J. Soil Sci. and Agric. Eng., Mansoura Univ., Vol. 5 (2): 237 - 251, 2014

WHEAT RESPONSE TO SILICON APPLICATION UNDER SALINE IRRIGATION WATER

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ABSTRACT

Two lysimeter experiments were conducted at Sakha Agric. Research Station Farm during two successive winter growing seasons (2011/2012 and 2012/2013) to study the effect of irrigation by saline water on soil salinity as well as investigate the possible effects of foliar application of silicon on alleviating the adverse effects of salinity and the possible mechanisms by which silicon could increase wheat tolerance to salinity. The experimental design was split plot design with four replicates, where six salinity levels of irrigation water (0.5, 4, 6, 8, 10 and 12 dS m^{-1}) were assigned as the main plots , while the silicon treatments (0, 1 and 2 mmol L^{-1}) were assigned as the sub-plots. Fresh water was used till complete germination, and then saline water was used. Results showed that irrigation by saline water up to 12 dSm^{-1} greatly affected the soil EC, and the contents of soluble sodium and chloride. Significant decrease in wheat dry weight was observed with increasing salinity of irrigation water. Foliar application of silicon to wheat plants at tillering and booting stages alleviated the salinity hazards effect and resulted in increasing wheat grains and straw dry weight by about 22.5 and 21.4 %, respectively under irrigation with saline water (EC=12 dS m^{-1}) and 1 mmol L^{-1} silicon compared to silicon absence treatment. However, 1 mmol silicon L^{-1} is superior to other levels in decreasing salinity hazard on plant. N, P and K contents are decreased in wheat plant with increasing salinity of irrigation water while sodium and proline contents were increased. Foliar application of silicon resulted in increasing N, P, K and proline contents, while sodium content of wheat plants was decreased at different salinity level as compared to the control. Therefore, silicon increased salinity tolerance of wheat may be through two possible mechanisms: 1) Silicon application either at low or high concentrations (1 or 2 mmol L^{-1}) led to increase K uptake and decrease Na uptake by wheat plant which adjust the osmotic pressure and encourage nutrients uptake , hence increase plant tolerance to salinity. 2) Silicon application resulted in increasing proline content in salt stressed wheat plants, which possibly acting either as buffer against osmotic imbalance due to high vacuolar ions concentration or as a protective agent for cytoplasmic enzymes.
Keywords: Wheat - silicon application – saline water.

INTRODUCTION

Increased agricultural production has become an urgent requirement of the expanding world population (Howell, 2001; Chen *et al.,* 2011). Yet, there has been a continued decrease in available fresh water that can be used by agricultural production (Cai and Rosegrant, 2003). At the same time, the quality of irrigation water has also deteriorated. This compels the countries to use low quality waters such as saline and sodic ground waters for irrigation purpose which helps to overcome drought and increase crop yields but also increases the risk of soil salinization (Choudhary *et al.,* 2004 and Wenjun *et al.,* 2008). Excessive soil salinity causes yield reduction of many agronomic crops. Yield reduction may range from a slight loss to complete crop failure, depending on the particular crop and severity of salinity problem. Living with salinity is the only way of sustaining agricultural production in the salt affected soil (Al-Rawahy *et al.,* 2011). In this situation, there is usually no single way to achieve safe use of saline water in irrigation but many different approaches and practices could be performed to alleviate salt hazard and safeguard soil and environment. An approach to increase the agricultural potential of saline soil has been suggested by many researchers who demonstrated that salt tolerance of plants can be increased by addition of small amount of soluble Si to the soil or the plants. Although Si is not generally listed as an essential element and considered as one of the important beneficial nutrient for plant growth (Liang *et al.,* 2006). In this respect, Vlamis and Williams (1967) stated that yields of Gramineae species (barley, oats, wheat, and rye) were substantially decreased when the plants were grown in the absence of silicon. Ahmed (1987) reported that 10 mM NaCl L^{-1} added to irrigation water decreased the dry weight of wheat (Pak-81) by 46 %, while irrigation water containing 10 mM NaCl L^{-1} plus 20 ppm Si reduced the dry weight of the plants by 4% only. Baradbury and Ahmed (1990) stated that the addition of 0.46 mM SiO_2 L^{-1} to the irrigation water containing 0, 90 and 170 mM NaCl L^{-1} had a negligible effect on the dry weight of Prosopis juliflora, but when the plants were irrigated with 260 mM NaCl containing 0.46 mM SiO_2 L^{-1}, the dry weight was 34% greater than the plant irrigated with 260 mM NaCl L^{-1} alone. Thus, Si can stimulate the growth of salt stressed plants to some extent. Silicon was reported to reduce the hazard effects of various abiotic and biotic stresses including salt stress, metal toxicity, drought stress, radiation damage, various pests and diseases caused by both fungi and bacteria, nutrients imbalance, high temperature and freezing (Ma, 2004). Under pots experiment, foliar application of silicon to wheat plants significantly increased shoots height and leaf area as well as grain yield / plant grown either in normal and/or in saline conditions (Hanfey *et al.,* 2008). Silicon reduces various stress factors suffered by the plant, both biotic and abiotic (Carvalho *et al.,* 2009). Parveen and Ashraf (2010) stated that application of varying concentrations of Si significantly improved the growth of maize cultivar under saline regimes. Hellal *et al.,* (2012) found that silicon application to faba beans as foliar spray significantly improved chlorophyll and carotene, pod yield and seed number per plant grown either in normal and/or in saline conditions.

The present research aims to study the effect of irrigation by saline water on soil salinity as well as investigate the possible effects of foliar application of silicon on alleviating the adverse effects of salinity hazards and the possible mechanisms by which silicon could increase the wheat tolerance to salinity.

MATERIALS AND METHODS

Two lysimeter experiments were conducted in Sakha Agric. Research Station Farm during two successive winter growing seasons (2011/2012 and 2012/2013)) to study the effect of irrigation by saline water on soil salinity as well as investigate the possible effects of foliar application of silicon on alleviating the adverse effects of salinity and the possible mechanisms by which silicon could increase wheat tolerance to salinity. The experimental design was split plot design with four replicates, where six salinity levels of irrigation water (0.5, 4, 6, 8, 10 and 12 dS m^{-1}) were assigned as the main plots, while the silicon treatments (0, 1 and 2 mmol L^{-1}) were assigned as the sub-plots. Fresh water was used till complete germination, and then saline water was used. The used saline water was prepared by mixing sea water with fresh water at proper ratios to get the required salinity levels. Silicon in the form of sodium meta silicate solution was sprayed to wheat crop at two times, at tillering stage (after 40 days from sowing) and at boating stage (after 90 days from sowing). The recommended inorganic fertilizers were added in the forms of ammonium sulfate for N, super-phosphate for P and potassium sulfate for K at the rates 30 kg N, 25 kg P_2O_5 and 250 kg K_2O per fed., respectively. Wheat (*Triticum aestivum L*.) var. Gemieza 9 was sown on 12 and 16 November, 2011 and 2012, respectively.

Chemical characteristics of the used irrigation water were determined according to Jackson (1967) and outlined in Table (1).

Soil samples from the surface layer (0-25 cm) were taken before planting and after harvesting and prepared for physical and chemical analysis according to Jackson (1967). Available P according to Olsen et al (1954) and K according to Page (1994). Mechanical analysis was determined according to Piper (1950). Total N content was determined by micro-Kjeldahl method (Jackson, 1967). Total P was determined according to Snell and Snell, (1967). Total Na and K contents was determined using flame photometer (Jackson 1967). Some soil characteristics before cultivation are illustrated in Table (2).

Plant samples were taken randomly at maturity stage to estimate straw and grain dry weight in g $plant^{-1}$. Total nitrogen, phosphorus, potassium and sodium were determined in the plant digestion according to the method described by Faithfull (2002). Free proline content was determined in dry matter (DM) of wheat grains using Spectrophotometer according to Bates et al. (1973).

Data were analyzed statistically according to procedures outlined by Cochran and Cox (1960).

Table (1): Chemical characteristics of irrigation water used in the experiment.

EC (dSm^{-1})	pH	Soluble cations (meq L^{-1})				Soluble cations (meq L^{-1})				SAR
		Na^+	Ca^{++}	Mg^{++}	K^+	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	
0.50	7.55	01.65	01.52	01.73	0.21	0.00	3.50	1.24	00.26	01.3
4.00	7.51	24.80	06.88	07.88	0.45	0.00	4.00	20.35	15.66	09.1
6.00	7.44	33.26	12.00	13.85	0.91	0.00	4.00	18.70	37.32	09.3
8.00	7.32	41.67	17.98	19.22	1.20	0.00	4.50	32.79	42.78	09.7
10.00	7.26	54.78	21.05	22.63	1.55	0.00	4.50	43.82	51.69	11.7
12.00	7.20	66.40	25.30	26.43	1.92	0.00	5.00	52.64	62.41	13.1

Table (2): Some soil physical and chemical properties before planting:

Parameters		Values
Particle size distribution (%)	Sand (%)	54.6
	Silt (%)	31.8
	Clay (%)	13.6
	Texture	Sandy loam
	O.M (%)	0.87
	$CaCO_3$ (%)	1.80
	EC (dS m^{-1})	0.55
	pH	8.02
Soluble cations (meq L^{-1})	Ca^{2+}	1.65
	Mg^{2+}	1.82
	Na^{+}	1.78
	K^{+}	0.25
Soluble anions (meq L^{-1})	CO_3^{2-}	0.0
	HCO_3^{-}	3.50
	Cl^{-}	1.37
	SO_4^{2-}	0.63
Total macronutrients (%)	N	0.10
	P	0.03
	K	0.26
Available macronutrients (ppm)	N	12.2
	P	4.6
	K	131

RESULT AND DISCUSSION

1) Effect of irrigation with saline water on some chemical properties of soil:

Soil chemical properties showed remarkable changes to irrigation water qualities as shown in Table (3). The harmful effects are mainly associated with accumulation of salts in the soil profile where slow growth rate in plants is observed (Mass, 1990; Feizi, 1998; CSSRI, 1998). The results of soil chemical properties are as follows:

A. Soil pH:

Soil pH is the most important parameter which shows the over all changes in soil chemical properties. The analysis of soil showed that pH values are decreased as a salinity level of irrigation water increased up to 12 dSm^{-1} (Table 3). The maximum pH value (8.02)is recorded under fresh water while, minimum pH(7.42)is noted at higher levels of saline water(12.0dS m^{-1}). This trend may be related to the fact that H^{+} ions are released from the exchanging complex due to the influence of other soluble cations in the applied saline water (Mahrous *et al.,* 1983).

B. Soil Electrical Conductivity

Soil electrical conductivity is increased as a result of increasing salinity levels of irrigation water (Table 3). The maximum EC values after the first and second seasons (3.52 and 3.57 dS m^{-1}, respectively) are recorded in soil irrigated with the higher water salinity level (EC 12.0 dS m^{-1}), while the minimum EC values with both seasons (0.55 and 0.59 dS m^{-1}, respectively) are recorded in soil irrigated with fresh water (0.50 dS m^{-1}). These results are in agreement with the findings of Abd El-Nour (1989), Ragab (2001) and Abd El-Aziz (2000).

C. Soluble sodium

Soluble Na^+ concentrations are increased as the salinity level of irrigation water increased from 0.50 to 12.0 dS m^{-1} as shown in Table (3). The highest Na values after the first and second seasons (15.2 and 15.52 meq L^{-1}, respectively) are recorded under the highest water salinity (12.0 dSm^{-1}). However the lowest contents of soluble Na^+ for both seasons (1.78 and 1.92 meq L^{-1}, respectively) are documented in soil irrigated with fresh water (0.5 dS m^{-1}). These results are confirmed with that obtained by Hassanein et al. (1993) and Abd El-Aziz (2000).

D. Soluble chloride

Chloride content in soil is increased significantly with increasing salinity level of irrigation water up to 12 dSm^{-1} as shown in Table (3). The maximum soil Cl^- contents after the first and second seasons (12 and 12.22 meq L^{-1}, respectively) are recorded with the highest salinity level of the irrigation water (12.0 dS m^{-1}), while the minimum values of Cl^- for both seasons (1.37 and 1.46 meq L^{-1}, respectively) are noticed in the soil irrigated with the fresh water. These results are confirmed by the findings of Belhouchette et al. (1997).

E. Soluble potassium

Data in Table (3) show that increasing salinity level of irrigation water increases the contents of soluble K^+, where the maximum concentration values after the first and second seasons (0.57 and 0.59 meq L^{-1}, respectively) are recorded with the highest salinity level of irrigation water (12.0 dS m^{-1}), while the minimum values (0.26 and 0.28 meq L^{-1}, respectively) are found in the soil irrigated with fresh water. The increase in K^+ contents could be attributed to its higher contents in the saline irrigation water. These results are in agreement with those of Abd El-Aziz (2000).

Table (3): Effect of irrigation with different saline water levels on some soil chemical properties after first and second cultivation seasons:

Irri. water salinity	pH		EC_e (dSm^{-1})		Soluble Na^+ (meq L^{-1})		Soluble K^+ (meq L^{-1})		Soluble Cl^- (meq L^{-1})	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
0.5	8.02	8.00	0.55	0.59	1.78	1.92	0.26	0.28	1.37	1.46
4.0	7.92	7.88	1.08	1.12	4.50	4.72	0.33	0.34	3.38	3.6
6.0	7.81	7.75	1.45	1.57	6.35	6.91	0.37	0.38	4.76	5.22
8.0	7.68	7.63	2.38	2.43	10.50	10.78	0.43	0.45	7.90	8.11
10.0	7.56	7.50	2.98	3.05	12.87	13.23	0.48	0.51	9.80	10.11
12.0	7.49	7.42	3.52	3.57	15.20	15.52	0.57	0.59	12.00	12.22

2) Effect of irrigation by saline water on some plant elemental contents:

A) Nitrogen (N) contents:

Data in Tables (4 & 5) show that increasing the salinity of irrigation water leads to a highly significant decrease in N contents either in grains or in straw of wheat. The highest N content values (1.76 and 1.4%) are obtained with irrigation by fresh water (0.5 dS m^{-1}), while the lowest values in grains and straw (1.4 and 1.11%, respectively) are detected with the highest salinity level of irrigation water (12 dS m^{-1}). The decrease in nitrogen might be related to the antagonistic relation between Cl^- and NO_3^- ions (Meloni et al. 2004). These results are agreed with those obtained by Hellal *et al.,* (2012). Data also indicated that foliar application of silicon to wheat has highly significantly effect on N percentage. Where increasing silicon concentration to 1mmole L^{-1} resulted in increasing N percentage by about 17.7 and 16.5% with irrigation by fresh water, while these values are decreased in grains and straw by about 14.7 and 15%, respectively under irrigation by saline water (12 dS m^{-1}). These results are in a harmony with those obtained by Hanfey *et al.,* (2008).

B) Phosphorus content (P):

Data in (Table 4 & 5) indicate that increasing of irrigation water salinity lead to a highly significantly decrease in P content. The lowest values of P content in grains and straw (0.24 and 0.51 %, respectively) are detected with irrigation by saline water (12 dS m^{-1}), while the highest values (0.30 and 0.63 %, respectively) are obtained with fresh water. These results may be attributed to that the phosphate solubility is decreased with increasing the neutral salts concentrations, possibly due to its precipitation by Ca^{++} that generally occurs under saline condition (Seyam, 1989). These results are in agreement with those obtained by El- Sikhry (1990), Mostafa (1990) and Atwa (1999). Data indicate also that the foliar application of silicon to wheat plant has a highly significantly effect on P content. Increasing silicon concentration in foliar solution from 0 to 1 mmole L^{-1} resulted in increasing P content in grains and straw by about 16.5 and 17%, respectively with irrigation by fresh water, while these values are decreased to 14.8 and 13.7% with irrigation by saline water (12 dS m^{-1}). These results are in a harmony with those obtained by Liang *et al.,* (2007).

C) Potassium (K) content:

Data in (Table 4 & 5) indicate that increasing salinity of irrigation water resulted in a highly significantly decrease in K content either in grains or straw of wheat. The highest values of K in grains and straw (0.52 and 2.21%, respectively) are obtained with the lowest salinity level of the irrigation water, while the lowest values (0.42 and 1.79%, respectively) are detected with the highest salinity of irrigation water (12 dS m^{-1}). These results may be due to an antagonistic phenomenon between Na and K ions. These results are in a harmony with those obtained by El-Gayer et al. (1986), El-Sikhry (1990), Abou El- Defan (1998) and Atwa (1999). Data indicate also that foliar application of silicon to wheat has a highly significantly effect on potassium percentage. Therefore, increasing silicon concentration in foliar spray solution up to 1 mmol L^{-1} resulted in increasing K content in grains and straw by about 15.5 and 16.1% ,respectively, with irrigation by fresh water, while these values are decreased to 15.1 and 13%, respectively, with irrigation by saline water (12 dS m^{-1}). These results are in accordance with those obtained by Al-Aghabary et al. (2004) and Abdelhamid et al. (2010).

D) Sodium (Na) content:

Data presented in (Table 4 & 5) indicate that increasing salinity levels of irrigation water significantly increased Na percentage in wheat grains and straw. The highest values of Na content in grains and straw (0.207 and 0.513%, respectively) are obtained with irrigation by saline water having EC of 12 dS m^{-1}, while the lowest values (0.087 and 0.222 %, respectively) are detected with irrigation by fresh water. These results are in accordance with those obtained by Hassanein et al. (1993), Mosllam (1993) and Bahmaniar (2006). The accumulation of sodium either in grains or straw of wheat plant irrigated by saline water is one of the most important physiological characteristics responsible for osmotic adjustment (Kylin and Hansson, (1971). In this respect, Imamul-Hug and Larcher (1983) and Haroun (1985) found that increasing the NaCl increased the accumulation of Na^+ in bean plant to the concentration that inhibited the transport of certain other inorganic ions.

The obtained results indicate that the foliar application of silicon to wheat has a highly significantly effect on its sodium content. The increasing of silicon concentration in foliar spraying solution from 0 to 1 mmole L^{-1} resulted in reducing Na content in grains and straw by 39.3 and 29.5 %, respectively, with irrigation by fresh water, while these values are decreased by 26.4 and 13.3%, respectively, with irrigation by saline water (12 dS m^{-1}). These results are agreed with those obtained by Hanfey et al. (2008), Parveen and Ashraf (2010) and Hellal *et al.* (2012).

3) Effect of irrigation by saline water on wheat dry weight and proline content:

A) wheat dry weight :

Data in Table (6) indicate that increasing irrigation water salinity up to 12 dSm^{-1} leads to highly significantly decrease in dry weight of wheat grains and straw. The highest values of dry weight for grains and straw (2.76 and 5.81g $plant^{-1}$, respectively) are obtained with irrigation by fresh water while the lowest values (0.81 and 1.81g $plant^{-1}$, respectively) are detected under the highest salinity level of irrigation water (12 dS m^{-1}). This means that the maximum yield reduction in grain and straw (70 and 68 %, respectively) are achieved with 12 dS m^{-1} salinity level. The severe reduction in wheat yield with saline water is a reflection of severe reductions in leaves area and this may be ascribed to the retardation in water uptake, the inhibition in cell division and/or cell enlargement, the disruption in cell structure and/or imbalance in metabolic activities, the particularly biosynthesis of endogenous phytohormones, photosynthesis, nucleic acids and protein. These results are in harmony with those recorded by Rus et al.(2000); Zein et al.(2003) ; Ashraf et al. (2008) ; Ragab et al. (2008) and Ashraf (2009).

On the other hand, data indicate that the foliar application of silicon has a highly significantly effect on dry weight of wheat especially with 1 mmole L^{-1} silicon. Increasing silicon concentration in spraying solution up to 1 mmole L^{-1} increases the dry weight of wheat grains and straw by 22.5 and 21.4%, respectively, with irrigation by saline water (12 dS m^{-1}) , while these values are increased by only 5.2 and 6% with irrigation by fresh water. These results are in agreement with those obtained by Hanfey et al. (2008), Parveen and Ashraf (2010) and Hellal et al. (2012).

Table (4): Effect of irrigation with different saline water levels on some elemental contents of wheat grains after first and second seasons

Salinity (dS m^{-1})	Silicon (mmole L^{-1})	N (%)		P (%)		K (%)		Na (%)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
0.5	0	1.72	1.55	0.290	0.260	0.512	0.470	0.099	0.121
	1	2.03	1.82	0.330	0.310	0.590	0.545	0.050	0.086
	2	1.80	1.63	0.300	0.280	0.523	0.495	0.067	0.096
Means		1.85	1.67	0.307	0.283	0.541	0.503	0.072	0.101
4	0	1.63	1.46	0.270	0.250	0.464	0.447	0.138	0.171
	1	1.85	1.66	0.310	0.280	0.557	0.508	0.086	0.107
	2	1.72	1.54	0.290	0.260	0.492	0.464	0.115	0.146
Means		1.73	1.55	0.290	0.263	0.505	0.473	0.113	0.141
6	0	1.57	1.42	0.260	0.240	0.460	0.429	0.156	0.182
	1	1.77	1.6	0.290	0.270	0.517	0.483	0.107	0.136
	2	1.65	1.49	0.270	0.250	0.488	0.452	0.139	0.162
Means		1.66	1.5	0.273	0.253	0.488	0.455	0.134	0.160
8	0	1.51	1.36	0.250	0.230	0.442	0.412	0.172	0.208
	1	1.70	1.53	0.280	0.260	0.497	0.464	0.120	0.160
	2	1.58	1.43	0.270	0.250	0.407	0.437	0.155	0.181
Means		1.6	1.44	0.267	0.247	0.470	0.438	0.149	0.183
10	0	1.42	1.29	0.240	0.220	0.424	0.391	0.206	0.217
	1	1.61	1.45	0.270	0.250	0.480	0.445	0.127	0.177
	2	1.55	1.39	0.260	0.240	0.454	0.420	0.173	0.194
Means		1.53	1.38	0.257	0.237	0.453	0.418	0.168	0.196
12	0	1.36	1.23	0.230	0.210	0.398	0.372	0.224	0.251
	1	1.56	1.41	0.260	0.240	0.460	0.427	0.145	0.207
	2	1.47	1.32	0.240	0.230	0.438	0.404	0.179	0.236
Means		1.46	1.32	0.243	0.227	0.432	0.401	0.182	0.231
Salinity	F test	***	***	***	***	***	***	***	***
	LSD (0.05)	0.011	0.008	0.002	0.002	0.006	0.004	0.003	0.028
Silicon	F test	***	***	***	***	***	***	***	***
	LSD (0.05)	0.006	0.006	0.001	0.001	0.005	0.003	0.002	0.024
interaction		***	***	***	***	***	***	***	***

Table (5): Effect of irrigation with different saline water levels on some elemental contents of wheat straw after first and second seasons:

Salinity (dS m-1)	Silicon (mmol L^{-1})	N (%)		P (%)		K (%)		Na (%)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
0.5	0	1.38	1.22	0.620	0.560	2.179	1.961	0.256	0.279
	1	1.61	1.42	0.720	0.660	2.531	2.278	0.179	0.198
	2	1.45	1.28	0.650	0.590	2.281	2.053	0.197	0.221
Means		1.48	1.31	0.663	0.603	2.331	2.097	0.210	0.233
4	0	1.31	1.16	0.590	0.540	2.048	1.843	0.371	0.394
	1	1.5	1.33	0.670	0.610	2.395	2.155	0.216	0.245
	2	1.37	1.21	0.620	0.560	2.154	1.939	0.309	0.335
Means		1.39	1.23	0.627	0.570	2.199	1.979	0.299	0.325
6	0	1.26	1.12	0.570	0.520	2.010	1.809	0.402	0.418
	1	1.42	1.26	0.640	0.580	2.248	2.024	0.288	0.313
	2	1.33	1.18	0.600	0.540	2.098	1.888	0.336	0.372
Means		1.34	1.19	0.603	0.547	2.119	1.907	0.342	0.368
8	0	1.20	1.07	0.540	0.500	1.925	1.733	0.427	0.479
	1	1.36	1.20	0.620	0.560	2.150	1.935	0.340	0.369
	2	1.29	1.15	0.580	0.530	2.025	1.823	0.382	0.417
Means		1.28	1.14	0.580	0.470	2.033	1.830	0.383	0.422
10	0	1.15	1.02	0.520	0.470	1.838	1.655	0.453	0.500
	1	1.30	1.15	0.590	0.530	2.092	1.883	0.377	0.408
	2	1.24	1.10	0.560	0.510	1.969	1.772	0.416	0.447
Means		1.23	1.09	0.557	0.503	1.967	1.770	0.415	0.452
12	0	1.09	0.97	0.500	0.450	1.765	1.589	0.542	0.576
	1	1.26	1.11	0.570	0.510	1.994	1.795	0.439	0.475
	2	1.19	1.05	0.540	0.490	1.890	1.701	0.499	0.543
Means		1.18	1.04	0.537	0.483	1.883	1.695	0.493	0.532
Salinity	F test	***	***	***	***	***	***	***	***
	LSD (0.05)	0.007	0.007	0.005	0.004	0.011	0.010	0.0056	0.007
Silicon	F test	***	***	***	***	***	***	***	***
	LSD (0.05)	0.005	0.006	0.003	0.003	0.012	0.011	0.0039	0.004
interaction		***	***	***	***	***	***	***	***

Table (6): Effect of irrigation with saline water on wheat dry weight (g plant^{-1}) and proline content (umole g^{-1} DM of grains) after both harvesting seasons:

Salinity (dS m^{-1})	Silicon (mmol L^{-1})	Grain yield (g plant^{-1})		Straw yield (g plant^{-1})		Proline (umol g^{-1} DM of grains)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season
0.5	0	2.83	2.57	5.89	5.39	69.99	58.33
	1	2.98	2.69	6.24	5.72	78.58	64.22
	2	2.86	2.60	6.04	5.53	73.92	60.78
Means		2.89	2.62	6.06	5.55	74.16	61.11
4	0	2.48	2.25	5.11	4.73	84.31	67.58
	1	2.69	2.44	5.62	5.16	114.06	94.05
	2	2.55	2.32	5.29	4.88	97.74	79.67
Means		2.57	2.34	5.34	4.92	98.70	80.43
6	0	1.97	1.78	4.03	3.67	92.41	75.91
	1	2.40	2.16	4.88	4.54	128.06	104.59
	2	2.14	2.00	4.50	4.20	119.31	97.00
Means		2.17	1.98	4.47	4.14	113.26	92.5
8	0	1.48	1.30	2.91	2.63	104.63	84.59
	1	1.90	1.74	3.91	3.64	141.46	116.94
	2	1.65	1.46	3.38	3.06	126.24	103.5
Means		1.68	1.50	3.40	3.11	124.11	101.68
10	0	1.18	1.08	2.27	2.03	121.55	99.50
	1	1.53	1.39	2.90	2.75	158.8	131.27
	2	1.27	1.16	2.42	2.25	148.52	120.75
Means		1.33	1.21	2.53	2.34	142.96	117.17
12	0	0.75	0.71	1.71	1.54	147.98	120.71
	1	0.92	0.87	2.02	1.92	187.45	155.00
	2	0.82	0.80	1.90	1.77	178.39	144.02
Means		0.83	0.79	1.88	1.74	171.27	139.93
Salinity	F test	***	***	***	***	***	***
	LSD (0.05)	0.020	0.022	0.033	0.031	2.086	1.130
Silicon	F test	***	***	***	***	***	***
	LSD (0.05)	0.011	0.015	0.020	0.018	1.170	0.750
interaction		***	***	***	***	***	***

B) Proline content of wheat grains:

Data in Table (6) indicate that, increasing salinity leads to highly significantly increase in proline content. The highest proline content in wheat grains (155.6 umole g^{-1}) is obtained with irrigation by saline water (12 dS/m), while the lowest value (67.64 umole g^{-1}) is detected with irrigation by fresh water. These results are in agreement with those obtained by Liu and Hellebust (1976) and Abd El-Aziz (2000) who found that the increase in the osmolarity of the medium, rapidly increases the synthesis of proline, but it was rabidly reduced when the cells were transferred back to low osmolarity media. Therefore, Stewart and Henson (1980) suggested that the proline accumulation is an indicator of the stress damage.

Data indicate also that the foliar application of silicon to wheat plants has a highly significantly effect on proline content of wheat grains. Increasing silicon concentration up to 1 mmole L^{-1}, resulted in increasing proline content by about 27.5 % with irrigation by saline water (12 dS m^{-1}), while these values are increased by only 11.14 % with irrigation by fresh water. These results in a harmony with those recorded by Liang et al. (2007).

4) The possible mechanisms by which Si could increase wheat tolerance to salinity:

The previous data indicate that increasing salinity led to decrease the dry weight of wheat plant in the absence of silicon more than in its presence. Thus, silicon can stimulate the growth of salt stressed wheat plant to some extent. Thus the possible mechanisms by which Si increase salinity tolerance of wheat plant and enhances the plant growth may be:

- Silicon application led to increase K uptake and decrease Na uptake by wheat plant which result in osmotic adjustment that encourage nutrients uptake and hence increase plant tolerance to salinity. Theses results are in agreement with that obtained by Bradbury and Ahmed (1990) and Yongchao Liang et al. (1996).
- Silicon application resulted in increasing proline content in salt stressed wheat plant. The high cytoplasmic concentrations of inorganic solutes such as proline (Cavalieri and Huang, 1979) accumulated in salt stressed plants, were possibly acting either as buffer against osmotic imbalance caused by high vacuolar ion concentration (Field, 1976) or as a protective agent for cytoplasmic enzymes (pollard and Wyn Jones, 1979). Therefore, increasing the accumulation of proline as a result of silicon application to the salt stressed plant offers a great promise as one of the major physiological mechanism of salt tolerance in wheat plant.

Conclusion:

Under saline condition, foliar application of silicon during tillering and early boating stages is important for increasing wheat yield through alleviating the hazardous effects of salinity.

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استجابة القمح لإضافة السليكون تحت الري بمياه مالحة

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أقيمت تجربتان حقليتان باستخدام الأحواض الأسمنتية بمحطة البحوث الزراعية بكفر الشيخ خلال موسمي النمو 2011-2012 و 2012-2013 وذلك لدراسة تأثير الري بمياه مالحة على ملوحة التربة وكذلك دراسة التأثير المحتمل لرش القمح بالسيلكون على تخفيف التأثير الضار للملوحة والميكانيكية التي يتوقع أن يعمل بها السليكون على زيادة القدرة على تحمل الملوحة. و قد صممت التجربة بنظام القطع المنشقة حيث احتلت مستويات ملوحة مياه الري القطع الرئيسية (0.5 ، 4 ، 6 ، 8 ، 10 و 12 ديسيسيمنز/ متر) بينما احتلت تركيزات رش السليكون القطع المنشقة (0 ، 1 و 2 مليمول/ لتر).

وقد أظهرت النتائج أن الري بمياه مالحة أثرت بصورة كبيرة على الخواص الكيميائية للتربة وذلك من خلال زيادة ملوحة التربة (EC_e) و زيادة محتواها من الصوديوم والكلوريد الذائبين. كذلك أدى الري بالمياه المالحة إلى انخفاض ملحوظ في الوزن الجاف للقمح. وقد أدى رش القمح بالسليكون إلى تقليل نسبة الانخفاض في الوزن الجاف (الناتج عن الملوحة) لكل من الحبوب والقش وبالتالي زيادة الوزن الجاف لهما بنسبة حوالي 22.5 و 21.4 % على الترتيب تحت الري بمياه مستوى ملوحتها 12 ديسيسيمنز/ متر مقارنة بمعاملة الكنترول (بدون رش سيلكون). وقد اوضحت النتائج تفوق الرش بالمستوى 1 مللى مول سيليكون/لتر على المستويين الاخرين فى تقليل الآثار الضارة للملوحة على النبات. كذلك أدى الري بالمياه المالحة إلى تقليل محتوى كل من حبوب وقش القمح من النيتروجين والفسفور والبوتاسيوم مع زيادة الملوحة بينما أزداد محتوى النبات من الصوديوم والبرولين. عمل الرش بالسليكون على زيادة محتوى القمح من النيتروجين والفسفور والبوتاسيوم وكذلك البرولين بينما قل محتوى الصوديوم. وعلى ذلك يعمل السليكون على زيادة قدرة القمح على تحمل الملوحة ربما من خلال ميكانيكيتين محتملتي الحدوث : 1) إضافة السليكون أدى إلى زيادة امتصاص القمح للبوتاسيوم ونقص امتصاصه للصوديوم مما نتج عنه تعديلا اسموزيا شجع امتصاص القمح للمغذيات و زيادة قدرته على تحمل الملوحة خاصة مع تركيز 1 مللى مول سيليكون/لتر. 2) نتج عن إضافة السليكون زيادة في محتوى القمح من البرولين الذي يعمل كمنظم للخلل الاسموزى الناتج عن زيادة تركيز الايونات في خلايا النبات أو كعامل حماية للإنزيمات السيتوبلازمية.

استجابة القمح لإضافة السليكون تحت الري بمياه مالحة
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