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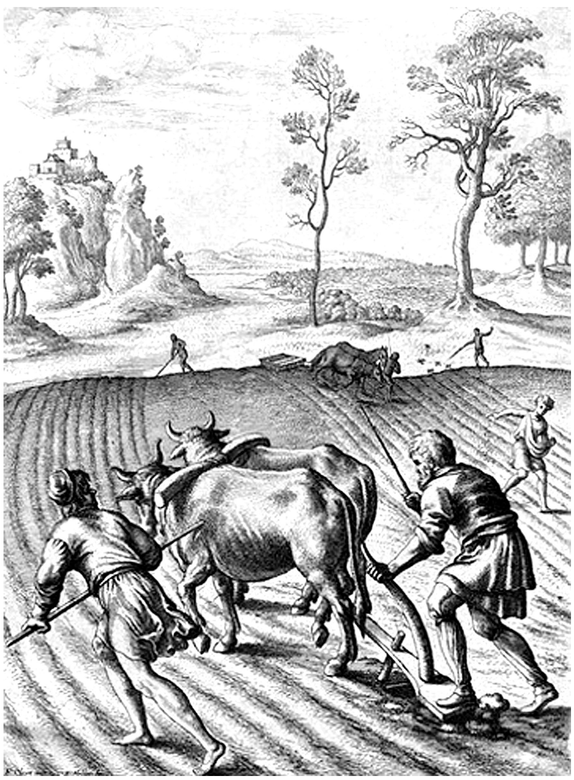

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The Interactive Effects of Saline Irrigation Water, Potassium and Gypsum on Mineral Nutrient Accumulation and Grain Protein Content of Wheat (*Triticum aestivium* L.)

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Abstract: This study was conducted to determine the effect of saline water, potassium and gypsum application on accumulation of some mineral nutrients in plant and grain protein content in wheat (*Triticum aestivium* L. cv. *Tajan*), during 2002-2003 growing season. For this purpose, five levels of electrical conductivity of irrigation water namely 0.8 (well water), 3, 6, 9 and 12 dS m^{-1} (mixture of Caspian Seawater and well water), four levels of potassium (0, 0.4, 0.8 and 1.2 g K_2O pot^{-1}) and three levels of gypsum (0, 1.75 and 3.50 g pot^{-1}) were applied in a Completely Randomized Factorial Design in pot experiment. The results showed that with increasing salinity of irrigation water, amount of sodium accumulation in leaves, roots and grain protein content increased, potassium content and K^+/Na^+ in roots and leaves decreased, significantly ($p<0.01$). With increasing salinity of irrigation water, the amount of sodium in roots, leaves and grain protein content increased, but K^+ and K^+/Na^+ decreased in leaves and roots. Potassium application increased the amount of potassium and K^+/Na^+ in roots and leaves, and gypsum application increased the calcium accumulation and reduced the Na^+/Ca^{2+}. Grain protein content, K^+ and K^+/Na^+ increased with interactive effects of potassium and salinity. Simultaneous application of potassium and gypsum increased the accumulation of K^+ and Ca^{2+} in leaves and reduced Na^+ in roots. The amount of grain protein increased in lower potassium treatments, but decreased in higher amounts of K^+.

Key words: Gypsum, K^+/Na^+ , Na^+ , potassium, protein, saline water

INTRODUCTION

Reduction of water potential in nutrition element media and accumulation of ions in plant tissues are considered as the main reasons behind inhibitory effects of salinity on plant growth. These ions accumulation, in turns cause toxicity or ion disequilibrium (Barsoni *et al*., 2001; Greenway *et al*., 1980; Irshad *et al*., 2003) and toxicity of specific ions in saline conditions have also been confirmed (Grattan and Grieve, 1992; Marschner, 1995). Meanwhile, high concentration of ions, especially Na^+, will cause decline in absorption of some elements such as potassium and calcium (Hamdy, 1988; Munns *et al*., 1986; Tanji, 1991). Also, in saline conditions, the amount of Na^+ and Cl^- will increase in plants and they will indicate the deficiency of another ions that are in low concentration. For instance, in saline conditions with Na^+ dominant to K^+, the plant will show excess needs for K^+ (Rains and Epstein, 1967). and with increasing the salinity, the amount of potassium in leaves will decrease (Ball *et al*., 1987). However, application of potassium fertilizer will decrease the salinity effects (Hu *et al*., 1997).

With increasing the salinity of irrigation water, the accumulation of Na^+ in plant tissues has been increased, while P, K^+ and Mg^{2+} have been decreased (Birendra and Singh, 1996). Application of sulfur, which can cause a reduction on Na^+/K^+ ratio, will decrease the salinity effects and improve the absorption of P and K^+ (Mostafa and Hassan, 1995). Also, using NPK and decreasing salinity can increase the absorption of P, K^+ and Ca^{2+} (Lai and Lai, 1990). In wheats that are in lower influence of salinity, maximum K^+ and minimum Na^+ will be concentrated in flag leaves (Mahlooji and Akbari, 2001). In contrast, in plants which are more influenced by salinity, an excess amount of Na^+ in roots and above ground plant parts have been accumulated, while the K^+ concentration have severely reduced (Abdolzadeh and Safari, 2002). Application of K^+ can reduce Na^+ and Mg^{2+} concentration which will be resulted in improvement of K^+/Ca^{2+}, K^+/Na^+ and K^+/Mg^{2+} (Borsani *et al*., 2005).

Higher Na^+/Ca^{2+} ratio in media cause a reduction in absorption of Ca^{2+} and showing Ca^{2+} deficiency in plants. Inadequate Ca^{2+} concentration that influence on cell wall may also made a negative effect on plant growth (Cramer *et al*., 1986; Lazof and Bernstein, 1999; Maas and

Grieve, 1987). Ca^{2+} will prevent from cell wall destruction by making equivalence among elements ratios and it will substitute by Na^+ ions when the Na^+ amounts are in high concentrate. (Cramer *et al.*,1985; Cramer *et al.*, 1986; Lynch *et al.*, 1987). Also, by increasing the salinity of irrigation water, there has been less reduction of wheat kernel protein (Sharma *et al.*, 1991). However, application of sulfur and organic matter can increase the adsorption of P, K^+ and protein percentage (Shabana *et al.*, 1998). The current experiment is going to show the effects of saline water, potassium and gypsum treatments on accumulation of minerals and their ratios in leaves and roots and also the effects of these treatments on the K^+/Na^+, Na^+/Ca^{2+} in roots, leaves and the amount of protein in grains.

MATERIALS AND METHODS

The present experiment was held on a clay loam soil during 2002-2003 growing season. Soil physico-chemical characteristics and chemical composition of irrigation water were analyzed (Table 1 and 2). Four levels of potassium (0, 0.4, 0.8 and 1.2 g pot^{-1} K_2O) from K_2SO_4 source, three levels of gypsum (0, 1.75 and 3.50 g pot^{-1}) and five levels of electrical conductivity of irrigation water namely 0.8 dS m^{-1} (well water), 3, 6, 9 and 12 dS m^{-1} (mixture of Caspian Seawater and well water) were applied in a completely randomized factorial design in green house. Pots were cylinders with 25 cm diameter and 20 cm height. They were partially filled with soil up to 17 cm. Likewise, 0.75 g pot^{-1} N (1/3 in seedling, 1/3 in tillering and 1/3 in panicle stages) and 0.50 g pot^{-1} superphosphate triple were applied in seedling stage. Pots were irrigated with five levels of electrical conductivity up to maturity stage. For determination of Na^+, K^+ and Ca^{2+} in leaves, four upper leaves were sampled in panicle stage (Havlin *et al.*, 1999). The amounts of Na^+, K^+ in leaves and Na^+ and K^+ of roots and also protein in grain were determined.

Table 1: Physico-chemical characteristics of soils

Clay (%)	Silt (%)	Sand (%)	O.C (%)	Avail.K (mg kg^{-1})	Avail. P (mg kg^{-1})	EC (dS m^{-1})	pH
34	31	35	1.2	266	15.3	1.16	7.65

RESULTS AND DISCUSSION

Influence of saline irrigation water: Table 3 shows highest amount of accumulated potassium in leaves belonged to 1.2 g pot^{-1} k_2O and 0.8 dS m^{-1} salinity. Increasing of salinity concentration of irrigation water caused an increase on amount of leaves sodium accumulation, a partial increase on amount of leaves calcium and sodium on calcium ratio, while it will reduce the amount of leaves and roots potassium accumulation. However, reduction in potassium accumulation has been increased severely when the salinity density has been raised (Table 3 and 4). The results of current experiment was in accordance with the published result of Hamdy (1988), Tanji (1991) and Drihem and Pilbeam (2002) for influencing of enhancing salinity increasing in irrigation water on extra leaves sodium accumulation and then reduction amount of leaf potassium accumulation. The amount of grain protein has been raised with enhancing the level of salinity and in treatment 9 and 12 dS m^{-1} were significant (Table 4). However, Sharma *et al.* (1991) did not observe significant changes in amount of kernel protein due to raising the level of salinity.

Influence of potassium application: Application of 0.8 g pot^{-1} K_2O has not significant influence on leaf and root sodium accumulation, however, application of 1.2 g pot^{-1} K_2O reduced considerably the negative effects of salinity and caused a reduction on the amount of accumulated sodium significantly (Table 5). Hue *et al.* (1997) and Irshad *et al.* (2002). have evaluated the role of nutrient element on reduction of salinity effects. Using potassium will cause an increase on amount of accumulated potassium in leaves that this is according to the results of Lai and Lai (1990) and Bohra and Doerffling (1993). Addition of potassium caused extra absorption of calcium and increasing its amount in plant leaves and roots and then with substitution of sodium ions with calcium will cause sodium ion reduction in leaf. By increasing the amount of potassium application, the Na^+/Ca^{2+} ratio in leaves has been reduced. Meanwhile, the ratio of K^+/Na^+ has been enhanced using potassium and

Table 2: Chemical composition of irrigation water

EC (dS m^{-1})	Na^+ (meq L^{-1})	Ca^{2+} (meq L^{-1})	Mg^{2+} (meq L^{-1})	Cl^- (meq L^{-1})	HCO_3^- (meq L^{-1})	SO_4^{2-} (meq L^{-1})	SAR
0.7	2.8	3.0	3.0	4.5	4.0	0.3	1.62
3.0	18.3	2.0	10.5	22.0	4.5	4.5	7.32
6.0	36.7	4.5	18.5	45.0	4.0	10.0	10.95
9.0	56.3	8.0	26.0	68.5	4.5	17.0	13.65
12.0	82.0	10.0	39.0	103.0	4.0	24.0	16.56

Table 3: Analysis variance table of mineral nutrient in leaves and roots

Source	df	Na^+ (leaf)	K^+ (leaf)	Ca^{2+} (leaf)	Na^+ (root)	K^+ (root)
R	2	0.023	0.257	0.102	0.011	0.001
K	3	0.009**	0.116^{ns}	2.270**	0.066**	0.003**
G	2	0.001^{ns}	0.022^{ns}	0.251**	0.011**	0.002**
K.G	6	0.001^{ns}	0.313**	0.189**	0.033**	0.003**
S	4	0.140**	12.824**	6.900**	0.160**	0.040**
K.S	12	0.001^{ns}	0.088^{ns}	0.083**	0.005**	0.001^{ns}
G.S	8	0.001^{ns}	0.093^{ns}	0.056^{ns}	0.005**	0.001^{ns}
K.G.S	24	0.001^{ns}	0.103^{ns}	0.024^{ns}	0.003^{ns}	0.001^{ns}
Error	118	0.001	0.085	0.034	0.002	0.001

K = Potassium, S = Salinity, G = Gypsum, R = Replication, df = Degrees of freedom, **$p<0.01$, ns = not significant

Table 4: Interactive effects of K^+ and salinity on Na^+/Ca^{2+} (Leaf), K^+/Na^+ (Leaf), K^+ (Root) and grain protein

		EC ($dS\ m^{-1}$)				
Elements	K_2O g pot^{-1}	0.7	3.0	6.0	9.0	12.0
Na^+/Ca^{2+}	0.0	0.17^{efg}	0.20^{bcde}	0.17^{defg}	0.20^{bcde}	0.27^{a}
(Leaf)	0.4	0.24^{ab}	0.14^{fgh}	0.18def	0.21^{bcde}	0.27^{a}
	0.8	0.12^{b}	0.18^{cdef}	0.23^{b}	0.22^{bcd}	0.23^{b}
	1.2	0.13^{gh}	0.12^{b}	0.18^{cde}	0.20^{bcde}	0.22^{bc}
K^+/Na^+	0.0	20.12^{bc}	15.77^{ef}	13.13^{f}	10.96^{h}	6.96^{j}
(%)	0.4	22.55^{b}	17.20^{cde}	13.78^{fg}	10.31^{hi}	7.00^{j}
(Root)	0.8	25.20^{a}	20.41^{bc}	15.58^{def}	11.02^{h}	9.26^{hij}
	1.2	26.54^{a}	21.09^{b}	18.15^{cd}	11.40^{gh}	7.92^{ij}
K^+	0.0	0.107^{d}	0.064^{n}	0.071^{i}	0.059^{o}	0.061^{o}
(%)	0.4	0.135^{c}	0.078^{h}	0.073^{jk}	0.074^{j}	0.067^{m}
(Root)	0.8	0.147^{b}	0.080^{g}	0.076^{i}	0.074^{j}	0.072^{i}
	1.2	0.197^{a}	0.084^{f}	0.079^{h}	0.083^{f}	0.072^{i}
Protein	0.0	17.52^{abcd}	16.11^{def}	16.38^{cdef}	17.18^{abcde}	17.41^{abcde}
(%)	0.4	16.15^{def}	16.65^{bcdef}	16.03^{ef}	17.80^{abc}	17.77^{abc}
	0.8	15.50^{f}	17.19^{abcde}	16.62^{bcdef}	18.60^{a}	17.57^{abcd}
	1.2	16.37^{adcf}	16.43^{adcf}	16.51^{cdef}	18.45^{a}	18.03^{ab}

The same letter (s) showed no significant effects

Table 5: Interactive effects of K^+ and Gypsum on Na^+ /Ca^{2+} (Leaf), K^+/Na^+ (Leaf), Na^+ and K^+ (Root) and grain protein

		K_2O (g pot^{-1})			
Elements	Gypsum (g pot^{-1})	0	0.4	0.8	1.2
Na^+/Ca^{2+} (Leaf)	0	0.22^{bc}	0.24^{ab}	0.16^{e}	0.18^{de}
	1.75	0.27^{a}	0.18^{de}	0.18^{de}	0.20^{cd}
	3.50	0.20^{cd}	0.16^{e}	0.18^{de}	0.18^{de}
K^+/Na^+ (Leaf)	0	14.32^{def}	13.02^{f}	15.22^{cd}	15.02^{cde}
	1.75	15.43^{cd}	16.64^{abc}	14.21^{def}	15.44^{cd}
	3.50	13.45^{ef}	17.22^{ab}	18.10^{a}	15.73^{bcd}
Na^+ (Root%)	0	0.31^{abcd}	0.31^{abcd}	0.35^{ab}	0.34^{abc}
	1.75	0.37^{ab}	0.25^{cd}	0.21^{d}	0.36^{ab}
	3.50	0.40^{a}	0.32^{abc}	0.22^{d}	0.29^{bcd}
K^+ (Root%)	0	0.067^{h}	0.081^{e}	0.088^{c}	0.081^{e}
	1.75	0.116^{a}	0.072^{f}	0.080^{e}	0.088^{c}
	3.50	0.117^{a}	0.093^{b}	0.070^{g}	0.084^{d}
Protein (%)	0	16.89^{bc}	16.57^{bc}	17.30^{abc}	16.99^{bc}
	1.75	17.16^{abc}	16.49^{bc}	17.25^{abc}	16.56^{bc}
	3.50	17.48^{ab}	18.21^{a}	16.94^{bc}	16.32^{c}

The same letter (s) showed no significant effects

Table 6: Content of grain protein wheat in different salinity irrigation water, potassium and Gypsum

	K_0			K_1			K_2			K_3		
EC	Gypsum (g pot^{-1})			Gypsum (g pot^{-1})			Gypsum (g pot^{-1})			Gypsum ($gpot^{-1}$)		
($dS\ m^{-1}$)	0	1.75	3.50	0	1.75	3.50	0	1.75	3.50	0	1.75	3.50
0.7	17.31	17.94	17.30	15.85	16.66	15.92	15.33	14.60	16.55	18.01	16.22	14.87
3.0	15.42	15.49	17.42	17.21	16.73	15.99	17.09	17.22	17.26	17.65	16.17	15.46
6.0	16.53	15.08	17.52	15.92	16.03	16.15	16.59	15.64	17.61	18.42	15.63	15.48
9.0	17.27	17.29	17.20	16.62	18.68	18.09	18.85	17.96	19.08	18.86	17.84	18.55
12.0	17.92	17.26	16.64	19.32	17.67	16.30	18.13	17.38	17.21	18.05	18.74	17.92

K_0 = without k_2O K_1 = 0.4 g/pot k_2O K_2 = 0.8 g/pot K_2O K_3 = 1.2 g/pot K_2O LSD (5%) = 1.635

the treatment of 1.2 g k_2O pot^{-1} showed better than the other treatments (Table 4). Sodium ions substitution by calcium together with the reduction of sodium contents in leaves were studied by Cramer et al. (1985 and 1986) and Lynch *et al.* (1987). In current study application of potassium, has increased Ca^{2+} and K^+ absorption and their accumulation in leaves and roots. The phenomenon of decreasing Na^+ ions in leaves and roots has been supposed to be due to substitution of sodium ions by calcium one.

Influence of gypsum application: Application of gypsum in soil increased the amount of calcium in leaves that, in turn, causes a reduction on Na^+/Ca^{2+} ratio in leaves. Addition of 3.5 g gypsum pot^{-1} causes maximum calcium accumulation in leaves and then maximum reduction in ratio of Na^+/Ca^{2+} (Table 5). Although using gypsum increased potassium absorption and its accumulation in leaves and roots and also increase in grain protein, there were no significant differences among data. Using sulfur and organic matter, Shabana *et al.* (1998) emphasized on increasing absorption of some minerals and grain protein contents in wheat.

Interactions of salt, gypsum and potassium: Interaction of potassium and salt on amount of accumulated potassium in roots and leaves was significant ($p<0.01$). This means that using potassium had an increasing effect on potassium accumulation, Na^+/Ca^{2+} and K^+/Na^+ ratios in leaves and roots, and grain protein contents in condition of increasing salinity of irrigation water (Table 4). Application of 0.8 g K_2O pot^{-1} and 9 dS m^{-1} salinity produced maximum protein and the least protein was achieved in non-saline water treatment (Table 4).

Application of synchronized potassium and gypsum increased potassium and calcium accumulation in leaves and reduced sodium accumulation in roots. Maximum accumulation of potassium in leaves were observed using 1.2 g K_2O and 1.75 g gypsum per pot. Increasing of K^+/Na^+ ratio was also under influence of using synchronized potassium and gypsum. Again it was maximum in treatment 0.8 g K_2O and 3.50 g gypsum per pot (Table 5). Interaction of potassium and gypsum has significantly reduced the percentage of grain protein. The maximum protein was obtained from treatment 0.4 g K_2O and 3.5 g gypsum per pot; however, minimum protein belongs to treatment 1.2 g K_2O and 3.5 g gypsum per pot (Table 5).

Triple interaction of salinity, potassium and gypsum on grain protein contents was significant ($p<0.05$). Maximum protein content belongs to treatment 12 dS m^{-1}, 0.4 g K_2O pot^{-1} and no gypsum, however minimum was related to treatment 0.8 g K_2O, 1.75 g gypsum pot^{-1} and no saline water (Table 6).

CONCLUSIONS

Application of saline water in irrigation of wheat increased sodium accumulation in leaves and roots and reduced the amount of potassium in leaves. The grain protein contents of wheat has increased by addition of salinity of irrigation water. Using potassium in addition of increasing potassium and calcium contents, reduced the amount of sodium ions in leaves and roots and then, increased Na^+/Ca^{2+} and K^+/Na^+ ratios. Application of gypsum increased calcium accumulation in leaves and it, in turn, caused reduction in Na^+/Ca^{2+} ratio. Using synchronized potassium and saline water, in addition to increase in the amount of potassium, increases K^+/Na^+ ratio in leaves and roots. Application of gypsum together with potassium caused additional accumulation of calcium and potassium and reduced the grain protein percentage and root sodium contents. Maximum protein content raised from 12 dS m^{-1}, 0.4 g K_2O per pot using no gypsum.

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