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Effect of salinity and deficit irrigation on some ions uptake by rapeseed (*Brassica napus* L.) under two planting methods

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ABSTRACT- In this study, effect of deficit irrigation with different salinity levels and planting methods (in-furrow and on-ridge) on nutrient and toxic ions uptake by rapeseed was investigated in a two-year experiment. The experiment was conducted at Research Station, located in the College of Agriculture, Shiraz University, I.R. of Iran. Results indicated that an increase in water stress level decreased uptake of potassium (K), calcium (Ca), sodium (Na) and chloride (Cl) by plant and with exception of K, those uptakes were enhanced by an increase in salinity of water and soil. Furthermore, a decrease in applied water decreased the threshold of Na in soil for seed yield reduction. Deficit irrigation had a significant effect on slope of the fitted line between Cl in plant (Cl_p) and Cl in soil. The Cl_p threshold for seed yield reduction was significantly different for two planting methods in full irrigation regime so that seed yield reduction occurred in higher Cl_p in in-furrow planting method. Also, a decrease in applied water decreased Cl_p threshold for seed yield reduction.

INTRODUCTION

Soil salinity decreases the osmotic potential and water stress decreases the matric potential of soil water. Therefore, the reduced osmotic and matric potentials affect water and nutrient uptake by plant (Francois, 1994; Ilyas et al., 2001; Enferad et al., 2004; Parida and Das, 2005; Rameeh et al., 2012; Sepaskhah and Tafteh, 2012; Tafte and Sepaskhah, 2012). Osmotic stress and ionic toxicity in saline conditions resulted in depressed specific metabolic process in carbon uptake (Ashraf and McNeilly, 2004) and promotion of imbalance in plant nutrient metabolism (Rajpar et al., 2006).Water salinity from NaCl salt dissolution resulted in accumulation of toxic ions like Na (Francois, 1994; Ashraf and McNeilly, 2004; Rameeh et al., 2004; Rajpar et al., 2006; Bybordi, 2010; Rameeh et al., 2012) and Cl (Francois, 1994; Rameeh et al., 2004; Bybordi, 2010) and decrease in nutrient ions like Ca (Ashraf and McNeilly, 2004; Rameeh et al., 2004; Rameeh et al., 2012), K (Francois, 1994; Ashraf and McNeilly, 2004; Rameeh et al., 2004; Rajpar et al., 2006; Bybordi, 2010;; Tuncturk et al., 2011; Rameeh et al., 2012) and Mg (Francois, 1994) in leaves and aerial parts of plant. However, as reported by Francois (1994) saline water with NaCl and $CaCl_2$ salt compound increased Ca ion in leaves of rapeseed. Under salinity conditions, due to similar uptake mechanisms for K and Na ions (Rameeh et al., 2012) by plant, Na can be substituted for K reducing the K ion activity (Bybordi, 2010). Ca and K ions ameliorate the adverse effects of salinity on plants (Rameeh et al., 2012) and Ca could play a regulatory role in responses of rapeseed to saline environments (Rameeh et al., 2012). There is a positive relationship between Na and Cl and a negative relationship between Na and K concentration in roots and leaves. Higher concentration of Na and lower concentration of K in saline conditions resulted in lower K/Na ratio in plant tissue (Ashraf et al., 2012; Rameeh et al., 2012). Furthermore, ratio of K/Na in plant decreased when electrical conductivity and sodium adsorption ratio (SAR) of soil increased (Porcelli at al., 1995).

Nutrient uptake by root is a function of many factors such as: root morphology, nutrient absorption kinetics of the root and soil nutrient supply (Gutierrez-Boem and Thomas, 1999). Decrease in soil water availability affects the rate of diffusion of many nutrients. Marschner (1986) reported that a marked decrease in nutrient uptake by plants due to a decrease in ions transfer to the root occurred over a period of water stress. Understanding the biochemistry of rapeseed adaptation to water stress will help to develop varieties with enhanced stress tolerance. Potassium uptake by the roots of rapeseed and its translocation to the shoots decreased at low water potential (Moradshahi et al., 2004; Soltani-Gerdefaramarzi et al., 2009). Similar results about a decrease in nutrient uptake as a result of low soil water content were reported by Rouphael et al. (2008) for mini-watermelon, Ilyas et al. (2001) for wheat and Iqbal et al. (2006) for forage maize.

In-furrow planting is a method to cope with water scarcity which mitigates the effect of irrigation water salinity on crop growth and yield in furrow irrigation. Better conditions for plant growth are provided in in-furrow planting due to higher soil moisture, higher salt leaching and lower salt concentration in root zone (Zhang et al., 2007; Li et al., 2010; Shabani et al., 2013a). Ions uptake by plant depends on soil ion supplyand soil water content. In furrow, lower salt concentration affects the soil ion supply and results in a decrease in ion uptake. Furthermore, higher soil water content in furrow increases plant ion uptake. Therefore, understanding the process of ions uptake (increase and/or decrease) by plant root in saline conditions in-furrow planting is complicated (Ashraf and McNeilly, 2004; Tafteh and Sepaskhah, 2012). Dong et al. (2010) observed that Na accumulation of leaf in in-furrow planting method was lower in comparison with flat planting method for cotton. The effects of irrigation water salinity level and deficit irrigation at different planting methods on rapeseed yield and growth and physiological responses are reported by Shabani et al. (2013a, 2013b). However, their effects on ions uptake by rapeseed are to be evaluated. This study intends to study the effects of deficit irrigation, salinity and planting methods (in-furrow and on-ridge) on ions uptake in rapeseed (*Brassica napus* L.) in a silty clay loam soil under semi-arid climate.

MATERIALS AND METHODS

This experiment was conducted at the Experimental Research Station in Agricultural College, Shiraz University, I. R. of Iran, in 2009-2010 and 2010-2011 growing seasons. Due to excessive weed in the field in the first year, the experiment in the second year was conducted in another field near the previous one with similar physical and chemical properties of soil and water. Physical and chemical properties of soil and water averaged for two years are shown in Table 1. Experimental design was a split-split plot arrangement in randomized complete block design with irrigation regime as the main plot, salinity levels of water as the subplot and planting method as the sub-subplot with three replications. Irrigation treatments included water requirement plus 20% leaching fraction (full irrigation, FI), deficit irrigation of 75 (0.75FI), and 50 (0.5FI) percent of FI in the first growing season of 2009–2010 and FI, deficit irrigation of 65 (0.65FI), and 35 (0.35FI) percent of FI in the second growing season of 2010–2011. The salinity treatments of irrigation water were 0.6 (well water), 4.0, 7.0, and 10.0 dS m^{-1} in the first growing season and 0.6, 4.0, 8.0, and 12.0 dSm^{-1} in the second growing season. The planting methods were on-ridge planting and in-furrow planting. Saline water obtained by addition of NaCl and $CaCl_2$ to the well water with equal proportion. The dimension of each plot was 3×4 m^2 and the distance between two adjacent plots was 1.0 m to prevent water invasion from one plot to another (side effect). Talaieh cultivar of rapeseed (a local cultivar) with potential yield of 3.5-4.0 kg $ha^{-1}$was planted on 27th September 2009 and 28th September 2010. Seeds were planted in five rows with spacing between rows of 0.5 m with seed planting rate of 8.0 kg ha^{-1}. Average density of plants was 78 plants per m^2.

Table 1. Averaged soil physical and chemical properties of the experimental site and irrigation water for the two years.

	Soil depth (cm)					
Soil physical properties	0-10	10-30	30-60	60-90		90-120
FC(cm^3 cm^{-3})	0.30	0.32	0.33	0.33		0.33
PWP(cm^3 cm^{-3})	0.16	0.16	0.19	0.19		0.19
ρ_b(g cm^{-3})	1.3	1.43	1.43	1.43		1.43
Clay (%)	35	31	39	34		29
Silt (%)	55	57	51	50		53
Sand (%)	10	12	10	16		18
Soil texture	Silty clay loam					
Soil chemical properties						
EC (dS m^{-1})	0.65	0.65	0.51	0.58		0.53
Cl (meq l^{-1})	3.22	3.22	1.58	2.35		1.78
Ca (meq l^{-1})	3.36	3.36	2.66	2.98		2.74
Mg (meq l^{-1})	3.68	3.68	3.30	3.48		3.34
Na (meq l^{-1})	1.02	1.02	0.74	0.87		0.77
K (meq l^{-1})	0.17	0.25	0.28	0.27		0.27
Water chemical properties	EC, dS m^{-1}					
	0.6	4.0	7.0	8.0	10.0	12.0
Cl (meq l^{-1})	2.05	40.37	77.98	91.31	119.16	148.59
Ca (meq l^{-1})	3.80	39.41	74.27	85.89	109.13	132.37
Na (meq l^{-1})	1.09	3.03	4.74	5.31	6.45	7.59
HCO_3(meq l^{-1})	5.24	4.64	4.10	3.92	3.56	3.20

Before each irrigation, soil water content at different depths of 0.2, 0.3, 0.6, 0.9, 1.2 and 1.5 m was measured with neutron scattering method (CPN 503dr hydroprobe). Soil water content in the root zone was used to determine the amount of irrigation water as calculated by the following equation:

$$d_n = \sum_{i=1}^{n} \left(\theta_{fci} - \theta_i\right)\Delta z_i \quad (1)$$

where d_n is the irrigation water depth (m), Θ_{fci} and Θ_i are the volumetric soil water content in layer i at field capacity and before irrigation, respectively (m^3 m^{-3}), Δz is the soil layer thickness (m) and n is the number of soil layers. Depth of root during the growing season was estimated by the following equation (Borg and Grimes, 1986):

$$Z_r = R_{DM}\left[0.5 + 0.5\sin\left(\frac{3.03 D_{as}}{D_{tm}} - 1.47\right)\right] \quad (2)$$

where Z_r is the root depth (m), R_{DM} is the maximum root depth, 0.9 m, D_{as} is the number of days after planting, D_{tm} is the number of days for maximum root depth, 214 d. Leaching fraction of 20% was applied to prevent salt accumulation in the root zone.

Figs. 1 and 2 show the amounts of reference evapotranspiration (ET_0), irrigation water applied for each irrigation event for different irrigation regimes and rainfall for 2009-2010 and 2010-2011, respectively. Amount of ET_0 and irrigation water in the second year were higher than those values in the first year. Triple superphosphate at a rate of 100 kg ha^{-1} and urea as 30% of total requirement (150 kg ha^{-1}) were mixed with the soil at plowing. The remaining urea was applied in spring in two times, i.e., before stem elongation and flowering stage.

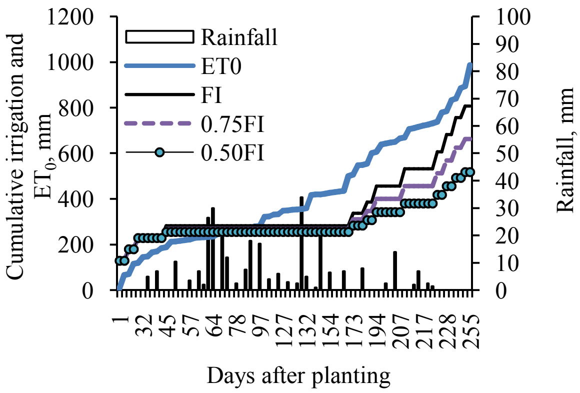

Fig. 1. Cumulative reference evapotranspiration (ET_0) and rainfall and applied irrigation (FI, 0.75FI, 0.5FI) water in 2009-2010.

To determine ions concentration in plant, three plants were selected from each plot and Na, K, Ca and Cl concentration of aerial part of plant were determined in 178 (stem elongation stage), 215 (flowering stage), and 255 (at harvest) days after planting in 2009-2010 and 186, 207, 228 and 255 days after planting in 2010-2011. The concentrations of K and Na in each sample were measured by flame photometer (Corning 400, Halstead, Essex, UK) and Ca and Cl were measured by EDTA (Kalra, 1998) and silver nitrate titration (Chapman and Pratt, 1961), respectively.

Soil samples were collected from each plot at 189, 223 and 255 days after planting in the first year and 186, 226 and 255 days after planting in the second year to measure soil saturation extract salinity. Soil samples were taken in 0.3 m increment to depth of 1.2 m to assess the soil salinity in the root zone. Soil samples were taken from bed of furrow in in-furrow planting and from top of ridge in on-ridge planting methods. To determine electrical conductivity and ions concentration of soil, soil saturation extract was prepared as described by the U.S. Salinity Laboratory Staff (USDA, 1954). In soil saturation extract of each sample, the concentrations of Mg and Ca were measured by EDTA titration (Waling et al., 1989) and Cl was measured by silver nitrate titration (Chapman and Pratt, 1961) and Na was measured by flame photometer (Jones, 2001).

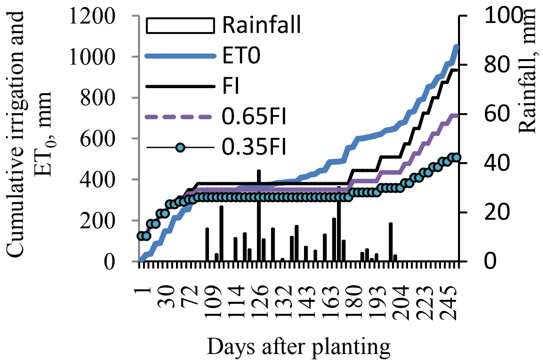

Fig. 2. Cumulative reference evapotranspiration (ET_0) and rainfall and applied irrigation (FI, 0.65FI, 0.35FI) water in 2010-2011.

RESULTS AND DISCUSSION

Soil salinity

The electrical conductivities of soil saturation extract (EC_e) averaged in root zone during the growing season for each treatment for both years are presented in Table 2. In both years maximum EC_e was observed in full irrigation with maximum level of irrigation water salinity, and on-ridge planting method. Electrical conductivity of the soil saturation extract was less than that of irrigation water (EC_{iw}). This is due to the fact that before irrigation, soil was not saline and rainfall in winter (288 mm in the first year and 258 mm in the second year) decreased irrigation requirement; therefore, soil salinity was not high. Salt accumulation was higher in on-ridge planting in full irrigation regime in both years and in 0.75FI irrigation treatment in the first year. However, in other deficit irrigations (0.65FI, 0.5FI and 0.35FI), salt concentration was higher in in-furrow planting due to lower applied water, drier soil in furrow and less salt transfer to the ridge (Table 2). EC_e in different soil depths and days after planting in each irrigation, water salinity and on-ridge planting method for two years are shown in Tables 3 and 4. During growing season, salt accumulation in soil occurred as a result of an increase in applied water. This accumulation was higher in surface layer of soil (0-30 cm) especially for 0.50FI and 0.35FI due to lower applied water, lower deep percolation and drier soil, and less salt transfer to deeper soil layers. The difference between EC_e of soil layers decreased by an increase in applied water due to higher deep percolation from top layers so that in FI treatment at the end of the growing season, this difference was more obvious.

Table 2. Electrical conductivities of the soil saturation extract (EC_e) and Ca and Mg concentration of soil averaged in root zone for the two years.

Year	Irrigation regime	Planting method							
		On-ridge planting				In-furrow planting			
Electrical conductivities of the soil saturation extract (EC_e), dS m^{-1}									
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
2009-10	Full irrigation (FI)	0.60	2.54	5.35	5.79	0.56	2.61	4.20	4.60
	0.75FI	0.59	2.61	3.68	4.66	0.52	1.86	3.01	3.75
	0.5FI	0.75	1.58	1.96	2.30	0.59	2.05	2.61	3.61
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	8.0	12.0	0.6	4.0	8.0	12.0
2010-11	FI	0.54	2.31	4.25	8.10	0.58	2.22	3.56	7.34
	0.65FI	0.62	2.88	4.74	5.26	0.58	3.16	3.88	6.19
	0.35FI	0.64	1.12	2.61	3.45	0.60	1.55	2.90	4.30
Ca concentration of soil, meq l^{-1}									
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
2009-10	FI	3.89	12.36	24.83	27.70	3.35	12.32	19.63	20.83
	0.75FI	3.82	12.16	17.04	21.02	2.74	9.59	13.98	18.70
	0.5FI	4.59	8.26	10.38	12.58	3.80	10.27	13.14	17.69
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	8.0	12.0	0.6	4.0	8.0	12.0
2010-11	FI	3.02	10.46	20.61	38.92	3.03	11.01	16.93	34.18
	0.65FI	4.49	14.30	23.84	26.55	3.71	15.69	19.06	28.90
	0.35FI	4.22	5.72	11.13	17.25	3.08	7.99	14.86	21.11
Mg concentration of soil, meq l^{-1}									
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
2009-10	FI	2.75	9.47	19.76	20.61	2.47	9.49	15.02	16.75
	0.75FI	2.79	9.94	12.71	17.53	2.57	7.17	10.43	12.74
	0.5FI	3.52	6.37	7.93	10.14	2.84	7.58	9.24	14.50
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	8.0	12.0	0.6	4.0	8.0	12.0
2010-11	FI	2.62	8.33	15.17	28.39	2.59	8.93	12.97	25.41
	0.65FI	2.91	10.23	18.95	20.50	2.88	11.37	13.80	21.93
	0.35FI	3.30	4.12	8.79	12.97	2.93	5.87	11.22	16.12

Elements concentration in soil

Elements concentration in soil (Ca, Mg, Na and Cl) averaged in root zone during the growing season for each treatment for both years are presented in Tables 2 and 5. Variation of soil elements concentration was similar to electrical conductivity of soil saturation extract so that increasing salt accumulation in soil resulted in an increase in soil elements concentration. In full irrigation regime and water salinity of 0.6 dS m^{-1} with exception of Ca in the first year, soil ions concentration decreased compared with the initial values of the soil elements (Table 1) due to salt leaching from soil profile in the root zone. Ion concentrations of soil were close to initial values by a decrease in applied water in salinity level of 0.6 dS m^{-1} due to lower entered ions into soil. Tables 2 and 5 indicated that availability of soil ions decreased in each salinity level of irrigation with a decrease in applied water. An increase in irrigation water salinity increased the soil ions due to the increase in entered ions to soil.

In deficit irrigation of 0.65FI, 0.5FI and 0.35FI, concentration of soil ions was higher in in-furrow planting method in comparison with on-ridge planting due to more salt accumulation in furrow. Sodium adsorption ratio (SAR) values were low, ranging between 0.44 and 1.5 in full irrigation regime and 12.0 dS m^{-1} salinity in the second year. Due to the high concentration of calcium in the irrigation water, no difficulties are expected with soil structural degradation and drainage problem in the soils. SAR increased in higher salinity level of irrigation water and higher applied water due to higher concentration of Na in comparison with Ca and Mg. Fig. 3 shows the relationship between SAR and EC_e. By increasing EC_e, SAR increased and this relationship was not linear. In higher EC_e, the rate of increase in SAR was lower due to higher concentration of Ca and Mg in comparison with Na and a decrease in the role of Na hazard. To assess the effects of deficit irrigation and planting methods on relationships between SAR and EC_e, these relationships were determined separately for each treatment. For comparison between two exponential lines, natural logarithm transformation was used to convert these relationships to a linear form. Slopes and intercepts of those lines were compared by Fisher F-test. Results indicated that there was no significant difference between the effect of deficit irrigation and planting methods on relationships between SAR and EC_e at 5% level of probability. Therefore, the relationship between SAR and EC_e obtained from all data is as follows (Fig. 3):

$$SAR=0.581\ (EC_e)^{0.42}\ R^2=0.91,\ n=53,\ SE=0.123,\ P<0.001 \quad (3)$$

where SAR is the sodium adsorption ratio and EC_e is the electrical conductivity of the soil saturation extract (dS m^{-1}).

Table 3. The average electrical conductivities of soil saturation extract (dS m^{-1}) in different layers during the growing season for each treatment for 2009-2010.

Treatment	Days after planting											
	189				223				255			
	Soil layer											
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
$I_1S_1P_1$*	0.55	0.43	0.48	0.44	0.59	0.59	0.83	0.86	0.88	0.52	0.54	0.52
$I_1S_1P_2$	0.56	0.53	0.40	0.40	0.62	0.46	0.47	0.48	0.79	0.48	0.48	0.59
$I_1S_2P_1$	2.69	1.55	0.67	0.81	0.45	2.83	2.49	2.24	5.28	1.99	2.61	1.50
$I_1S_2P_2$	1.22	0.84	0.79	0.82	2.36	2.58	2.99	1.53	4.68	4.60	3.11	1.26
$I_1S_3P_1$	4.25	2.16	1.07	0.85	6.32	4.45	3.08	2.20	7.82	6.36	5.06	2.20
$I_1S_3P_2$	2.97	1.54	0.44	0.33	5.15	3.34	3.65	0.52	6.29	5.65	4.27	2.69
$I_1S_4P_1$	3.44	2.55	1.40	1.18	6.73	5.76	3.68	1.92	9.11	7.85	6.25	4.29
$I_1S_4P_2$	2.25	1.92	1.12	0.35	5.97	5.25	3.26	2.24	7.39	5.83	4.57	3.19
$I_2S_1P_1$	0.51	0.50	0.58	0.57	0.56	0.48	0.47	0.46	0.88	0.66	0.68	0.59
$I_2S_1P_2$	0.52	0.48	0.47	0.22	0.52	0.47	0.45	0.45	0.63	0.51	0.52	0.51
$I_2S_2P_1$	1.90	1.28	0.65	0.69	3.36	1.06	0.94	0.87	5.84	3.52	1.76	1.14
$I_2S_2P_2$	1.41	0.74	0.50	0.56	2.16	1.68	0.57	0.49	4.18	1.68	0.86	0.88
$I_2S_3P_1$	3.37	2.04	1.67	0.89	4.00	2.98	1.27	1.23	7.18	3.65	1.82	1.74
$I_2S_3P_2$	2.05	0.99	0.64	0.95	3.75	1.89	2.55	0.84	6.23	4.35	1.95	0.81
$I_2S_4P_1$	5.17	1.79	1.18	0.87	5.72	1.91	0.77	0.99	7.78	4.96	2.37	1.85
$I_2S_4P_2$	3.09	1.20	0.69	0.81	5.07	1.86	0.73	0.43	6.73	4.86	2.65	1.74
$I_3S_1P_1$	0.72	0.60	0.56	0.52	0.82	0.81	0.75	0.57	0.93	0.63	0.59	0.53
$I_3S_1P_2$	0.67	0.47	0.51	0.51	0.59	0.43	0.45	0.51	0.69	0.55	0.52	0.46
$I_3S_2P_1$	1.13	0.66	0.69	0.76	1.27	0.93	0.76	0.84	4.00	2.61	0.93	0.79
$I_3S_2P_2$	1.83	0.63	0.50	0.62	2.50	1.52	0.65	0.54	5.24	1.00	0.68	0.71
$I_3S_3P_1$	0.76	0.69	0.94	0.68	3.29	1.23	0.58	0.52	5.38	2.45	0.79	0.89
$I_3S_3P_2$	2.62	0.83	0.89	0.69	2.71	0.89	0.60	0.58	7.75	1.43	1.08	0.70
$I_3S_4P_1$	2.51	0.74	0.95	0.64	4.00	1.73	1.08	1.50	5.58	1.42	0.90	0.85
$I_3S_4P_2$	4.12	1.26	0.70	0.75	4.70	2.21	0.54	0.54	6.68	4.20	1.85	0.89

*I_1, I_2, I_3: Full irrigation (FI), 0.75FI and 0.50FI, respectively. S_1, S_2, S_3 and S_4: 0.6, 4.0, 7.0 and 10.0 dS m^{-1} irrigation water salinity, respectively. P_1 and P_2: On-ridge and in-furrow planting methods, respectively.

Table 4. The average electrical conductivities of soil saturation extract (dS m^{-1}) in different layers during the growing season for each treatment for 2010-2011.

Treatment	Days after planting											
	186				226				255			
	Soil layer											
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
$I_1S_1P_1$*	0.48	0.47	0.51	0.50	0.50	0.55	0.53	0.64	0.74	0.55	0.54	0.56
$I_1S_1P_2$	0.52	0.49	0.51	0.53	0.56	0.64	0.55	0.64	0.73	0.57	0.53	0.53
$I_1S_2P_1$	1.02	0.82	1.10	0.95	3.28	2.28	0.96	0.97	3.77	3.43	2.23	2.07
$I_1S_2P_2$	1.91	0.60	0.92	1.07	1.52	1.76	1.02	1.08	3.56	3.17	2.54	1.73
$I_1S_3P_1$	1.77	0.91	1.27	1.63	4.67	4.11	3.17	2.59	7.39	6.37	6.03	3.45
$I_1S_3P_2$	1.59	0.59	0.91	0.81	3.03	3.50	2.61	2.51	6.43	5.99	5.03	3.89
$I_1S_4P_1$	4.98	1.30	2.18	2.91	10.39	9.57	4.71	3.21	11.63	8.29	8.08	7.37
$I_1S_4P_2$	4.07	1.75	2.17	1.69	10.50	9.30	4.63	2.69	9.94	7.21	7.00	5.76
$I_2S_1P_1$	0.52	0.49	0.51	0.53	0.70	0.77	0.64	0.63	0.73	0.54	0.51	0.52
$I_2S_1P_2$	0.48	0.47	0.51	0.50	0.80	0.54	0.56	0.64	0.83	0.46	0.49	0.50
$I_2S_2P_1$	1.02	0.82	1.10	0.95	4.81	2.83	1.15	1.34	5.99	3.49	1.95	1.56
$I_2S_2P_2$	1.91	0.60	0.92	1.07	4.11	3.52	2.94	2.96	5.17	3.30	2.75	2.70
$I_2S_3P_1$	1.65	0.65	1.27	1.78	7.87	6.34	4.97	2.99	8.74	6.99	3.71	2.27
$I_2S_3P_2$	2.83	0.83	2.07	2.35	2.90	3.90	2.17	2.98	6.39	6.20	3.65	2.64
$I_2S_4P_1$	1.72	1.02	1.48	1.36	9.53	6.11	2.55	2.86	10.98	6.72	4.05	2.96
$I_2S_4P_2$	3.82	1.13	1.51	1.18	8.09	6.16	4.13	3.38	7.91	7.78	7.21	5.06
$I_3S_1P_1$	0.58	0.49	0.59	0.51	0.85	0.66	0.57	0.61	0.81	0.55	0.44	0.50
$I_3S_1P_2$	0.70	0.42	0.47	0.49	0.60	0.54	0.50	0.52	0.57	0.63	0.44	0.47
$I_3S_2P_1$	0.61	0.59	0.67	0.60	1.06	0.74	0.99	1.00	3.41	1.21	0.97	0.84
$I_3S_2P_2$	0.61	0.41	0.46	0.49	3.38	0.92	1.04	1.13	4.43	0.76	0.76	0.87
$I_3S_3P_1$	0.52	0.49	0.51	0.53	3.80	1.52	1.74	1.39	8.04	2.33	1.32	1.58
$I_3S_3P_2$	0.78	0.47	0.51	0.50	4.69	3.04	1.39	1.41	8.88	2.65	1.50	1.13
$I_3S_4P_1$	0.55	0.54	0.86	0.86	8.59	0.81	0.84	2.31	11.62	2.14	1.58	2.23
$I_3S_4P_2$	1.71	1.19	1.17	1.51	9.72	2.29	1.82	2.07	11.03	2.30	2.22	1.28

*I_1, I_2, I_3: Full irrigation (FI), 0.65FI and 0.35FI, respectively.
S_1, S_2, S_3 and S_4: 0.6, 4.0, 8.0 and 12.0 dS m^{-1} irrigation water salinity, respectively.
P_1 and P_2: On-ridge and in-furrow planting methods, respectively.

Relationship between yield and Na in soil

In full irrigation regime, based on different irrigation water salinities and two planting methods for two years, the relationship between relative seed yield reported by Shabani et al. (2013a) and Na in soil (Na_s) determined by regression analysis was as follows (Fig. 4):

(Y_a/Y_m) = 1-0.031 (Na_s-1.94) R^2=0.66, n = 12, *SE* = 0.05, *P*=0.001 (4)

where Y_a is the actual crop yield (Mg ha^{-1}) at the designated salinity level, Y_m is the maximum expected crop yield (Mg ha^{-1}) at salinity level of 0.6 dS m^{-1} and Na_s is the Na in soil (meq l^{-1}). The value of 1.94 meq l^{-1} is the Na_s threshold for seed yield reduction. The slope (3.1%) in Equation (4) indicates a reduction of seed yield per unit increase in Na_s. To assess the effects of deficit irrigation and planting methods on relationships between relative yield and Na_s, these relationships were determined separately for each treatment (Table 6).

There was no significant regression relationship between relative yield and Na_s for most intensive deficit irrigations (0.50FI and 0.35FI). Results indicated that there was no significant difference between the effect of deficit irrigation and planting method on slope of these relationships (Table 6). There was no significant difference in Na_s threshold for seed yield reduction for two planting methods in FI and 0.75FI and 0.65FI treatments. In in-furrow planting method and for all data in both planting methods, results of the comparison between the Na_s threshold for seed yield reduction of two irrigation regimes (FI and 0.75FI and 0.65 FI) indicated that there was a significant difference. A decrease in applied water decreased Na_s threshold for seed yield reduction in in-furrow planting method and for all data in both planting methods. In 0.75 and 0.65

full irrigation regime in comparison with full irrigation regime, the Na_s threshold for seed yield reduction decreased by 45.6 and 33.5 % for in-furrow planting method and for all data in both planting methods, respectively. Therefore, deficit irrigation had a significant effect on relationships between relative yield and Na_s.

Elements concentration in plant

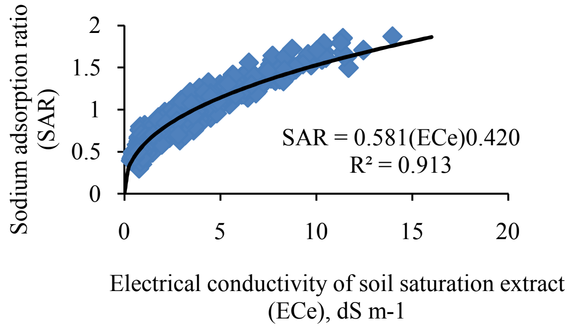

Fig. 3. Relationship between sodium adsorption ratio and electrical conductivity of soil saturation extract.

Chloride

In the two years, plant chloride concentration decreased with a decrease in applied irrigation water. Due to the decrease in soil water content that resulted in a decrease in water stream toward plant and reduction of soil salinity (Table 2) in deficit irrigation regime, Cl uptake by plant reduced (Table 7).

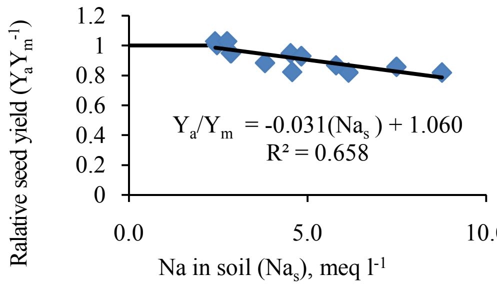

Fig. 4. Relationship between relative seed yield and Na in soil.

Table 5. Na and Cl concentration and sodium adsorption ratio of soil averaged in root zone for the two years.

Year	Irrigation regime	Planting method							
		On-ridge planting				In-furrow planting			
		Na concentration of soil, meq l^{-1}							
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
2009-10	Full irrigation (FI)	0.85	2.86	5.80	6.15	0.83	2.75	4.53	4.83
	0.75FI	0.79	2.81	3.75	5.00	0.78	2.16	3.43	4.04
	0.5FI	1.09	1.76	2.25	2.97	0.87	2.39	2.69	4.24
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	8.0	12.0	0.6	4.0	8.0	12.0
2010-11	FI	0.79	2.47	4.57	8.76	0.83	2.42	3.81	7.49
	0.65FI	0.86	2.97	5.30	6.28	0.80	3.31	4.55	6.41
	0.35FI	0.90	1.46	2.63	3.66	0.88	1.91	3.23	4.57
		Cl concentration of soil, meq l^{-1}							
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
2009-10	FI	2.41	26.15	58.33	66.25	2.17	27.24	46.99	47.84
	0.75FI	2.38	25.14	39.56	51.57	1.56	17.28	30.96	39.65
	0.5FI	4.65	13.89	17.63	27.86	2.65	20.09	26.38	41.84
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	8.0	12.0	0.6	4.0	8.0	12.0
2010-11	FI	2.62	32.94	72.23	105.47	2.67	32.69	63.64	90.02
	0.65FI	2.25	39.05	69.36	80.18	2.27	38.43	59.58	82.32
	0.35FI	2.84	18.32	39.41	54.59	2.10	20.25	47.62	56.70
		Sodium adsorption ratio							
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
2009-10	FI	0.47	0.83	1.22	1.23	0.49	0.81	1.08	1.10
	0.75FI	0.44	0.84	0.96	1.10	0.48	0.72	0.92	0.96
	0.5FI	0.54	0.62	0.71	0.85	0.48	0.77	0.77	1.04
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	8.0	12.0	0.6	4.0	8.0	12.0
2010-11	FI	0.47	0.80	1.04	1.50	0.50	0.75	0.95	1.35
	0.65FI	0.45	0.81	1.08	1.24	0.45	0.88	1.12	1.27
	0.35FI	0.47	0.65	0.77	0.81	0.51	0.70	0.83	0.97

With the exception of Cl at 255 days after planting in the first year, there was a significant difference between plant chloride concentration in full irrigation regime and 0.50FI in the first year and 0.35FI in the second year. There was a significant difference in plant chloride concentration in different salinity treatments in the two years. Chloride in plant increased by enhancing the salinity of irrigation water and soil saturation extract that resulted in higher Cl uptake by plant. As mentioned in the soil salinity section, salt accumulation in soil during the growing season occurred as a result of an increase in applied water that resulted in higher Cl in soil and the enhancement of Cl in plant. Except for Cl at 178 days after planting in the first year and 207 days after planting in the second year, there was no significant difference between the effects of planting method on Cl in plant in the two years. Chloride in plant was higher in in-furrow planting method in comparison with on-ridge planting due to higher soil water content and higher soil salinity in 0.35FI, 0.50FI and 0.65FI irrigation regimes that resulted in higher Cl uptake by plant in in-furrow planting method. There was a significant interaction effect between deficit irrigation (I), salinity levels (S) and planting method (P), (I×S×P), on Cl concentration measured at 215 days after planting in the first year (Table 8) and for interaction between I × S and I×P for Cl at 186 days after planting in the second year (data not shown). However, there was no signification interaction effect on Cl in plant at different growing seasons in the two years (data not shown). Maximum Cl in plant was obtained in full irrigation and water salinity of 10.0 dS m^{-1} at in-furrow planting method due to high soil water content and soil salinity that resulted in higher Cl uptake by plant.

Table 6. Relationship between relative seed yield (Mg ha^{-1}) and Na in soil (Na_s, meq l^{-1}) in each irrigation regime and planting methods for the two years.

Treatments	On-ridge			In-furrow			Both planting methods		
	Slope	Threshold	R^2	Slope	Threshold	R^2	Slope	Threshold	R^2
Full irrigation (FI)	-0.027a*	0.70a	0.70	-0.032a	2.63a	0.69	-0.031a	1.94a	0.66
0.75 and 0.65 FI	-0.043a	1.35ab	0.89	-0.065a	1.43b	0.69	-0.051a	1.29b	0.62
0.5 and 0.35 FI	-0.028	1.014	0.16^S	-0.035	1.063	0.38^S	-0.027	1.023	0.22^S

* Same letters in each column and each row for each factor are not significantly different at 5% level of probability, ^{S}: P_{value} of regression analysis is higher than 0.05.

Table 7. Mean values of Ca, Cl and K concentration in plant for each irrigation, water salinity and planting methods for the two years in different days after planting in the growing season.

	Cl, mg g^{-1}							Ca, mg g^{-1}							K, mg g^{-1}						
Year																					
DAP**	178	215	255	186	207	228	255	178	215	255	186	207	228	255	178	215	255	186	207	228	255
Irrigation treatment																					
FI***	12.3a*	12.2a	17.5a	9.1a	16.4a	14.1a	23.4a	15.9a	17.7a	16.4a	15.8a	16.2a	18.3a	16.6a	6.9a	4.6a	5.1a	6.0a	5.9a	3.8a	4.0a
0.75FI	11.2a	11.7a	17.1a					15.9a	17.4a	16.1a					6.8a	4.2ab	5.1a				
0.65FI				8.2a	14.0b	12.9a	23.0a				15.5a	15.9a	17.3a	15.4b				5.7a	5.7a	3.7a	3.7a
0.5FI	9.8b	10.1b	16.0a					15.6a	16.5a	15.3a					6.4a	4.0b	4.8a				
0.35FI				6.7b	11.2c	10.1b	19.6b				15.0a	15.6a	16.3a	14.5c				5.6a	5.6a	3.6a	3.6a
Salinity levels dS m^{-1}																					
0.6	5.4d	6.3d	6.9c	4.1d	6.8d	5.8d	7.5d	15.0b	14.9b	14.8c	14.5b	15.3b	15.1b	13.8d	7.0a	4.5a	5.2a	6.1a	6.0a	4.0a	4.0a
4.0	11.1c	11.3c	17.3b	7.4c	14.6c	12.7c	20.0c	15.5b	17.1a	15.5bc	15.4ab	15.4b	16.9ab	15.1c	6.8a	4.3a	5.0a	6.0a	5.9a	3.8b	3.7b
7.0	12.9b	13.1b	21.1a					15.7ab	18.1a	16.3ab					6.7ab	4.2ab	4.9a				
8.0				9.5b	16.4b	14.8b	26.1b				15.6ab	16.0b	18.1a	16.1b				5.8ab	5.8a	3.5bc	3.7b
10.0	15.0a	14.7a	22.2a					16.9a	18.7a	17.1a					6.3b	4.0b	4.8a				
12.0				10.9a	17.8a	16.3a	34.6a				16.3a	17.0a	19.0a	17.1a				5.3b	5.2b	3.4c	3.6b
Planting method																					
On-ridge	10.6b	11.5a	17.3a	8.2a	13.5b	12.2a	21.2a	15.8a	17.1a	15.9a	15.3a	15.9a	17.1a	15.4a	6.8a	4.3a	5.1a	5.8a	5.8a	3.9a	3.7a
In-furrow	11.6a	11.2a	16.4a	7.8a	14.3a	12.6a	22.9a	15.7a	17.3a	16.0a	15.6a	16.0a	17.5a	15.7a	6.6a	4.3a	4.8a	5.8a	5.7a	3.5b	3.8a

*Means followed by the same letters in columns for each factor and each trait are not significantly different at 5% level of probability, using Duncan multiple rang test, **DAP: Days after planting, ***FI: Full irrigation.

Relationship between Cl in plant and EC_e and Cl in soil

Figs. 5 and 6 show the relationships between Cl in plant (Cl_p) and EC_e and Cl in soil (Cl_s), respectively. The relationship between Cl_p and ECe was not linear. By increasing EC_e and Cl_s, Cl_p increased. In higher EC_e, the rate of increase in Cl_p was lower. The relationships between Cl_p and EC_e and Cl_s obtained from all data are as follows (Figs. 5 and 4):

$Cl_p=8.727\ (EC_e)^{0.531}$ $R^2=0.74$, n = 199, SE = 0.27, P <0.001 (5)

$Cl_p=0.243\ Cl_s+7.889$ $R^2=0.67$, n = 199, SE = 4.03, P <0.001 (6)

where Cl_p is the Cl in plant (mg g^{-1}), EC_e is the electrical conductivity of soil saturation extract (dS m^{-1}) and Cl_s is the Cl in soil (meq l^{-1}).

To assess the effects of deficit irrigation and planting methods on relationships between Cl_p and EC_e and Cl_s, these relationships were determined separately for each irrigation regime (Table 9 and Figs.7 and 8).

Table 8. Mean values of interaction between irrigation regimes, water salinity and planting methods for Cl and K concentration and ratio of K/Na in plant.

Year	Irrigation regime	Planting method							
		On-ridge planting				In-furrow planting			
Cl concentration in plant in 215 days after planting, mg g^{-1}									
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
2009-10	FI**	8.2ghi*	12.6cde	14.6abc	15.6ab	6.5hij	10.3efg	13.7bcd	16.3a
	0.75FI	6.9hi	12.5cde	13.0cd	13.6b-d	6.1hij	13.8a-d	12.2c-f	15.8ab
	0.5FI	4.3j	8.5gh	13.8a-d	14.1a-d	5.9ij	9.9fg	11.5def	12.5cde
K concentration of plant in 178 days after planting, mg g^{-1}									
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
2009-10	FI	6.81bcd	6.92bcd	6.15cd	6.75bcd	7.54ab	7.77ab	7.20bc	6.06cd
	0.75FI	6.76bcd	6.80bcd	7.60ab	6.99bcd	6.77bcd	6.68bcd	7.15bc	6.03cd
	0.5FI	8.35a	6.70bcd	6.07cd	6.06cd	6.02cd	5.95d	5.95d	6.10cd
K/Na ratio in plant in 215 days after planting									
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
2009-10	FI	48.9cde	38.7d-g	34.6d-g	29.0d-g	91.0a	34.4d-g	34.4d-g	27.1fg
	0.75FI	40.5d-g	61.2bc	28.6efg	29.8d-g	80.3efg	37.1d-g	24.1fg	28.4efg
	0.5FI	66.4bc	41.2def	33.6d-g	35.1d-g	62.9bc	50.3cd	31.8d-g	19.6g

*Means followed by the same letters in columns for each factor and each trait are not significantly different at 5% level of probability, using Duncan multiple rang test. **FI: Full irrigation

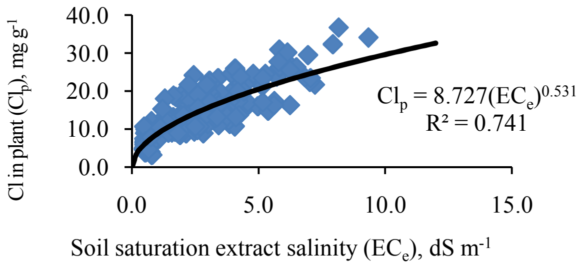

Fig. 5. Relationship between Cl in plant and soil saturation extract salinity (EC_e).

To compare the power functions, natural logarithm transformation was used to convert these relationships to linear forms. The slopes and intercepts of lines were compared by Fisher F-test. Results indicated that there was no significant difference between the effect of deficit irrigation and planting methods on relationships between Cl_p and EC_e (data not shown). Statistical comparison of slopes and intercepts of relationships between Cl_p and Cl_s indicated that deficit irrigation had a significant effect on the slope of the fitted line between Cl_p and Cl_s so that in 0.35 and 0.50 full irrigation regime, the slope increased by 37.2% in comparison with full irrigation regime (Table 9 and Fig. 8).

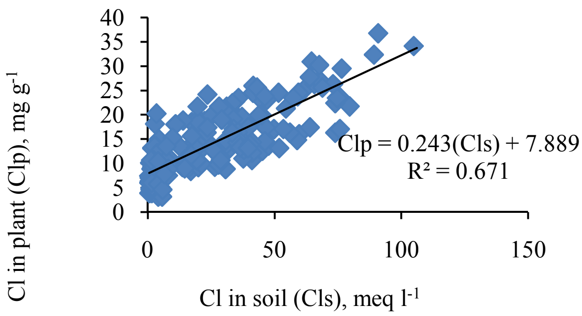

Fig. 6. Relationship between Cl in plant and Cl in soil.

Table 9. Relationship between Cl in plant (Cl_p) and Cl in soil (Cl) in different irrigation regimes for the two years.

Irrigation regime	Equation	R^2	Slope	Intercept
Full irrigation (FI)	Cl_p=0.231 (Cl_s) + 8.182	0.71	a*	a
0.65 and 0.75FI	Cl_p=0.222 (Cl_s) + 7.988	0.64	a	a
0.35 and 0.50FI	Cl_p=0.317 (Cl_s) + 7.015	0.68	b	a

* Same letters in columns for each factor are not significantly different at 5% level of probability

Relationship between yield and Cl in plant

In full irrigation regime, the relationship between relative seed yield reported by Shabani et al. (2013a) and Cl_p determined by regression analysis was as follows (Fig. 9):

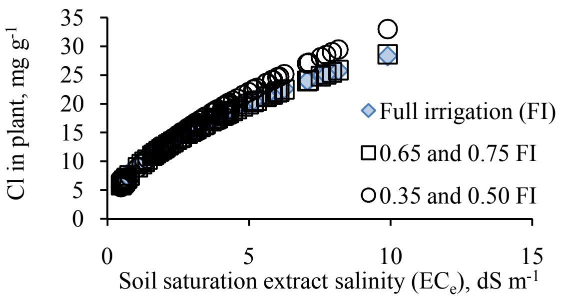

Fig. 7. Relationship between Cl in plant and soil saturation extract salinity (EC_e) for different irrigation regimes

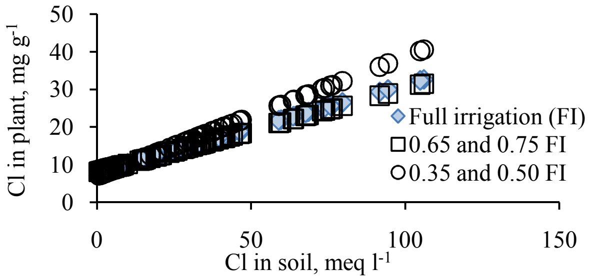

Fig. 8. Relationship between Cl in plant and Cl in soil for different irrigation regimes.

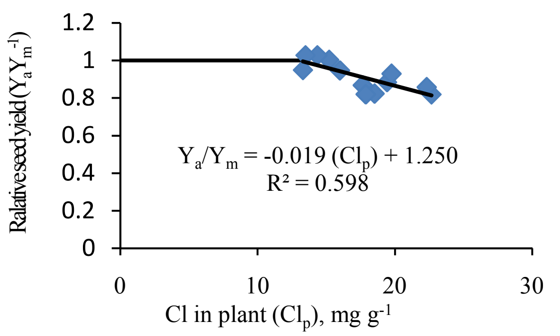

Fig. 9. Relationship between relative seed yield and Cl in plant.

$$(Y_a/Y_m) = 1-0.019\ (Cl_p-13.16)$$
$$R^2=0.60,\ n = 12,\ SE = 0.05,\ P = 0.003 \quad (7)$$

where Cl_p is the Cl in plant (mg g^{-1}). The value of 13.16 is the Cl_p threshold (mg g^{-1}) for seed yield reduction. The slope (1.9%) in Eq. (7) indicates a reduction of seed yield per unit increase in Cl_p. To assess the effects of deficit irrigation and planting methods on relationships between relative yield and Cl_p, these relationships were determined separately for different irrigation regimes (Table 10).

There was no significant regression relationship between relative yield and Cl_p for most intensive deficit irrigations (0.50FI and 0.35FI). Results indicated that there was no significant difference between the effect of deficit irrigation regime and planting methods on the slope of these relationships. The Cl_p threshold for seed yield reduction was significantly different for two planting methods in the full irrigation regime so that seed yield reduction occurred in higher Cl_p concentration in in-furrow planting method due to lower soil salinity, lower Cl_s and more water content that resulted in lower osmotic and matric potential of soil water. In in-furrow planting method, results of comparison between the Cl_p threshold for seed yield reduction of three irrigation regimes (FI and 0.75FI and 0.65 FI) indicated that there was a significant difference between these values and a decrease in applied water reduced the threshold for seed yield reduction. In 0.75 and 0.65 full irrigation regime in comparison with full irrigation regime, the Cl_p threshold for seed yield reduction decreased by 28.9 and 16.1% for in-furrow planting method and for all data in both planting methods, respectively.

Calcium

With the exception of Ca at 255 days after planting in the second year, deficit irrigation and planting method had no significant effect on the Ca in plant (Table 7). An increase in intensity of water stress decreased the Ca in plant. There was significant difference between the effects of salinity levels on Ca in plant. An increase in salinity of irrigation water resulted in enhancement of Ca in plant due to higher Ca concentration in soil and irrigation water as reported by Francois, (1994). Calcium could play a regulatory role in response of rapeseed to saline environment (Rameeh et al., 2004). There was a rising trend in Ca during the growing season. However, as a result of leaves senescence, Ca in plant decreased at the end of the growing season due to the fact that leaves contained higher Ca compared to other plant organs (Tuncturk et al., 2011). Furthermore, there was no significant interaction effect between deficit irrigation (I), salinity levels (S) and planting method (P), (I×S×P) on Ca concentration of plant in the two years (data not shown).

Table 10. Relationship between relative seed yield (Mg ha^{-1}) and Cl in plant (Cl_p, mg g^{-1}) in different irrigation regimes and planting methods for the two years.

Irrigation regime	On-ridge			In-furrow			Both planting methods		
	Slope	Threshold	R^2	Slope	Threshold	R^2	Slope	Threshold	R^2
Full irrigation (FI)	-0.019a*	11.31a	0.60	-0.019a	15.05b	0.90	-0.019a	13.16ab	0.60
0.75 and 0.65 FI	-0.020a	10.5ac	0.63	-0.026a	10.7c	0.77	-0.024a	11.04c	0.70
0.50 and 0.35 FI	-0.008	7.88	0.10^S	-0.014	11.64	0.37^S	-0.011	9.73	0.21^S

* Same letters in each column and each row for each factor are not significantly different at 5% level of probability, ^{S}: P_{value} of regression analysis is higher than 0.05.

Potassium

Potassium in plant showed an inverse relationship with the increase in salinity of soil and irrigation water (Table 7). Potassium in plant decreased as a result of an increase in Na in soil. Sodium can be substituted for K due to similar mechanisms of uptake for both ions (Rameeh et al., 2004) and Na is the major cause of reduction in K ion activity (Bybordi, 2010). Contrary to deficit irrigation and planting method, there was a significant difference between the effect of different salinity levels on K in plant. There was a significant interaction effect between deficit irrigation (I), salinity levels (S) and planting method (P), (I×S×P) on K concentration at 178 days after planting in the first year (Table 8). Furthermore, there was a significant interaction effect of I × S and I×P for K at178 days after planting (data not shown). However, there was no significant interaction effect on K in plant at different growing seasons in the two years (data not shown).

Sodium

Salinity regime caused a significant increase in Na content of rapeseed (Table 11) due to higher added Na to soil and its higher uptake by plant. In the second year at 207 and 228 days after planting, deficit irrigation had a significant effect on Na in plant. A decrease in applied water resulted in the reduction in Na uptake by plant due to lower soil water content and lower water flux to root and lower water and Na uptake in water stress conditions. In contrast to the findings of Dong et al. (2010) for cotton, the Na in plant in in-furrow planting method was higher than that of on-ridge planting for rapeseed. However, there was no significant difference between the effect of two planting methods on Na in plant. Furthermore, no significant interaction effect was found between deficit irrigation (I), salinity levels (S) and planting method (P), (I×S×P), on Na concentration of plant in the two years (data not shown).

Table 11. Mean values of Na concentration and K/Na ratio of plant in different irrigation regime, water salinity and planting methods for the two years in different days after planting during the the growing season.

	Na, mg g^{-1}							K/Na						
Year	2009-10			2010-11				2009-10			2010-11			
DAP**	178	215	255	186	207	228	255	178	215	255	186	207	228	255
Irrigation regime														
FI***	0.14a*	0.13a	0.35a	0.39a	0.43a	0.27a	0.43a	72.5a	42.3a	45.1a	20.7a	15.6a	19.4a	18.1a
0.75FI	0.15a	0.13a	0.17a					62.8a	41.3a	41.2a				
0.65FI				0.36a	0.33b	0.25a	0.53a				21.5a	22.2a	21.6a	14.4b
0.5FI	0.11a	0.11a	0.16a					78.8a	42.6a	40.9a				
0.35FI				0.28a	0.27b	0.18b	0.40a				24.3a	23.5a	24.8a	13.5b
Salinity levels dS m^{-1}														
0.6	0.06c	0.08b	0.07a	0.21b	0.23c	0.11d	0.13d	117.4a	65.0a	83.2a	35.5a	32.1a	42.3a	33.5a
4.0	0.11bc	0.10b	0.14a	0.26b	0.34b	0.21c	0.30c	68.7b	43.8b	39.5b	25.8b	19.7b	19.1b	16.4b
7.0	0.17ab	0.14a	0.21a					58.0bc	31.2c	27.5c				
8.0				0.43a	0.38ab	0.27b	0.63b				15.6c	17.1bc	14.4bc	6.4c
10.0	0.20a	0.17a	0.48a					41.4c	28.2c	19.4c				
12.0				0.48a	0.43a	0.34a	0.77a				11.7c	12.8c	11.9c	4.9c
Planting method														
On-ridge	0.12a	0.12a	0.16a	0.32a	0.33a	0.22a	0.44a	76.3a	40.6a	44.8a	23.4a	21.8a	24.9a	15.9a
In-furrow	0.15a	0.13a	0.29a	0.37a	0.36a	0.25a	0.48a	66.7a	43.4a	40.0a	20.9a	19.0a	19.0b	14.7a

*Means followed by the same letters in columns for each factor and each trait are not significantly different at 5% level of probability, using Duncan multiple rang test, **DAP: Days after planting, ***FI: Full irrigation.

Ratio of K/Na

With an increase of salinity and applied water, the ratio of K/Na decreased (Table 11). With the exception of K/Na at 228 days after planting for planting method and 255 days after planting for deficit irrigation in the second year, there was no significant difference between the effect of deficit irrigation and planting method on K/Na ratio. K/Na ratio in in-furrow planting method was lower than that of on-ridge planting method due to higher Na uptake and lower K uptake by plant. Salinity caused increased Na influx and K efflux (Rameeh et al., 2004). Therefore, higher Na and lower K in high salinity level and low applied water resulted in decreased K/Na. K/Na ratio can be applied as the selection criteria for assessing salinity tolerance of different crop species. The comparison between K/Na obtained in this study and values reported by Tuncturk et al. (2011) indicated that Talaieh cultivar in this research is a tolerant variety. K/Na ratio in the first year was higher than those in the second year due to lower Na and higher K in plant in the first year in comparison with the second year. There was a significant interaction effect between deficit irrigation (I), salinity levels (S) and planting method (P) (I×S×P), on K/Na ratio at 215 days after planting in the first year (Table 8) and for the interaction between P×S at this time and I×S for K/Na ratio at 255 days after planting in the second year (data not shown). However, there was no significant interaction effect on K /Na ratio at different growing seasons in the two years (data not shown).

CONCLUSIONS

Salinity and water stress affect water and nutrient uptake by plant. Deficit irrigation decreased uptake of potassium (K), calcium (Ca), sodium (Na) and chloride (Cl) by plant and with the exception of K, those uptakes were enhanced by an increase in the salinity of water and soil saturation extract. A decrease in applied water decreased the threshold of Na in soil for seed yield reduction. Deficit irrigation and planting methods had no significant effect on relationships between Cl in plant and soil saturation extract salinity. Deficit irrigation had a significant effect on the slope of the fitted line between Cl in plant and Cl in soil so that in 0.35FI and 0.50FI**,** the slope increased by 37.2% in comparison with full irrigation regime. The Cl_p threshold for seed yield reduction was significantly different for two planting methods in full irrigation regime so that seed yield reduction occurred in higher Cl concentration in plant in in-furrow planting method. A decrease in applied water decreased Cl_p threshold for seed yield reduction. K/Na ratio in in-furrow planting method was lower than that of on-ridge planting method due to higher Na uptake and lower K uptake by plant. Based on the results of the present study, in-furrow planting method is preferred for rapeseed planting or other sensitive crops in saline conditions of water and soil due to the decrease in Cl_p and Na_s threshold for yield reduction.

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اثر شوری و کم آبیاری بر جذب برخی عناصر توسط کلزا (*Brassica napus* L.) تحت دو روش مختلف کاشت

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شوری آب آبیاری

روش کاشت

کلزا

شوری

چکیده- در این تحقیق اثرات کم آبیاری و شوری آب آبیاری و روش کاشت (داخل جویچه و روی پشته) بر جذب یون های سمی و مغذی توسط کلزا در یک آزمایش دو ساله مورد بررسی قرار گرفت. کم آبیاری موجب کاهش جذب پتاسیم، کلسیم، سدیم و کلر توسط گیاه گردید و به استثناء پتاسیم جذب این عناصر تحت تاثیر شوری آب و خاک افزایش یافت. کاهش مقدار آب آبیاری موجب کاهش حد آستانه کاهش عملکرد در اثر جذب سدیم گردید. کم آبیاری اثر معنی داری بر شیب خط رابطه بین غلظت کلر در گیاه و غلظت کلر در خاک داشته است. در تیمار آبیاری کامل، حد آستانه غلظت کلر در گیاه برای کاهش عملکرد در دو روش کاشت تفاوت معنی داری با یکدیگر داشته است بطوری که کاهش عملکرد دانه در روش کاشت داخل جویچه در مقایسه با کاشت روی پشته در غلظت بیشتری از کلر در گیاه اتفاق افتاده است. حد آستانه کاهش عملکرد در اثر غلظت کلر در گیاه با کاهش مقدار آب آبیاری کاهش یافته است.