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IMPACT OF POTASSIUM ON GROWTH AND YIELD OF BARLEY (*HORDEUM VULGARE* L.) UNDER WATER DEFICIT CONDITIONS

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ABSTRACT

Potassium plays a major role in enhancing tolerance of plants to drought by increasing translocation and maintaining water balance. A field experiment was undertaken to assess the growth and yield of barley (*Hordeum vulgare* L.) under the various irrigation and potassium levels during 2013-14 in a three replicated split plot design. The treatments consisted of three irrigation levels (I_0 = soaking dose, I_1 = one irrigation at 35 days after sowing (DAS) and I_2 = two irrigations at 35 and 70 DAS), and three potassium levels (K_0 = 0.0 kg ha^{-1} (control), K_1 = 25 kg ha^{-1} and K_2 = 50 kg ha^{-1}). The results indicate that irrigation and potassium levels affected significantly ($P \leq 0.05$) the growth and yield of barley. Among irrigation levels, significantly ($P \leq 0.05$) highest grain yield (2474.3 kg ha^{-1}) was recorded with two irrigations (35 and 70 DAS). In case of potassium levels, considerably ($P \leq 0.05$) maximum grain yield (2430.5 kg ha^{-1}) was noted with potassium application rate of 50 kg ha^{-1}. With respect to interactive effects, higher, though statistically equal ($P \geq 0.05$), grain yield (2677.0 and 2570.7 kg ha^{-1}) was documented in interactive effect of irrigation applied twice (35 and 70 DAS) x potassium applied at 50 kg ha^{-1}, and one irrigation (35 DAS) x potassium at 50 kg ha^{-1}, respectively. Our results suggest that potassium can compensate drought stress and its application at 50 kg ha^{-1} coupled with one irrigation (35 DAS) and/or two irrigations (35 and 70 DAS) can be suitable for obtaining optimum yield of barley.

Keywords: barley, growth, Irrigation, potassium, water deficit conditions, yield

INTRODUCTION

Barley (*Hordeum vulgare* L.) is a cereal grain used in bread making individually or in combination with wheat flour, and in preparation of many human foods and beverages. Like wheat and rye, barley contains gluten (Shekhawat *et al*., 2013). Barley is considered as strong crop that could be grown under adverse conditions of climatic i.e. drought conditions and new land (Mishra and Shivakumar, 2000). In the soils where wheat, maize, rice and sugarcane cannot

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be cultivated easily, the barley can be cultivated because it is a tolerant crop and can resist harsh environments. Barley gives good yields with lesser agriculture inputs and it could also replenish the damaged soils (Naheed *et al*., 2015). Barley, like all other crops is affected by the saline soils, but due to its high resistance it can give better yields than other crops (Shaukat, 2013). In Pakistan during 2014-15 barley crop was cultivated on area of 66,000 hectares and the production obtained was 61,000 tons (GoP, 2015). Soliman *et al.* (2011a) reported that tolerance of barley plants to water stress conditions is of advantageous under shortage of irrigation water. Nevertheless, barley has been reported to have four water sensitive growth stages; the germination, booting, anthesis and milky stage. Irrigation management under water deficit conditions is the key factor to achieve desired yields in barley (Soliman *et al.,* 2011b).

Potassium is essentially required for plant growth and needed by plants in large quantities. Cakmak (2005) reported that potassium can enhance drought tolerance in plants by mitigating harmful effects as a result of increasing translocation and maintaining water balance. Potassium has the major role in osmoregulation, photosynthesis, transpiration, stomatal opening and closing, and synthesis of proteins (Milford *et al*., 2007). The researchers like Mengel and Kirkby (2001) reported that low K concentrations in soil during water deficit caused disturbance in stomatal opening. The harmful effects occurring due to drought could be minimized by sufficient supply of potassium (Sangakkara *et al*., 2000). Aown *et al.* (2012) reported that water deficit stress at critical growth stages adversely affected height of plant, spike length, number of spikelets spike^{-1}, number of grains spike^{-1}, seed index (1000-grain weight) and ultimately the grain yield of wheat, but application of potassium compensated the damage caused by water stress. Shekhawat *et al.* (2013) reported that considerable increase was observed in plant height, plant dry matter accumulation, total tillers, effective tillers, grains per spike, spike weight, 1000-grains weight, grain and straw yield of barley due to application of potassium.

The research on effects of drought conditions and potassium on the growth and yield of barley has been carried out mainly in India (Shekhawat *et al*., 2013), Bangladesh (Mollah and Paul, 2011), Iran (Noroozi and Sepanlou, 2013) Egypt (Thalooth *et al*., 2012) and many other countries. During our search for published literature related to this topic, we could not find any study conducted in Pakistan. So this study may be first of its kind in Pakistan. Considering the importance of potassium in water deficient environment, this expeiment was conducted to investigate the impact of potassium levels under water deficit conditions on growth and yield of barley.

MATERIALS AND METHODS

A field experiment was carried out at Students' Experimental Farm, Department of Agronomy, Sindh Agriculture University, Tandojam during *Rabi* 2013-14. The experimental design used was split plot design having three replications. The net plot size kept was 5 m × 3 m (15 m^2). The barley (variety Clipper) seed was sown using single coulter hand drill. The treatment plan comprised of three irrigation levels (I_0 = soaking dose, I_1 = one irrigation at 35 days after sowing (DAS) and I_2 = two irrigations at 35 and 70 DAS), and three potassium levels (K_0 = 0.0 kg ha^{-1} (control), K_1 = 25 kg K_2O ha^{-1} and K_2 = 50 kg K_2O ha^{-1}). The fertilizer form used for potassium was sulphate of potash (SOP). Nitrogen and phosphorus were applied as per recommended dose (Shaukat, 2013). Nitrogen at the rate of 168 kg ha^{-1} as urea fertilizer and phosphorus at the rate of 82 kg ha^{-1} as DAP fertilizer were applied. In case of soaking dose, all the fertilizers (N, P, and K) were applied as basal application. In the plots that were irrigated once, all P and K along with half N were applied as basal dose, and remaining half of N was applied at 1st irrigation. In case of two irrigations, all P and K, and 1/3rd of nitrogen was applied at sowing time and subsequent nitrogen was applied at 1st irrigation and at 2nd irrigation in two splits, respectively. Weeds were controlled by applying Atlantis 3.6% WG at 400 g ha^{-1} (One spray at 30 DAS). In order to record observations for agronomical attributes, five plants were selected at random in each plot and labelled. At maturity, the labelled plants were harvested and threshed manually.

Observations recorded

The observations were recorded for growth and yield parameters of economic importance such as number of tillers per m^2, plant height (cm), spike length (cm), grains $spike^{-1}$, seed index (1000-grain weight, g) and grain yield (kg ha^{-1}).

Statistical analysis

The data collected was statistically analyzed using Statistix version 8.1 (Statistix, 2006). The data was subjected to Two-Way analysis of variance (ANOVA) test. The least significant difference (LSD) test was applied to compare treatments at a probability level of 0.05.

RESULTS AND DISCUSSION

Number of tillers per m^2

The statistical analysis of data showed significant ($P \leq 0.05$) effect of irrigation and potassium levels and their interaction on number of tillers per m^2 of barley. The number of tillers per m^2 was significantly ($P \leq 0.05$) highest (444.0) in two irrigations (35 and 70 DAS) as compared to one irrigation at 35 DAS (388.7) and soaking dose (272.0) (Table 1). Potassium at 50 kg ha^{-1} produced markedly ($P \leq 0.05$) maximum number of tillers (438.3). In case of interactive effects two irrigations at 35 and 70 DAS with potassium at 50 kg K_2O ha^{-1} and one irrigation at 35 DAS with potassium at 50 kg K_2O ha^{-1} produced maximum (497.0 and 485.0 m^{-2}) and statistically similar ($P \geq 0.05$) number of tillers with each other. Our findings are supported by the results of Thalooth *et al*. (2012) who revealed that water stress at different growth stages significantly reduced number of tillers $plant^{-1}$ of barley. Similarly, Shekhawat *et al*. (2013) reported that application of potassium at 40 kg ha^{-1} caused significant increase in total tillers of barley. Maximum tillers $plant^{-1}$ of oats were recorded in three irrigations at 20, 40 and 60 DAS (Akhtar *et al*., 2013).

Table 1. Growth traits of barley as affected by irrigation and potassium levels

Potassium Levels (kg K_2O ha^{-1})	Number of tillers (m^{-2})				Plant height (cm)			
	Irrigation levels				Irrigation levels			
	Soaking dose	35 DAS	35&70 DAS	Mean	Soaking dose	35 DAS	35&70 DAS	Mean
0.0 (control)	213.0	280.0	370.0	287.7c	51.3	56.7	58.0	55.3 c
25	270.0	401.0	465.0	378.7 b	56.7	63.7	67.7	62.7 b
50	333.0	485.0	497.0	438.3 a	59.3	68.3	69.3	65.6 a
Mean	272.0 c	388.7 b	444.0 a	--	55.8 c	62.9 b	65.0 a	--
	Irrigation (I)	Potassium (K)		I x K	Irrigation (I)	Potassium (K)		I x K
SE ±	6.68	4.05		7.02	0.11	0.169		0.29
$LSD_{0.05}$	23.80	10.84		18.12	0.39	0.45		1.09

DAS: days after sowing. Each value is a mean of three replicates; values followed by different letters are significantly different at $P \leq 0.05$.

Plant height (cm)

The data (Table 1) showed that crop under two irrigations (35 and 70 DAS) resulted in considerably ($P \leq 0.05$) tallest plants (65.0 cm). The plant height declined to 62.9 cm in one irrigation (35 DAS) and 55.8 cm in no irrigation (soaking dose). In case of potassium levels, tallest plants (65.6 cm) were noted when crop was fertilized with potassium at 50 kg K_2O ha^{-1}. The plant height was declined to 62.7 cm under potassium at 25 kg K_2O ha^{-1} and lowest plant height (55.3 cm) was registered under control (no applied potassium). For interactive effects, tallest plants of 69.3 and 68.3 cm with non-significant statistical differences ($P \geq 0.05$) with each other were recorded in two irrigation at 35 and 70 DAS with potassium applied at 50 kg K_2O ha^{-1} and one irrigation at 35 DAS with potassium at 50 kg K_2O ha^{-1}. The findings are in concurrence with those revealed by Thalooth *et al*. (2012) who stated that withholding irrigation at any growth stage significantly reduced plant height of barley. Dahmardeh *et al*. (2015) revealed that water stress in dry regions decreased plant height of sorghum but potassium application increased plant height in water stress condition. The results are also in agreement with earlier researchers that height of barley (Shekhawat *et al*., 2013) and wheat plants (Aowan *et al*., 2012) was significantly increased by the application of potassium. The highest plant height was observed in the irrigation level of 40 mm and the lowest was in the control irrigation (Mollah and Paul, 2011).

Spike length (cm)

Spike length is a characteristic that influences number of grains $spike^{-1}$ and finally grain yield. The results (Table 2) indicated that two irrigations at 35 and 70 DAS gave significantly ($P \leq 0.05$) maximum spike length (7.5 cm). The spike length diminished to 6.4 cm under one irrigation at 35 DAS, whereas the minimum spike length (4.6 cm) was recorded under soaking dose. The significantly ($P \leq 0.05$) highest spike length of 6.9 cm was noted under potassium at 50 kg ha^{-1}. The spike length declined to 5.9 cm under potassium applied at 25 kg K_2O ha^{-1} and the minimum spike length of 5.6 cm was noted under control. The data further showed that superior spike length with statistically at par ($P \geq 0.05$) values of 8.5 and 7.4 cm was observed under the interaction of two irrigations at 35 and 70 DAS x potassium applied at 50 kg ha^{-1} and one irrigation at 35 DAS x potassium applied at 50 kg K_2O ha^{-1}. The statistically equal ($P \geq 0.05$) spike length under the interaction of one irrigation x potassium applied at 50 kg K_2O ha^{-1} and two irrigations x potassium applied at 50 kg K_2O ha^{-1} with each other was perhaps due to amelioration of potassium to barley plants under drought conditions. The results are corroborated with Mollah and Paul (2011) who found that spike length of barley increased with the increase of irrigation. Similarly, Alderfasi and Refay (2010) reported that low water supplies treatments reduced spike length of wheat. Application of 40 kg K_2O ha^{-1} significantly increased the spike length of barley (Shekhawat *et al*., 2013). Mesbah (2009) and Aowan *et al*. (2012) suggested that potassium has important role in increasing the plant tolerance to water deficit conditions.

Table 2. Yield traits of barley as affected by irrigation and potassium level

Potassium Levels (kg K_2O ha^{-1})	Spike length (cm)				Number of grains $spike^{-1}$			
	Irrigation levels				Irrigation levels			
	Soaking dose	35 DAS	35&70 DAS	Mean	Soaking dose	35 DAS	35&70 DAS	Mean
0.0 (control)	4.4	5.5	6.9	5.6 c	26.0	26.3	27.0	26.4 c
25	4.6	6.2	7.0	5.9 b	29.0	33.7	35.3	32.7 b
50	4.8	7.4	8.5	6.9 a	31.0	36.0	38.0	35.0 a
Mean	4.6c	6.4b	7.5a	--	28.7c	32.0b	33.4a	--
	Irrigation (I)	Potassium (K)		I x K	Irrigation (I)	Potassium (K)		I x K
SE ±	0.06	0.18		0.31	0.24	0.55		0.95
$LSD_{0.05}$	0.22	0.48		1.17	0.85	1.47		3.55

DAS: days after sowing. Each value is a mean of three replicates; values followed by different letters are significantly different at $P \leq 0.05$.

Number of grains $spike^{-1}$

The number of grains $spike^{-1}$ is one of the important yield contributing parameters that influence directly to grain yield of crop. The ANOVA showed that effect of irrigation, potassium and their interaction was significant ($P \leq 0.05$) on number of grains $spike^{-1}$. The grains $spike^{-1}$ (Table 2) were significantly ($P \leq 0.05$) higher (33.4) under two irrigations at 35 and 70 DAS as compared to 32.0 and 28.7 recorded under one irrigation at 35 DAS and soaking dose, respectively. Potassium applied at 50 kg K_2O ha^{-1} produced markedly ($P \leq 0.05$) maximum (35.0) grains $spike^{-1}$. However, potassium applied at 25 kg K_2O ha^{-1} and control produced less number of grains $spike^{-1}$ (32.7 and 26.4, respectively). The interaction of two irrigations at 35 and 70 DAS x potassium applied at 50 kg K_2O ha^{-1} and one irrigation at 35 x potassium applied at 50 kg K_2O ha^{-1} resulted in maximum and statistically similar ($P \geq 0.05$) grains $spike^{-1}$ of 38.0 and 36.0. The non-significant ($P \geq 0.05$) interactive effect of one irrigation x potassium applied at 50 kg K_2O ha^{-1} with two irrigations x potassium applied at 50 kg K_2O ha^{-1} for grains $spike^{-1}$ may be attributed to compensating role of potassium to barley plants under drought conditions. The results are in conformity with the findings of Alderfasi and Refay (2010) who reported that drought stress badly affected wheat grains $spike^{-1}$. The highest decrease in grains $spike^{1}$ was observed when water deficit occurred at flowering stage. Potash spray at various growth stages of wheat under drought conditions ameliorated the adverse effects of stress by improving the number of grains per spike to a significant level (Aown *et al*., 2012). Yadov (2006) stated that potassium plays a key role in improving the plant tolerance to stress conditions.

Seed index (1000-grain weight, g)

Seed index is a quality trait in grain crops and grain yield is directly influenced by this attribute. The data (Table 3) indicated that crop under two irrigations at 35 and 70 DAS produced maximum ($P \leq 0.05$) seed index of 27.9 g. The seed index declined to 25.8 g under one irrigation at 35 DAS while minimum seed index (22.4 g) was observed under soaking dose. In case of potassium, significantly ($P \leq 0.05$) highest (27.7 g) was noted when crop was supplied with potassium application at 50 kg K_2O ha^{-1}. The seed index was reduced to 25.7 g under potassium application at 25 kg K_2O ha^{-1} and least seed index (22.8 g) was noticed under control. However, maximum seed index (30.4 and 29.3 g) with non-significant ($P \geq 0.05$) statistical values to each other was recorded under the interaction of two irrigations at 35 and 70 DAS x potassium at 50 kg K_2O ha^{-1} and one irrigation at 35 DAS x potassium at 50 kg K_2O ha^{-1}. The statistically equal ($P \geq 0.05$), LSD 0.05 seed index under the interaction of one irrigation x potassium at 50 kg K_2O ha^{-1} and two irrigations x potassium at 50 kg ha^{-1} with each other was mainly associated with amelioration of potassium to barley plants under drought conditions. The at par results have also been recorded by Mollah and Paul (2011) who revealed that irrigation caused significant effect on seed index of barley where minimum seed index was noted in lowest irrigation, and seed index improved as amount of irrigation was increased. The results are also in line with Anjum *et al.* (2011) who reported that drought reduced grain weight of maize. Aowan *et al*. (2012) found that the drought stress caused significant effects on 1000-grain weight of wheat. Exogenous application of potassium significantly improved the 1000-grain weight. The crop produced heaviest grains when it faced no water deficit at any stage.

Table 3. Yield traits and yield of barley as affected by irrigation and potassium levels

Potassium levels ($kg\ ha^{-1}$)	Seed index (1000-grain weight, g)				Grain yield ($kg\ ha^{-1}$)			
	Irrigation levels				Irrigation levels			
	Soaking dose	35 DAS	35&70 DAS	Mean	Soaking dose	35 DAS	35&70 DAS	Mean
0.0 (control)	21.3	22.7	24.3	22.8 c	1868.3	1939.3	2274.3	2027.3c
25	22.7	25.3	29.0	25.7 b	1963.0	2276.7	2471.7	2237.1b
50	23.3	29.3	30.4	27.7 a	2043.7	2570.7	2677.0	2430.5a
Mean	22.4c	25.8b	27.9a	--	1958.3c	2262.2b	2474.3a	--
	Irrigation (I)	Potassium (K)	I x K		Irrigation (I)	Potassium (K)	I x K	
SE ±	0.35	0.50	0.87		23.72	31.92	55.28	
$LSD_{0.05}$	1.24	1.34	3.24		84.58	85.39	205.84	

DAS: days after sowing. Each value is a mean of three replicates; values followed by different letters are significantly different at $P \leq 0.05$.

Grain yield ($kg\ ha^{-1}$)

The statistical analysis of data showed that irrigation, potassium and their interaction significantly ($P \leq 0.05$) affected barley grain yield. The results (Table 3) suggested that two irrigations at 35 and 70 DAS produced significantly ($P \leq 0.05$) highest grain yield (2474.3 kg ha^{-1}). The grain yield decreased to 2262.2 kg ha^{-1} when crop was irrigated once at 35 DAS and least grain yield

(1958.3 kg ha^{-1}) of barley was noted under soaking dose. Among potassium levels, markedly ($P \leq 0.05$) maximum grain yield (2430.5 kg ha^{-1}) was recorded under the application of potassium at 50 kg K_2O ha^{-1}. The barley grain yield diminished to 2237.1 kg ha^{-1} when crop supplied with potassium at 25 kg K_2O ha^{-1} and the least grain yield (2027.3 kg ha^{-1}) was documented under potassium at 0.0 kg K_2O ha^{-1} (control). Among interactive effects, maximum and statistically equal ($P \geq 0.05$) to each other, grain yield (2677.0 and 2570.7 kg ha^{-1}) was noticed under interactive effect of two irrigations at 35 and 70 DAS x potassium applied at 50 kg ha^{-1} and one irrigation at 35 DAS x potassium applied at 50 kg K_2O ha^{-1}, respectively. The results of this study conferred that grain yield of barley was reduced under water deficit conditions and low dose or no application of potassium. The results are in concurrence with those of Soliman *et al.* (2011a & b) who reported that drought reduced photosynthesis and ultimately resulted in reduced yield contributing components and yield of barley. The grain yield between the interaction of one irrigation x potassium application at 50 kg K_2O ha^{-1} and two irrigations x potassium at 50 kg K_2O ha^{-1} was statistically equal ($P \geq 0.05$) possibly due to amelioration effect of potassium to barley plants under drought conditions. Similar results were also revealed by Mollah and Paul (2011) who stated that barley grain yield improved with increasing the irrigation. The maximum grain yield was noted in the irrigation level of 40 mm and the minimum was in the control irrigation. Alderfasi and Refay (2010) concluded that low water supplies treatments decreased grain yield of wheat. Anjum *et al.* (2011) and Brisson and Casals (2005) suggested that yield components and yield under drought stress can be improved by increasing plants stress tolerance. Potassium has important role in increasing the plant tolerance to water deficit conditions (Mesbah, 2009; and Aowan *et al*., 2012). Similarly, Shekhawat *et al*. (2013) revealed that application of 40 kg K_2O ha^{-1} markedly enhanced the grain yield of barley.

CONCLUSION

Our findings indicate that irrigation and potassium levels, and their interaction affected significantly ($P \leq 0.05$) to the growth and yield of barley. In terms of grain yield, the maximum yield (2474.3 kg ha^{-1}) was recorded with two irrigations (35 and 70 DAS). Among potassium levels, the highest grain yield (2430.5 kg ha^{-1}) was noted under potassium application at 50 kg K_2O ha^{-1}. With respect to interactive effects, maximum grain yield (2677.0 and 2570.7 kg ha^{-1}) was documented under the interaction of two irrigations x potassium application at 50 kg ha^{-1} and one irrigation x potassium applied at 50 kg K_2O ha^{-1}, respectively. Hence, it is suggested that for obtaining optimum yield of barley variety Clipper under water deficit conditions, the crop must be irrigated once and supplied with potassium at 50 kg K_2O ha^{-1}.

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