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Nutrient acquisition and yield response of Barley exposed to salt stress under different levels of potassium nutrition

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ABSTRACT: A greenhouse experiment was carried out in 2002 at Jordan University of Science and Technology, Agricultural Experiment Station to examine the effect of potassium fertilization on the response of barley (*Hordeum vullgare* L.) to different soil salinity levels. Five levels of potassium (0, 0.2, 0.4, 0.6, and 0.8 g K per pot as KCl) and two salt levels (0.75 and 13 ds/m) were investigated in a split plot design with four replications. Soil salinity affected growth and yield component parameters in most of the cases. However, potassium application alleviated the stress condition and significantly ($p < 0.05$) improved dry matter yield and yield components in barley. The highest dry matter yield (19.63 g/ pot) of barley grown on the very saline soil was obtained in response to the highest potassium level (0.8 g K/ pot). Number of kernels per spike, number of tillers per plant, weight of kernels per spike and total top (shoot) dry weight were all significantly influenced by the main effects and their interaction. The content of nitrogen and Potassium in barley shoot was also increased due to potassium application. In general, the result of this experiment indicated that application of potassium to barley grown on saline soil medium could bring about improvements in yield and yield component parameters, which would otherwise suffer badly.

Key words: *Barley, K^+/Na^+ ratio, potassium, salinity, yield, nutrient*

INTRODUCTION

The most prominent production constraints in arid and semi-arid environments are soil salinity and drought. The soils in such areas are usually calcareous that contain soluble salts in quantities sufficient to interfere with the growth of most crops. Saline soils are formed when evapor-transpiration greatly exceeds precipitation for at least part of the year and where salts are present in moderate to high amounts in the parent material of the soil or with a saline water table at shallow depth (Hale and Orcut, 1987). In other words, in arid and semi-arid conditions, salinity mainly occurs where the precipitation is not enough to leach the excess soluble salts from the root zone (Ehret and Ho, 1986). It is quite clear that salinity affects crop production and agricultural sustainability in many regions of the world mainly by reducing the value and productivity of the affected land (Mohammed, *et al.*, 1998). Water resources in arid areas are frequently brackish and constitute the only available alternative for crop production (Botella, *et al.*, 1993). Soluble salts accumulate in irrigated soils because plants absorb only a small fraction of the minerals dissolved in irrigation water and only pure water evaporates from the soil surface, causing severe yield reduction (Dirksen, 1985). It is also known that high salt concentrations are toxic and limit growth because nutrients are proportionally less available or create physiological drought as a consequence of the high osmotic pressure of the soil solution (Fageria, *et al.*, 1991; Hale and Orcutt, 1987). Excess irrigation is often used to remove the accumulated salts from the surface and mitigate the effects; nonetheless it lacks practicality and feasibility for water is mostly limited or scarce in arid and semi-arid regions (Dirksen, 1985; Al-Kharaki, 2000). In most arid regions, soils cannot be used for normal cropping unless salts are leached out by excess irrigation water (Botella, *et al.*, 1993; Dirksen, 1985). Unfortunately, due to lack of salt free irrigation water, the water available in the area is simply utilized for this purpose. Hence, it is believed that soils may have been made saline

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(*induced salinization*) by using poor irrigation water (FAO, 2000; Botella, *et al.*, 1993). Salinity generally inhibits plant growth and productivity (Al-Karaki, 2000). More precisely, detrimental effects of salinity on plant growth result from direct effects of ion toxicity or indirect effects of saline ions on soil water potential, which cause soil/ plant osmotic imbalances (Marschner, 1986; Hasegawa, *et al.*, 1986). Several authors summarized that salt stress significantly decreased shoot, root and total dry matter of corn plants, and noticed an increasing degree of reduction in dry matter production with increasing salinity levels (Pessarakli, *et al.*, 1988; Bar-Tal, *et al.*, 1991). In a study with different wheat genotypes, Saqib et al. (2000) reported a significant reduction in all growth parameters considered and an increased concentration of Na^+ and Cl^- , decreased concentration K^+, and decreased K^+: Na^+ ratio. Salt stress affects water absorption by plants by changing both water relations and the electrolyte balance of plant tissues (Pessarakli, *et al.*, 1989). Therefore, the ratio of water absorbed per unit of dry matter produced might be substantially higher for some stressed plants, which shows the water use efficiency of plants was markedly decreased by increasing salinity. This also implies that plants under salt stress require more water and more frequent irrigation than under normal (non – saline) condition (Pessaarakli, *et al.*, 1989). There is ample information regarding the beneficial effects of K on various plant processes (Marschner, 1986; Beaton and Sekhon, 1985; Mengel and Kirkiby, 1982; Hale and Orcutt, 1987; Tisdale, *et al.*, 1993). Aslam, *et al.* (1998) compared different methods of potassium application to rice in salt affected soils using salt tolerant and salt sensitive cultivars and reported that tillering capacity, paddy and straw yield and 1000-grain weight increased due to potassium application. Potassium is ubiquitous in all higher plants and plays a vital role in a wide range of biochemical and biophysical processes. Potassium is the most important inorganic cation in plant tissues and in physiological and biochemical processes (Mengel and Kirkiby, 1982), and an important nutrient in photosynthesis and maintenance of turgidity in plant cells (Carroll, *et al.*, 1994;Peoples and Kock, 1978). The maintenance of high cytoplasmic levels of K is therefore essential for plant survival in saline habitats (Chow, *et al.*, 1990). Adequate supply of K to plants growing in saline and drought stress environments is believed to have an important role in inducing tolerance (Beaton and Sekhon, 1985). This experiment was therefore carried out to investigate the response of barley to potassium application under very saline growing condition.

MATERIALS AND METHODS

A green house experiment was carried out at a research facility of Jordan University of Science and Technology in the year 2002. A split plot design with two salt levels (0.75 and 13 dS/m) as main plot and five potassium levels (0, 0.2, 0.4, 0.6, and 0.8 g K per pot as KCl) as sub-plot treatments were investigated in four replications.

The soil type used was calcareous which was taken from a naturally salt affected field with electrical conductivity (EC) value of 13 dS/m and from the university agricultural research field with electrical conductivity (EC) of 0.75 dS/m, representing very saline (S2) and non- saline soil (S1) respectively (Richards, 1954). The soil was air dried and sieved through 5-mm screen before filled in to pots of four-kilogram capacity. Texture of the non-saline soil after passing through a 5-mm sieve was 5.5% of sand (<2.0, >0.02), 61.0% silt (<0.02, >0.002), 33.5% clay (<0.002 mm), bulk density of 1.37 g/cm^3 and 0.79% organic matter. The chemical properties (before treatment) were: pH = 7.93, EC = 0.75 dS/m, P (ppm) = 6.5, K (ppm) = 726, N-NH4 (ppm) = 5.3, and N-NO3 (ppm) = 16.8. Chemical properties of the very saline soil were pH = 7.2, EC = 13.2 dS/m, P (ppm) = 17.19, K (ppm) = 1426 and Na (ppm) = 1379. In each pot three plants were selected from about ten germinated seeds and were retained until harvesting. The recommended rate of N and P fertilizers was applied uniformly at planting in the form of Urea (46% N) and TSP (46% P2O5) respectively. The rates of potassium were K1 (control, 0), K2 (0.2), K3 (0.4), K4 (0.6), and K5 (0.8 g K) per pot as KCl corresponding to 0, 5, 10, 15, and 20 mg K per 100g dry soil respectively. Finally, analysis of variance (ANOVA) was done to determine treatment differences.

RESULTS

The data obtained in this experiment indicated that soil salinity generally affected growth and productivity of barley. Most of the yield parameters recorded were significantly ($p < 0.05$) affected by soil salinity (Table 1). Yield and yield component parameters such as number of kernels per spike, number of tillers per plant, weight of kernels per spike and total top (shoot) dry weight were significantly influenced by the main effects and their interaction (Tables 1 and 2). Total top dry weight increased by about 30.9% and 27.7% in K4 and K5 plants respectively as compared with the control plants. Likewise, weight of kernels per spike increased by about 76.7% and 105.9% over the control, at K4 and K5 plants respectively. The concentration of phosphorus and potassium was significantly affected by potassium application while that of nitrogen was not influenced by both the main effects and their interaction (Table1). Total top dry weight, number of leaves per plant, number of tillers per plant, weight and number of kernels per spike, and hundred kernel weight were all influenced by potassium application (Table 2). The highest dry matter yield (19.63 g/pot) was obtained in response to the highest potassium level (0.8 g K/pot or 450 kg K_2O/ha) under the highly saline soil (Table3); whereas on the non-saline soil increased rates of potassium increased barley dry matter yield only up to the second potassium rate (0.2 g K/pot) (Fig. 2).

Nitrogen and potassium uptake of barley (total above ground) was significantly increased in response to potassium application (Table 4 & 5). On the other hand, more appealing from the results obtained was the observation that nutrient acquisition by barley shoot was highly enhanced with increased potassium application on the very saline soil than the non-saline medium (Figs. 1, 3 and 4). Obviously, at the control treatment (where no potassium was given), total top dry weight and other parameters recorded were significantly low on the very saline soil medium (Table 3 and Fig. 2), but positive changes were noticed with high rates of potassium application. Under the very saline soil medium, improvements in growth, yield and nutrient acquisition were evident only after the application of high doses of potassium, which apparently demonstrated the positive contribution of potassium nutrition to plants exposed to high soil salt levels.

Table 1: Probabilities of significance for different traits of barley grown under different salt and potassium rates

Traits	Salt	Potassium	Salt x Potassium
Shoot DM	*	*	*
# Tillers/plant	*	*	*
# Kernels/spike	*	*	*
Weight of kernels/spike	*	*	*
Plant height	NS	NS	NS
N content (*shoot*)	NS	NS	NS
P content (*shoot*)	NS	*	*
K content (*shoot*)	NS	*	NS
Na content (*shoot*)	*	NS	*

NS: Not significant, *: Significant

Table 2: Effect of potassium nutrition on some yield component parameters of barley

Plant parameters	Potassium levels (g K/pot)					
	0	0.2	0.4	0.6	0.8	$LSD_{0.05}$
Total top dry weight, g/plant	11.5	12.69	11.69	15.06	14.69	2.567
Total top fresh weight, g/plant	20.94	23.19	22.94	26.13	23.69	ns
# Leaves /plant	5.23	5.9	6.77	7.54	7.54	0.359
# Tillers/plant	3.24	4.51	5.28	6.41	7.11	0.156
Plant height, cm	57.85	58.41	57.33	59.54	58.87	ns
Weight of kernels/ spike	2.19	2.95	3.55	3.87	4.51	0.35
100 kernel weight	11.36	14.75	19.01	18.31	19.23	2.53

Table 3: The interaction effect of potassium and salt levels on shoot dry weight (g/plant) of barley

Salt	Potassium rates (g K/pot)					
	0	0.2	0.4	0.6	0.8	Mean
S1 (0.75 dS/m)	11.88	12.88	11.00	13.00	9.75	11.70
S2 (13 dS/m)	11.13	12.50	12.38	17.13	19.63	14.55
Mean	11.50	12.69	11.69	15.06	14.69	
	Factors		$LSD_{0.05}$			
	Salt	(P=0.0013)				
	Potassium	(P < 0.05)	2.57			
	S × K	(P < 0.05)	3.63			

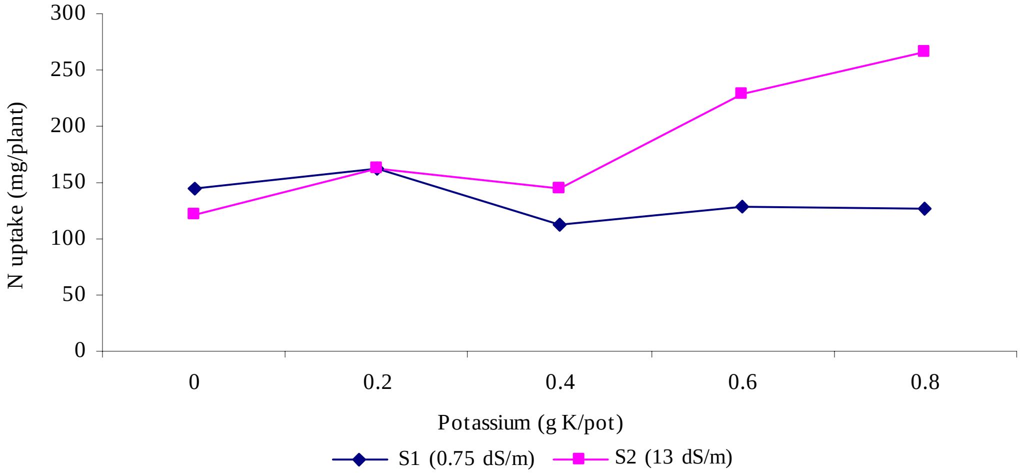

Fig. 1: Interaction effect of potassium and salt levels on N uptake by barley (shoot/straw)

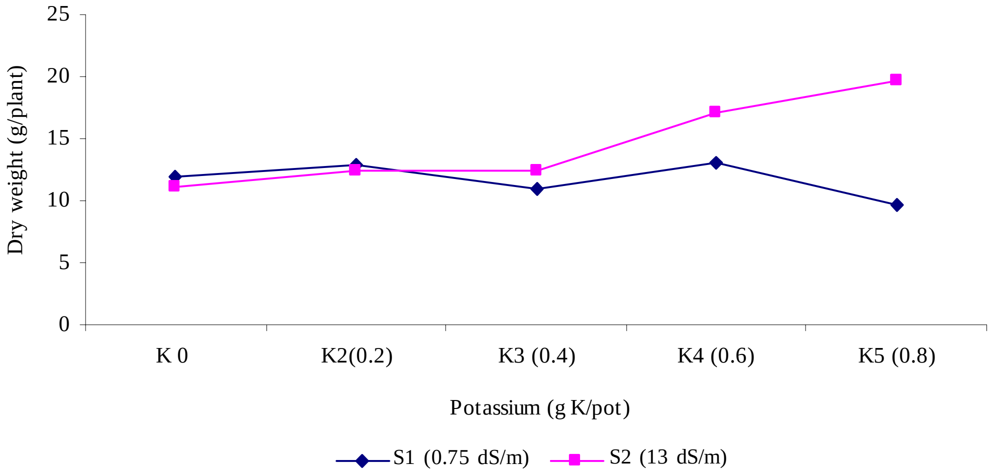

Fig. 2: Shoot dry weight of barley in response to potassium nutrition under different soil salinity levels

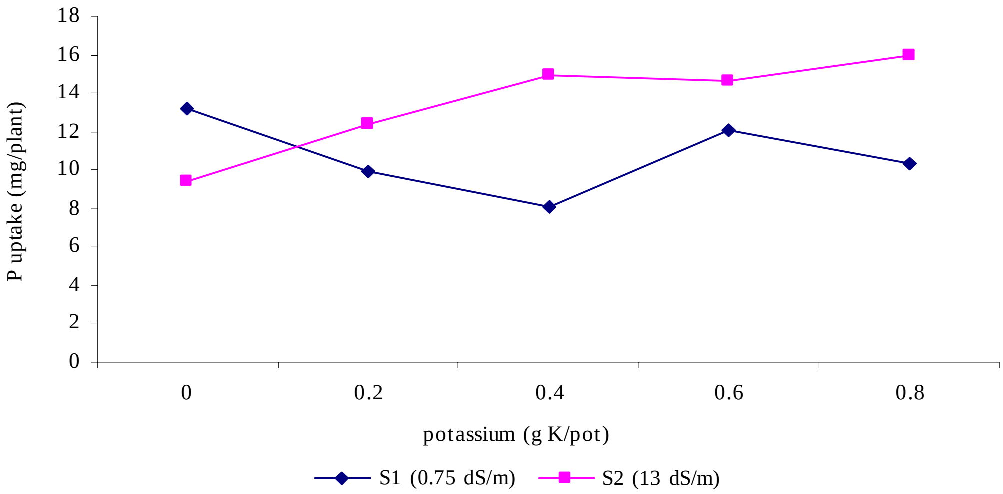

Fig. 3: Interaction effect of potassium and Salt levels on P uptake by barley (shoot)

The effect of salt stress on shoot N concentration was not significant; however, there was a marked increase in N concentration in barley plants grown on the very saline soil. This result agrees with previous findings for other crops such as sweet corn (Pessarakli, *et al.*, 1998), tomatoes (Pessarakli and Tucker, 1988), and red kidney beans (Frota and Tucker, 1978) in which an increase in total N concentration was observed when grown in saline substrate. In contrast to these findings, Mer, *et al.* (2000) reported reduced absorption of nitrogen by barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*) plants as a result of high salt concentrations in the soil. Higher potassium concentration was recorded in barley plants grown on the very saline soil which is generally consistent with the report by Toker, *et al.* (1999). Shoot Na^+ concentration decreased while K^+ concentration increased with increasing potassium supply, hence K^+: Na^+ ratio increased significantly (Fig. 5). This might be due to antagonistic interaction between Na^+ and K^+ (Ohno and Grunes, 1985).

DISCUSSION AND CONCLUSION

Total top dry weight of barley increased by about 30.9% and 27.7% in K4 and K5 plants respectively as compared with the control plants. Likewise, weight of kernels per spike increased by about 76.7% and 105.9% over the control, at K4 and K5 plants respectively. The concentration of phosphorus and potassium was significantly affected by potassium application while that of nitrogen was not influenced by both the main effects and their interaction (Table1). Numerous reports outlined that nutrient uptake and concentration in plant are affected by salinity (Howell, *et al.*, 1984; Yau, 2001; Memon, *et al.*, 1988 and Pessarakli, *et al.*, 1988). In most of the cases, a highly pronounced improvement in yield and yield components was evident under the very saline (S2) than the low or non saline (S1) treatment (Fig. 2). This result contradicts some reports that indicated significant promotion of plant growth at lower salinities in some halophytes, but inhibition of growth at higher salinities (Flowers, *et al.*, 1977; Khan, *et al.*, 2000). Without potassium application, growth and productivity of barley plants was relatively better on the non-saline than the very saline soil; however, the trend was reversed with potassium application where response of barley to potassium was highly notable on the very saline soil treatment (Fig. 2). The accumulation of K in highly salt stressed plants might have allowed osmotic adjustment to occur. The concentration of potassium ion in barley plants grown on the very saline soil increased considerably with potassium application (Tables 4 and 5), which might have contributed to better osmotic adjustment that can be explained by the higher shoot K^+:Na^+ ratio (Fig. 5), better yield and yield component parameters recorded (Table 3). Shoot Na^+ concentration decreased while K^+ concentration increased with increasing potassium supply, hence K^+: Na^+ ratio increased significantly (Fig. 5). This might be due to antagonistic interaction between Na^+ and K^+ (Ohno and Grunes, 1985). It is known that potassium represents the main cation in plant cells and is an important component of cell osmotic potential, which is involved in almost all physiological and biochemical processes including photosynthesis and maintenance of turgidity in plants exposed to salt stress condition (Al-Karaki, 1996; Carroll, *et al.*, 1994; Chow, *et al.*, 1990; Beaton and Sekhon, 1985; Mengel and Kirkiby, 1982; Peoples and Kock, 1978). A report by Mer, *et al.* (2000) and several other authors (Howell, *et al.*, 1984; Yau, 2001; Memon, *et al.*, 1988 and Pessarakli, *et al.*, 1988) underlined that high soil salt levels reduced absorption of nitrogen and phosphorus and caused imbalance of mineral nutrients that resulted in a reduction or an inhibition of plant growth. On the other hand the results obtained in this experiment indicated better pattern of improvement in growth and yield component parameters of barley under the very saline soil with increasing levels of potassium application (Tables 2 and 3, Fig. 2).

Table 4: The effect of potassium application on nutrient uptake by barley (*shoot/straw*)

K rates (g K/pot)	Nutrient uptake (mg/plant)			
	N	P	K	Na
0	133	11.28	382	52
0.2	162	11.15	415	55
0.4	128	12.45	406	47
0.6	179	13.35	541	53
0.8	196	14.45	485	63
$LSD_{0.05}$	49.82	NS	89.27	NS

Table 5: The effect of potassium application on the nutrient uptake of barley (grain)

K rates (g K/pot)	Nutrient uptake (mg/plant)			
	N	P	K	Na
0	73	11.88	19.10	1.40
0.2	112.49	13.58	25.13	1.49
0.4	101.82	14.53	24.94	1.60
0.6	105.89	14.41	26.86	1.73
0.8	118.03	16.35	28.17	1.60
$LSD_{0.05}$	12.01	NS	5.95	NS

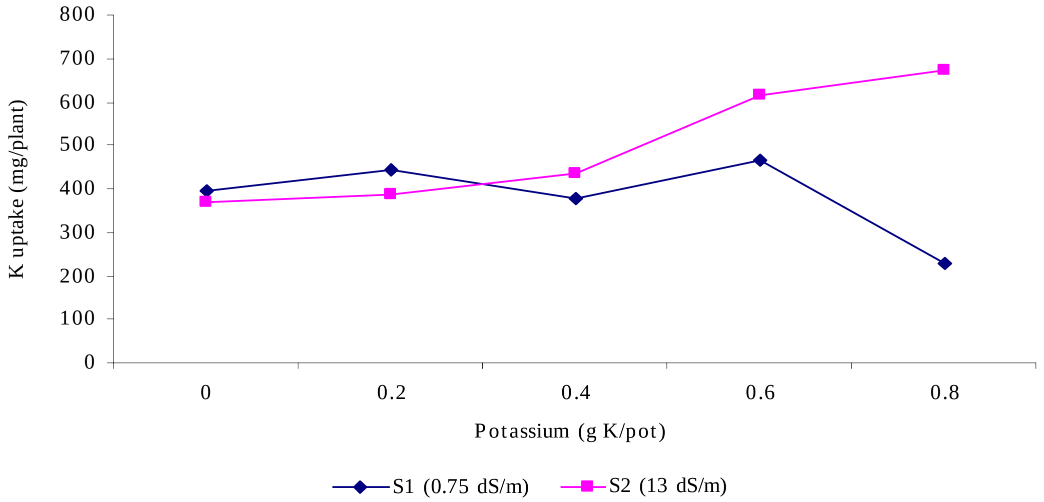

Fig. 4: Interaction effect of potassium and Salt levels on K uptake by barley (shoot)

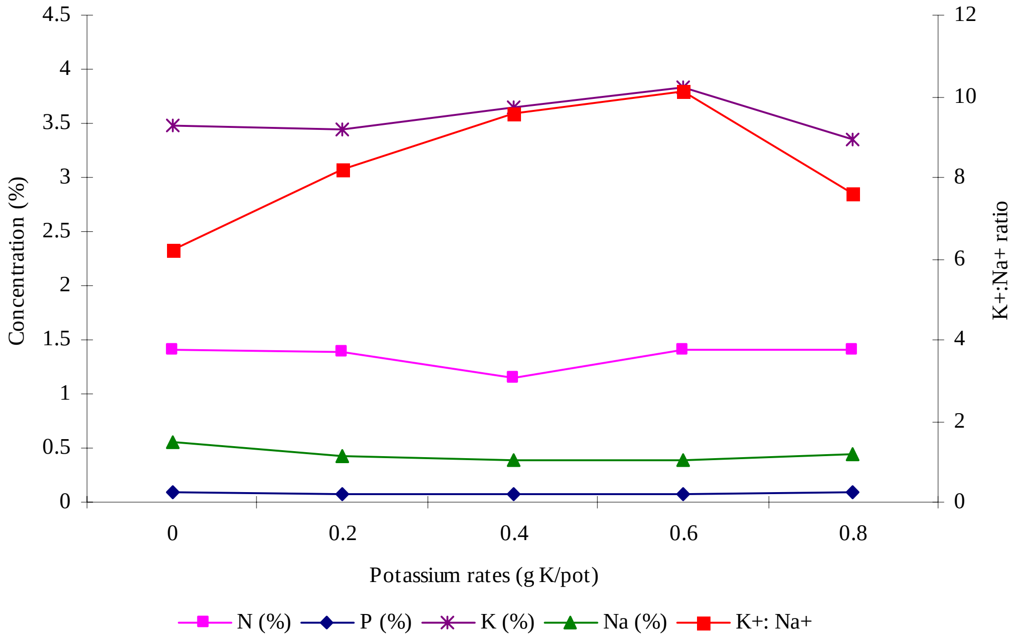

Fig. 5: The effect of potassium application on nutrient acquisition by barley shoot

In general, it can be concluded that soil salinity negatively affected growth and productivity of barley. Nutrient concentration and acquisition by barley shoot were also similarly influenced by salt stress. However, potassium application resulted in better crop performance that could be explained in terms of the better nutrient acquisition, growth and yield parameters recorded. The increased dry matter yield, yield components, potassium acquisition and high K^+/Na^+ ratio found in response to increased supply of potassium to barley plants grown on very saline soil confirmed the beneficial role and mitigating potential of potassium nutrition against salinity stress. In addition, the accumulation of K in highly salt stressed barley plants might have allowed osmotic adjustment to occur. Potassium is known to be a predominant osmotic solute in the vacuole, which helps to maintain a high tissue water level (Marschner, 1986), and contributes more than Na^+, Cl^- and glycinebetaine in osmotic adjustment under saline conditions (Ashraf and Sarwar, 2002). It is therefore believed that the application of potassium fertilizer have helped to mitigate the detrimental effects of the high soil salinity stress condition imposed on barley plants and resulted in better response in terms of nutrient acquisition, growth, yield and yield component parameters. Therefore, when barley is cultivated in a highly saline environment, improved potassium nutrition should be one of the most important factors to be considered in devising a successful crop production strategy. Finally, the results obtained in this research not only confirmed the well established fact that potassium nutrition helps mitigate the detrimental effects of soil salinity on crop productivity, but also indicated interesting results in terms of the significant and positive crop response to potassium application under highly saline soil than on the non-saline soil, which of course demands further investigations on the pattern of crop response in relation to intensity of stress conditions.

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