuwait 2	1.33	2.57	3.67	2.52	2.57	3.33	3.43	3.11	2.80^{a}
Kuwait 3	2.33	3.23	3.67	3.08	3.33	3.57	3.43	3.44	3.27^{a}
Kuwait 4	2.67	3.77	3.77	3.40	2.77	3.33	4.00	3.37	3.40^{a}
Kuwait 5	2.77	3.57	3.90	3.41	2.77	4.23	3.90	3.63	3.53^{a}
Kuwait 6	2.33	3.33	3.77	3.14	2.57	4.23	4.33	3.71	3.43^{a}
ari-e. GP	1.43	3.67	3.57	2.89	2.90	4.10	3.57	3.52	3.20^{a}
*ari-e.*1	2.43	3.67	3.67	3.26	2.77	4.00	3.90	3.56	3.40^{a}
*ari-e.*156	2.10	3.90	3.43	3.14	2.43	3.43	4.00	3.29	3.23^{a}
*ari-e.*228	2.67	3.67	3.90	3.41	2.43	3.90	4.23	3.52	3.47^{a}
Maythorpe	2.10	3.43	4.00	3.18	2.57	4.10	4.00	3.56	3.37^{a}
Bonus	1.77	3.43	3.67	2.96	2.90	3.57	3.67	3.38	3.17^{a}
Foma	2.23	3.10	4.57	3.30	3.00	4.43	3.10	3.51	3.40^{a}
California marriott	1.90	3.57	4.23	3.23	2.67	3.43	3.57	3.22	3.27^{a}
Gustoe	2.10	3.57	3.77	3.15	2.67	3.90	3.77	3.45	3.30
Mean	2.14	3.48	3.82	3.15	2.72	3.81	3.77	3.43	3.30

N_1 (Control): 0 kg N ha^{-1}, N_2: 50 kg N ha^{-1}, N_3: 100 kg N ha^{-1}, T_1: 100% irrigation, T_2: 75% irrigation, Mean values with 'a' superscripts in the column were significantly different ($p \leq 0.05$)

Harvest index: The irrigation treatments significantly affected the harvest index of the plants ($p<0.05$) where T_2 irrigation treatment displayed the highest mean harvest index values (40.74) in comparison to T_1 irrigation (38.91) given in Table 9. The cultivars Kuwait 2 (39.73), Kuwait 3 (40.54), Kuwait 5 (44.21), *ari-e.GP* (40.37), *ari-e.*1 (40.26), *ari-e.*156 (40.56), Maythorpe (40.50), Bonus (41.81), Foma (39.33) and Gustoe (41.47) exhibited higher mean harvest index values under T_2 in comparison to T_1irrigation (Table 9). However, it did not vary significantly between the fifteen different cultivars in the study. Likewise, the three nitrogen treatments did not vary the harvest index of the cultivars significantly and no significant interaction was observed between varieties, irrigation and nitrogen treatments.

Total biomass: The nitrogen treatments imposed a significant effect on total biomass where the higher nitrogen rates increased the mean value of total biomass yield under both irrigation levels. Under T_1 irrigation treatment, N_3 nitrogen treatment recorded the highest mean value for total biomass (10.01 kg ha^{-1}) in comparison to 5.47 kg ha^{-1} with N_1 treatment given in Table 10. Similarly, the highest mean total biomass value was noted under N_3 nitrogen treatment (9.39 kg ha^{-1}) followed by N_2 (9.33 kg ha^{-1}) and N_1 treatment (6.61 kg ha^{-1}) under T_2 irrigation treatment. However, a significant difference was not noted between the fifteen different cultivars as well as the two different irrigation treatments. Additionally, no significant interaction was observed among varieties, irrigation and fertilizer treatments (Table 10).

Table 9: Harvest index of 15 barley cultivars under different irrigation and nitrogen treatment

	T_1				T_2				
Genotype	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	Mean
Kuwait 1	39.22	45.88	36.70	40.60	41.19	39.76	39.34	40.10	39.65[a]
Kuwait 2	27.14	31.73	40.02	32.96	38.53	41.11	39.56	39.73	36.04[a]
Kuwait 3	42.91	40.38	35.53	39.61	44.82	38.68	38.11	40.54	39.40[a]
Kuwait 4	45.25	40.41	39.68	41.78	42.16	37.97	43.34	41.16	40.33[a]
Kuwait 5	43.08	42.86	42.53	42.82	46.17	44.20	42.25	44.21	42.53[a]
Kuwait 6	44.55	41.11	37.70	41.12	35.55	43.30	42.87	40.57	39.88[a]
ari-e. GP	28.04	39.34	32.96	33.45	40.85	42.40	37.86	40.37	36.78[a]
ari-e.1	42.86	39.34	37.95	40.05	40.92	39.10	40.75	40.26	38.77[a]
ari-e.156	39.40	39.39	34.89	37.89	42.11	37.16	42.42	40.56	38.32[a]
ari-e.228	46.27	39.76	38.35	41.46	39.00	41.36	40.95	40.44	39.57[a]
Maythorpe	33.18	40.02	40.69	37.96	41.25	42.40	37.84	40.50	39.32[a]
Bonus	33.21	40.02	35.53	36.25	39.56	42.35	43.53	41.81	38.52a
Foma	39.33	35.35	40.91	38.53	42.25	42.88	32.87	39.33	38.20[a]
California marriott	38.78	41.18	42.30	40.75	41.52	39.56	39.23	40.10	39.73[a]
Gustoe	42.00	36.06	37.07	38.38	42.18	40.33	41.89	41.47	38.51[a]
Mean	39.01	39.52	38.19	38.91	41.20	40.84	40.19	40.74	39.04

N_1 (Control): 0 kg N ha^{-1}, N_2: 50 kg N ha^{-1}, N_3: 100 kg N ha^{-1}, T_1: 100% irrigation, T_2: 75% irrigation, Mean values with 'a' superscripts in the column were significantly different ($p \leq 0.05$)

Table 10: Total biomass (kg ha^{-1}) of 15 barley cultivars under different irrigation and nitrogen treatments

	T_1				T_2				
Genotype	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	Mean
Kuwait 1	5.10	8.00	10.00	7.70	5.90	9.23	9.33	8.15	8.07[a]
Kuwait 2	4.90	8.10	9.17	7.39	6.67	8.10	8.67	7.81	7.77[a]
Kuwait 3	5.43	8.00	10.33	7.92	7.43	9.23	9.00	8.55	8.30[a]
Kuwait 4	5.90	9.33	9.50	8.24	6.57	8.77	9.23	8.19	8.43[a]
Kuwait 5	6.43	8.33	9.17	7.98	6.00	9.57	9.23	8.27	8.30[a]
Kuwait 6	5.23	8.10	10.00	7.78	7.23	9.77	10.10	9.03	8.60[a]
ari-e. GP	5.10	9.33	10.83	8.42	7.10	9.67	9.43	8.73	8.70[a]
ari-e.1	5.67	9.33	9.67	8.22	6.77	10.23	9.57	8.86	8.77[a]
ari-e.156	5.33	9.90	9.83	8.35	5.77	9.23	9.43	8.14	8.43[a]
ari-e.228	5.77	9.23	10.17	8.39	6.23	9.43	10.33	8.66	8.77[a]
Maythorpe	6.33	8.57	9.83	8.24	6.23	9.67	10.57	8.82	8.57[a]
Bonus	5.33	8.57	10.33	8.08	7.33	8.43	8.43	8.06	8.23a
Foma	5.67	8.77	11.17	8.54	7.10	10.33	9.43	8.95	8.90[a]
California marriott	4.90	8.67	10.00	7.86	6.43	8.67	9.10	8.07	8.23[a]
Gustoe	5.00	9.90	10.17	8.36	6.33	9.67	9.00	8.33	8.57[a]
Mean	5.47	8.81	10.01	8.10	6.61	9.33	9.39	8.44	8.44

N_1 (Control): 0 kg N ha^{-1}, N_2: 50 kg N ha^{-1}, N_3: 100 kg N ha^{-1}, T_1: 100% irrigation, T_2: 75% irrigation, Mean values with 'a' superscripts in the column were significantly different ($p \leq 0.05$)

Effects of irrigation and nitrogen treatments on water use efficiency: The nitrogen treatments revealed a significant impact by producing increased water use efficiency with increased nitrogen application rates. The water use efficiency significantly varied between the nitrogen treatments displaying the highest mean water use efficiency value with N_3 and lowest value with N_1 treatments under both the irrigation treatments. With T_1 irrigation treatment, the highest value was noted with N_3 treatment (0.99) followed by N_2 (0.90) and N_1 (0.56) treatments. Under T_2 irrigation, N_3 (0.96) as well as N_2 (0.96) treatments, exhibited 29.17% higher water use efficiency in comparison to N_1 treatment (0.68) given in Table 11. In contrast, water use efficiency did not vary significantly between the two different irrigation treatments applied in the experiment. Even though 75% irrigation treatment displayed the highest mean water use efficiency value (0.86), it failed to display a significant difference with the mean value under100% irrigation treatment (0.82). Similarly, the varietal difference did not impose any significant difference in the water use efficiency (Table 11).

Correlation analysis: Pearson correlation analysis was conducted to study the linear relationship between the eight dependent variables in the study. The correlation relationships illustrated at both 99 and 95% significant levels were represented by two and one stars respectively given in Table 12. The first variable in the test, the plant height displayed a high positive correlation with five variables in the

Table 11: Water use efficiency of 15 different barley genotypes subjected to different irrigation and nitrogen treatments

	T_1				T_2				
Genotype	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	Mean
Kuwait 1	0.52	0.82	0.99	0.78	0.62	0.94	0.96	0.84	0.81[a]
Kuwait 2	0.50	0.83	0.94	0.76	0.68	0.83	0.89	0.80	0.80[a]
Kuwait 3	0.56	0.82	1.01	0.80	0.76	0.94	0.92	0.88	0.84[a]
Kuwait 4	0.60	0.96	0.98	0.85	0.67	0.90	0.94	0.84	0.84[a]
Kuwait 5	0.66	0.85	0.94	0.82	0.61	0.98	0.94	0.85	0.83[a]
Kuwait 6	0.53	0.83	0.99	0.78	0.74	1.00	1.04	0.93	0.86[a]
ari-e. GP	0.52	0.99	1.00	0.84	0.73	0.99	0.97	0.89	0.87[a]
*ari-e.*1	0.59	0.96	0.97	0.84	0.69	1.05	0.98	0.91	0.87[a]
*ari-e.*156	0.55	1.01	0.94	0.83	0.59	0.94	0.97	0.83	0.83[a]
*ari-e.*228	0.59	0.94	1.04	0.86	0.64	0.97	1.06	0.89	0.87[a]
Maythorpe	0.65	0.88	0.98	0.83	0.64	0.99	1.08	0.90	0.87[a]
Bonus	0.55	0.88	0.99	0.80	0.75	0.86	0.86	0.83	0.82[a]
Foma	0.58	0.90	1.10	0.86	0.73	1.06	0.97	0.92	0.89[a]
California marriott	0.50	0.89	1.01	0.80	0.66	0.89	0.93	0.83	0.81[a]
Gustoe	0.51	1.01	1.01	0.85	0.65	0.99	0.92	0.85	0.85[a]
Mean	0.56	0.90	0.99	0.82	0.68	0.96	0.96	0.86	0.84[a]

N_1 (Control): 0 kg N ha^{-1}, N_2: 50 kg N ha^{-1}, N_3: 100 kg N ha^{-1}, T_1: 100% irrigation, T_2: 75% irrigation, Mean values with 'a' superscripts in the column were significantly different ($p \leq 0.05$)

following order, total biomass (0.768), water use efficiency (0.753), grain yield (0.664), number of spikes m^{-2} (0.653) and thousand kernel weight (0.402), whereas it was negatively correlated with harvest index (-0.170). Similarly, a high positive correlation was expressed by the number of spikes, the second variable with five dependent variables as follows, water use efficiency (0.862), total biomass (0.850), grain yield (0.827), plant height (0.653)and thousand kernels weight (0.643). The third variable, the number of kernels per spike expressed a very weak positive correlation relationship with the other dependent variables. The number of spikes was seen to be the highest correlated figure (0.254) with the number of kernels per spike. With the fourth test variable thousand kernel weight, the highest positive correlation was displayed by the grain yield (0.646) followed by the number of spikes (0.643), water use efficiency (0.633), total biomass (0.600) and plant height (0.402). The grain yield recorded a very strong positive correlation relationship with six other dependent variables of which water use efficiency (0.940), total biomass (0.930) and the number of spikes (0.827) expressed the strongest positive correlation. The sixth variable harvest index possessed a weak correlation relationship with the other dependent variables. The seventh dependent variable, total biomass recorded a mixture of positive, high, weak and negative correlation with other variables. The highest positively correlated dependent variable was water use efficiency (0.995) followed by the grain yield (0.930), the number of spikes (0.850), plant height (0.768) and the kernel weight (0.600). The eighth dependent variable water use efficiency displayed a high positive correlation with the total biomass (0.995) followed by the grain yield (0.940), number of spikes (0.862), plant height (0.753) and thousand kernel weight (0.633) while a negative correlation (-0.022) was noted with the harvest index (Table 12).

Regression analysis: Multiple regression analysis was carried out to estimate the relationship between independent variables (irrigation and nitrogen treatments) and dependent variables in the study. The results revealed the significant effect of irrigation as well as nitrogen treatments on all parameters except the number of kernels per spike. The correlation coefficient (R) values noted a strong relationship of plant height, number of spikes m^{-2}, thousand kernel weight, grain yield, total biomass and water use efficiency with irrigation and nitrogen. The number of kernels per spike and harvest index revealed a weak relationship with the independent variables. The irrigation imposed a negative effect on all parameters except plant height denoting the highest values under 75% irrigation. In contrast, the nitrogen treatments imposed a positive effect on all parameters except total biomass yield. The unstandardized coefficients have shown that a change in the irrigation and nitrogen application by one unit could change the number of spikes, thousand kernel weight, grain yield, water use efficiency by -1.102 and 0.647 spikes,-0.104 and 0.047 g, -0.012 and 0.014 g, -0.002 and 0.004 units respectively. The nitrogen did not possess any significant effect on the harvest index whereas every change in the irrigation treatment by one unit could change the harvest index by -0.073. In contrast, irrigation did not possess any significant effect on the total biomass whereas every change in nitrogen application rate by one unit could change its value by 0.037 given in Table 13.

Table 12: Pearson correlation analysis

	Plant height	Number of spikes m^{-2}	Number of kernels per spike	Thousand kernel weight	Grain yield	Total biomass	Harvest index	Water use efficiency
Plant height	1.000	0.653**	0.036	0.402**	0.664**	-0.170	0.768**	0.753**
Number of spikes m^{-2}	0.653**	1.000	0.254*	0.643**	0.827**	00.025	0.850**	0.862**
Number of kernels per spike	0.036	0.254*	1.000	0.042	0.097	0.018	0.098	0.099
Thousand kernel weight (g)	0.402**	0.643**	0.042	1.000	0.646**	0.168	0.600**	0.633**
Grain yield (g)	0.664**	0.827**	0.097	0.646**	1.000	0.305**	0.930**	0.940**
Harvest index	-0.170-	0.025	0.018	0.168	0.305**	1.000	-0.053	-0.022
Total biomass	0.768**	0.850**	0.098	0.600**	0.930**	-0.053	1.000	0.995**
Water use efficiency	0.753**	0.862**	0.099	0.633**	0.940**	-0.022	0.995**	1.000

*, **, *** showed different significant values ($p \leq 0.05$)

Table 13: Multiple regression analysis of irrigation and nitrogen doses on yield and yield components

			Unstandardized coefficients			Standardized coefficients		Significance		
Variables	R	Adjusted R square	Constant	Irrigation	Nitrogen	Irrigation	Nitrogen	Constant	Irrigation	Nitrogen
Plant height	0.72[a]	0.52	71.79	0.09	0.13	0.16	0.70	0.000	0.037	0.000
No. of spikes m^{-2}	0.858[a]	0.731	196.12	-1.102	0.647	-0.397	0.761	0.000	0.000	0.000
No. of kernels per spike	0.225[a]	0.029	45.14	-0.089	0.019	-0.184	0.129	0.000	0.082	0.219
Thousand kernel weight (g)	0.670[a]	0.437	51.03	-0.104	0.047	-0.374	0.556	0.000	0.000	0.000
Grain yield (g)	0.803[a]	0.636	3.62	-0.012	0.014	-0.202	0.777	0.000	0.002	0.000
Harvest index	0.280[a]	0.057	46.71	-0.073	-0.009	-0.259	-0.106	0.000	0.014	0.304
Total biomass	0.865[a]	0.743	7.65	-0.014	0.037	-0.099	0.859	0.000	0.068	0.000
Water use efficiency	0.859[a]	0.732	0.822	-0.002	0.004	-0.132	0.849	0.000	0.018	0.000

Mean values with 'a' superscripts in the column were significantly different ($p \leq 0.05$)

DISCUSSION

The yield and yield components such as plant height, number of spikes m^{-2}, thousand kernel weight, grain yield and total biomass exhibited a positive relationship with nitrogen application rates. The parameters displayed superior performance with N_3 and significantly decreased with reduced levels of nitrogen. Irrigation exhibited a negative relationship with the number of spikes m^{-2}, number of kernels per spike, thousand kernel weight, grain yield and harvest index presenting the highest values under 75% irrigation. A significant interactive effect between irrigation and nitrogen treatments was not imposed on any of the components except thousand kernel weight. Likewise, no interaction was noted between irrigation, nitrogen and cultivars for any of the components in the study. Current findings were in agreement with several previous studies that recorded a positive relationship between nitrogen application and yield as well as yield components.

A previous study has noted a decrease in plant height under reduced nitrogen levels owing to slow growth and decreased cell division due to nitrogen deficiency[14]. Similarly, the total number of spikes m^{-2} was shown to decrease with a decreased rate of nitrogen application which could be due to intense competition between plants to survive under reduced nitrogen in another study conducted on barley[14]. In the case of the number of kernels per spike, several earlier studies noted an increase in the number of kernels per spike with nitrogen application in agreement with current findings[15,16]. The increased translocation and assimilation of nitrogen for the synthesis and development of spikelets leads to a higher number of kernels per spike under higher nitrogen application rates during the post-anthesis phase[17]. Likewise, several previous studies noted a linear response of thousand kernel weight to nitrogen[17,18]. The increase in photosynthesis leads to the accumulation of carbohydrate in kernels resulting in an increase in thousand kernel weight with increased rates of nitrogen. Multiple regression analysis noted that total biomass (β = 0.859) revealed a strong positive relationship with nitrogen treatments. In addition, the Pearson correlation analysis has described a highly positive correlation between total plant biomass, grain yield and water use efficiency of the barley cultivars, which implied improved crop water use efficiency, which could lead to enhanced crop yield. Several previous studies have drawn a positive relationship between grain yield and nitrogen application rates[19,20]. In contrast, grain yield was shown to decrease under deficit irrigation in barley in several previous studies[21]. In the case of total biomass, the application of nutrients at adequate levels causes an increase in leaf area index, leaf area ratio resulting in increased interception of solar radiation which in turn increased the total biomass of the crop[22].

The water use efficiency in barley genotypes has increased significantly with increasing rates of nitrogen application under 100% irrigation treatments. The standardized coefficient from multiple regression analysis revealed a strong effect ($p<0.001$) of nitrogen application due to wide range of application rates (100, 50 and 0 kg N ha^{-1}) on water use efficiency, however it did not exhibit a significant relationship with irrigation. In a previous study conducted on the effect of nitrogen fertilization on yield and water use efficiency of canola in Australia, it was shown that the water use efficiency improved with increasing rates of fertilizer at the expense of yield per unit N (GRDC)[23]. The impaired photosynthesis in the nitrogen-deficient crop will reduce the dry matter per unit of transpiration. The effect of irrigation is lower ($p\geq 0.05$), perhaps due to the more limited range of irrigation rates (75 and 100%). Achieving precise irrigation rates under sprinkler irrigated field conditions is a challenge and so the relatively small difference between the 75 and 100% irrigation treatments, may not result in as high significance as between the nitrogen rates. In this context, the higher p-value for the effect of irrigation is to be expected and at less than 0.1 (10%) is likely in line with reasonable expectations for such a sprinkler irrigated experiment. Similarly, the effect of both irrigation and nitrogen together will be lower than the effect of nitrogen alone.

The increase in WUE with increasing nitrogen application rates could be attributed to the increased root length density and root growth in the deeper soil layers that lead to higher water uptake, which in turn leads to higher grain and biomass yield. Although 100% irrigation treatment revealed significantly higher water use efficiency with 100 kg N ha^{-1} nitrogen applications, 75% irrigation treatment did not record a significant difference in water use efficiency between 100 and 50 kg N ha^{-1} fertilizer application rates. This could be due to the decrease in the efficiency of N with an increase in drought stress[24]. Similarly, a significant variation in the water use efficiency values between the irrigation treatments was noted only with 100 kg N ha^{-1} nitrogen application rates where 75% irrigation recorded higher water use efficiency values. The barley genotypes under 50 as well as 0 kg N ha^{-1} treatments did not express a significant difference in their water use efficiency between the two irrigation rates. Besides, Pearson correlation analysis has described a highly positive correlation between total plant biomass, grain yield and water use efficiency of the barley cultivars, which implied improved crop water use efficiency, which could lead to enhanced crop yield.

Crop production per unit area of land will typically be highest when neither water nor nutrients are limiting and also neither is in excess. Crop production will be reduced if there is either insufficient water or nutrients. Excess water in soils with slow drainage may cause water logging and yield reduction. However, in freely draining sandy soils such as in this experiment, excess water will not cause crop stress and yield reduction but could result in leaching of soluble nutrients such as nitrogen below the root zone. This leaching may then result in stress due to insufficient nitrogen or can result in extra cost for applying additional nitrogen to compensate for the leaching loss. In contrast to yield per unit area, when crop production per unit volume of applied water is considered, a reduction in applied water that causes moderate stress and hence some yield reduction, often increase production per unit volume of water. This is because the relative reduction in yield per unit area may be small compared to the relative reduction in the volume of applied water. The results were in agreement with a similar study conducted in Egypt with an arid climatic condition, that investigated the effect of different levels of water treatments (full and desiccated watering) and five different nitrogen levels (0, 35, 70, 105 and 140 kg N ha^{-1}) on barley in moderately salt-affected soil. It was shown that water use efficiency did not vary significantly between the two irrigation treatments. In contrast, nitrogen treatments imposed a significant effect, which increased water use efficiency with increased nitrogen application rate and delivered the highest water use efficiency at 105 or 140 kg N ha^{-1}[25]. In the present study, the application of either 100 or 75 kg N ha^{-1} revealed the highest water use efficiency value. A previous study conducted in forage species reported that crop water use efficiency is adversely affected under limited nitrogen conditions as the transpiration decreases relative to soil water evaporation[26]. Another study conducted in southern Mediterranean regions on barley has shown that total biomass yield and grain yield was positively related to nitrogen uptake and mainly manifested through changes in water use efficiency[27]. Likewise, similar results were obtained from a previous study conducted in semi-arid regions of China on winter wheat which demonstrated improved WUE with increasing nitrogen application rates and the highest WUE was recorded with 120 kg N ha^{-1}[28]. Another study conducted in a semiarid Mediterranean agroecosystem has reported an increase in yield and water use efficiency by 98 and 77% respectively with nitrogen fertilization under conservation agriculture practices. The long-term application of conservation agricultural practices has improved soil water content, which eventually increased the crop response to increased nitrogen fertilization[29].

CONCLUSION

Improved crop yield and resource use efficiency are the key factors in enhancing crop production in any agricultural system that relies majorly upon irrigation and intense fertilization. The study identified moderate nitrogen application of 50 kg N ha^{-1} under 75% irrigation as the best water and fertilizer application rate for the selected barley cultivars as it produced the best grain yield, total biomass yield, harvest index and water use efficiency values. The yield, yield components and water use efficiency tend to increase with increasing doses of nitrogen, while it decreased with increasing rates of irrigation. A complex relationship exists between water use efficiency and yield under different irrigation and nitrogen regimes. A crop with higher water use efficiency generally reveals higher crop yield. Thus, a crop that consumes less water and maintains higher yield productivity is recommended for cultivation in these water-scarce regions.

SIGNIFICANCE STATEMENT

This study discovered that deficit irrigation of 75% ET0 at moderate nitrogen application of 50 kg N ha^{-1} could improve barley yield and water use efficiency under an arid environment. This could be beneficial to enhance sustainable barley production in arid as well as semi-arid countries under reduced water and fertilizer use. This study will help the researchers to uncover the critical areas of interaction between water and nitrogen application rates on enhancing sustainable barley production that many researchers were not able to explore.

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