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Responses of agronomic components of rapeseed (*Brassica napus* L.) as influenced by deficit irrigation, water salinity and planting method

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Abstract

Shortage and salinity of irrigation water are two major constraints that influence rapeseed production in arid and semi-arid regions of central and southern Iran. In this study, effects of deficit irrigation with different salinity levels and planting methods (in-furrow and on-ridge) as strategies for coping with water and salinity stresses on yield and yield quality of rapeseed were investigated in a two-year experiment. Irrigation treatments consisted of full irrigation (FI), 0.75 FI and 0.50 FI in first year and FI, 0.65 FI and 0.35 FI in second year and salinity levels of irrigation water were 0.6 (well water), 4.0, 7.0 and 10.0 dS m^{-1} in first year and 0.6, 4.0, 8.0 and 12.0 dS m^{-1} in second year. In 0.75 FI and 0.5 FI irrigation treatments, seed yield reduced by 15.0 and 25.9%, respectively and in 0.65 FI and 0.35 FI it decreased by 20.8 and 33.0% relative to FI, respectively. Planting in-furrow increased yield by 5.3 and 13.7%, respectively, in first and second year (with frost occurrence in dormant period in second year) relative to on-ridge planting. Deficit irrigation and salinity decreased dry matter, plant height, seed oil content, oil and protein yields and 1000-seed weight in both years. Results indicated that 11.0, 13.1 and 11.8% deficit irrigation (reduction in applied irrigation water compared to full irrigation) could be imposed without loss in seed yield, oil and protein yields of rapeseed, respectively. In-furrow planting increased water use efficiency compared with on-ridge planting by 7.0 and 13.2% for first and second year, respectively. Increase in salinity level at same conditions of deficit irrigation and planting method decreased water use efficiency. Therefore, deficit irrigation and in-furrow planting method strategies can be used to increase water use efficiency in water scarce conditions.

Keywords: Planting method; Rapeseed; Salinity; Water stress; Yield components.

Introduction

Rapeseed is one of the important imported agricultural products in Iran. To decrease the imports of rapeseed and enhance food security, rapeseed cultivation promotion is a priority. Shortage and salinity of irrigation water are two major constraints for rapeseed production in arid and semi-arid regions of central and southern Iran. To cope with water scarcity, different approaches are proposed to reduce water consumption and increase water use efficiency in crop production. These methods are raised bed planting (Kukal et al., 2010), in-furrow planting (Zhang et al., 2007; Buttar et al., 2006), deficit irrigation (Pirmoradian et al., 2004a; Pirmoradian et al., 2004b; Sepaskhah and Akbari, 2005; Sinaki et al., 2007; Ahmadi and Bahrani, 2009; Istanbulluoglu et al., 2010; Sepaskhah and Ahmadi, 2010; Shabani et al., 2010; Sepaskhah and Tafteh, 2012) and identification of drought-resistant varieties (Naderi and Emam, 2010; Abbasi and Sepaskhah, 2011a; Abbasi and Sepaskhah, 2011b).

Reduction in soil evaporation from in-furrow planting resulted in decreased water consumption and increased water productivity (Buttar et al., 2006). Deficit irrigation reduced seed and oil yield of rapeseed (Istanbulluoglu et al., 2010; Sinaki et al., 2007; Gan et al., 2004). Shabani et al. (2010) indicated that deficit irrigation had negative significant effect on yield and yield quality of rapeseed such as weight of 1000-seed and seed oil and seed protein content and oil yield. Water productivity is an important parameter for the evaluation of deficit irrigation strategies. In arid and semi-arid areas, deficit irrigation enhances water productivity in comparison with rain-fed and full irrigation cultivation (Geerts and Raes, 2009).

To mitigate the effect of irrigation water salinity on crop yield, several strategies can be used such as: cultivation of resistant varieties to salinity (Ahmadi and Niazi-Ardekani, 2006; Mahmoodzadeh and Bemani-Naeini, 2007; Zamani et al., 2010; Bybordi, 2010), leaching the soil salinity during or out of the growing season to prevent salt accumulation and cultivation of plant in furrow (Dong et al., 2010; Zhang et al., 2007). Furrow irrigation with saline water caused salt accumulation on ridges and decreased soil salinity in the furrows (Wadleigh and Fireman, 1949). Better conditions for plant growth are provided in-furrow planting due to higher soil moisture, higher salt leaching and reduction in evaporation from the soil surface (Zhang et al., 2007; Li et al., 2010). Reduced soil evaporation and decreased in water requirement for leaching due to low salinity of root zone in-furrow planting resulted in reduced amount of irrigation water.

Interaction between the effects of the salinity level of water and the deficit irrigation on grain and straw weight of rice (Sepaskhah and Yousofi-Falakdehi, 2009), saffron yield (Sepaskhah and Yarami, 2009), madder growth (Sepaskhah and Beirouti, 2009) and corn yield (Amer, 2010) have been reported. Deficit irrigation and salinity resulted in reduction in matric and osmotic potential of soil water and these factors reduced root water uptake (Kramer and Boyer, 1995).

Rapeseed production is important in Fars province (semi-arid) and deficit irrigation strategy is one of the management practices for coping with drought and shortage of water in arid and semi- arid region. Furthermore, in-furrow planting could be one of the appropriate methods in saline conditions. The objectives of this investigation were to study the effects of deficit irrigation and salinity and planting method on yield, yield quality and water productivity of rapeseed (*Brassica napus* L.) in a silty clay loam soil.

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. Minimum temperature in November 2009 and 2010 was -5 and -8.6 ^{o}C, respectively. Frost occurred in initial growing stage before plant dormancy initiation in 2010-2011 growing season (Figure 1). In second year, experiment was conducted in other field near first year field 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 Tables 1 and 2. Experimental design was a split-split plot arrangement in randomized complete block design with irrigation treatment as the main plot, salinity levels of water as the subplot and planting method as the sup-subplot in three replications. Irrigation treatments included: water requirement plus 20% leaching fraction (full irrigation, FI), 75 and 50 percent of full irrigation in first growing season and FI, 65 and 35 percent of full irrigation in second growing season. The salinity treatments of irrigation water were 0.6 (well water), 4.0, 7.0 and 10.0 dS m^{-1} in first growing season and 0.6, 4.0, 8.0 and 12.0 dS m^{-1} in second growing season. The planting method included on-ridge planting and in-furrow planting. Pre-irrigation was applied before establishment of the plants in both years. Saline water was obtained by addition of NaCl and $CaCl_2$ to the well water in equal equivalent proportions. Dimension of each plot was 3×4 m^2 and distance between two adjacent plots was 1.0 m to prevent water invasion from one plot to another. Talaieh cultivar of rapeseed (a local cultivar) was planted on

27 September 2009 and 28 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. Irrigation interval was about 7-10 days and 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 before each irrigation event. Soil water content in the root zone was used to determine the amount of net irrigation water as calculated by the following equation:

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

where d_n is the net 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 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, 214d. Leaching fractions of 20% was applied to prevent salt accumulation in the root zone.

Water use efficiency was estimated by the following equation:

$$WUE = \frac{Y}{ET} \quad (3)$$

where WUE is the water use efficiency (kg m^{-3}), Y is the seed yield (kg ha^{-1}) and ET is the evapotranspiration (mm). The crop evapotranspiration for the irrigation intervals was estimated by the water balance procedure using the following equation:

$$ET = I + P - D \pm \Delta s \quad (4)$$

where I is the irrigation amount (mm), P is the precipitation (mm), D is the deep percolation (mm) and Δs is the change of soil water depth between two irrigations in root zone. Deep percolation was estimated by the following equation:

$$D = (I + P) - \sum_{i=1}^{n} (\theta_{fci} - \theta_i) \Delta z_i \quad (5)$$

In this region most rainfall occurs in winter and in this time soil surface is usually wet and it can be assumed that the soil water content reduction is equal to reference evapotranspiration (Farshi et al., 1987). Therefore, soil water content before rainfall was estimated approximately. Reference evapotranspiration was estimated by Penman-Monteith equation (Allen et al., 1998) which was calibrated by Razzaghi and Sepaskhah (2012) for semi-arid environments in the study area. Figures 2 and 3 show the amounts of reference evapotranspiration (ET_0), irrigation water applied for each irrigation event for different irrigation treatments and rainfall for 2009-2010 and 2010-2011, respectively. Total amount of rainfall was 298 and 258.3 mm for 2009-2010 and 2010-2011, respectively.

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

Physical properties	Soil depth (cm)				
	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				
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
HCO_3 (meq l^{-1})	---	---	---	---	---

Table 2. Chemical analysis of the saline irrigation water used in the experiment.

EC, dS m^{-1}	Cl	Ca	Na	HCO_3
	meq l^{-1}			
0.6	2.05	3.80	1.09	5.24
4.0	40.37	39.41	3.03	4.64
7.0	77.98	74.27	4.74	4.10
8.0	91.31	85.89	5.31	3.92
10.0	119.16	109.13	6.45	3.56
12.0	148.59	132.37	7.59	3.20

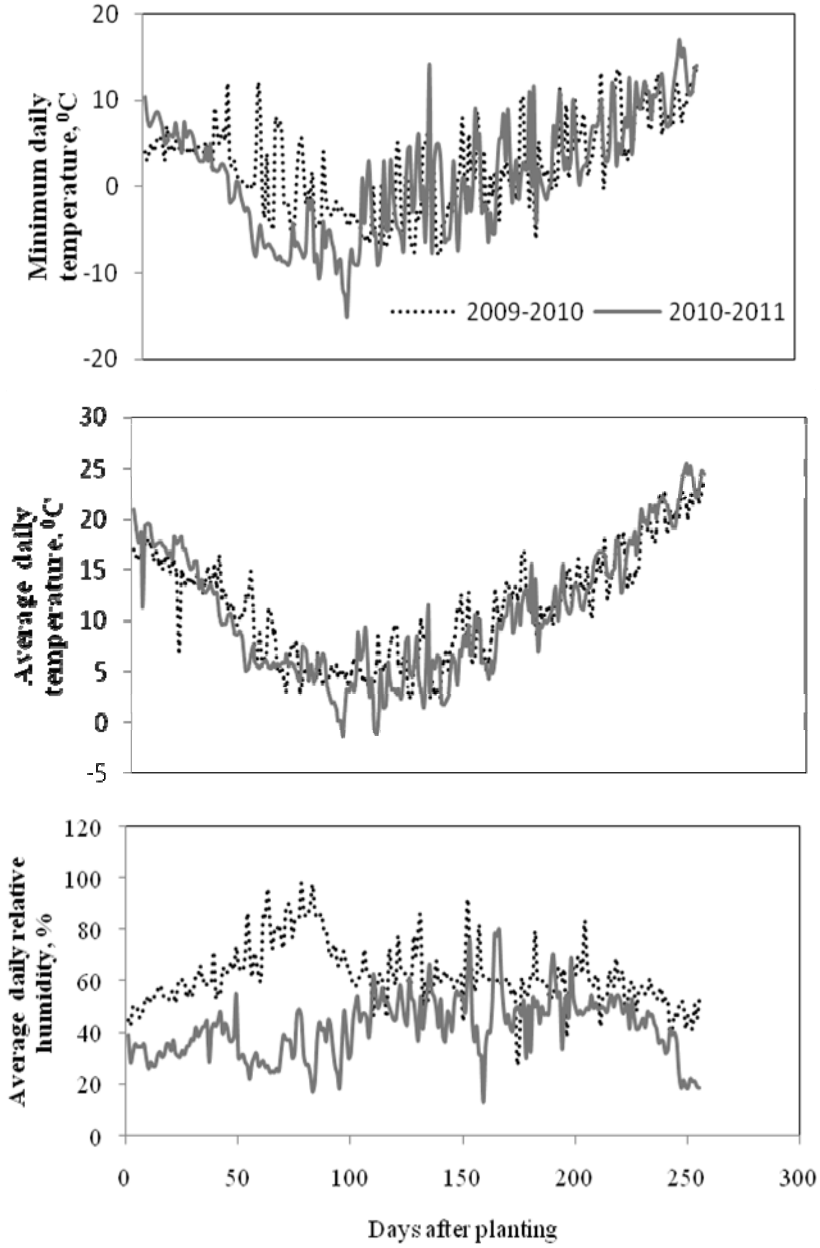

Figure 1. Minimum daily temperature, average daily temperature and average daily relative humidity of air in two years.

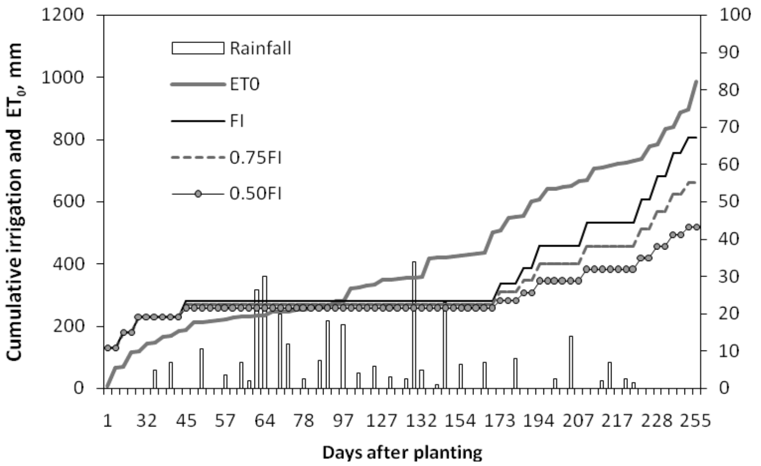

Figure 2. Cumulative reference evapotranspiration (ET_0) and rainfall and applied irrigation (FI, 0.75 FI and 0.5 FI) water in 2009-2010.

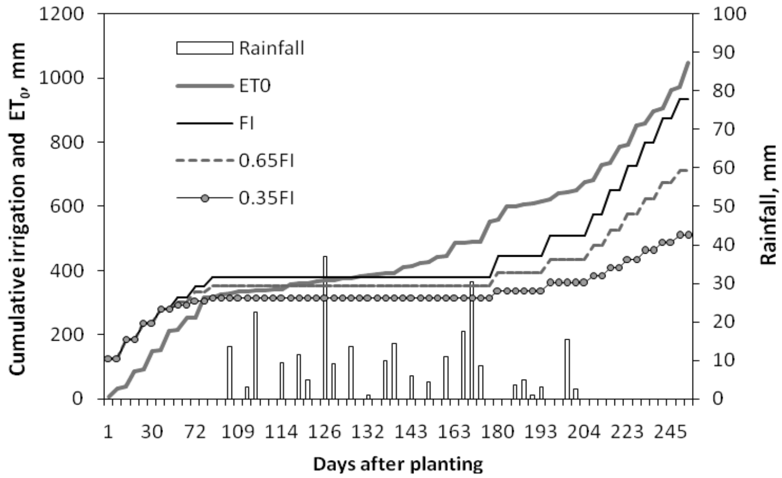

Figure 3. Cumulative reference evapotranspiration (ET_0) and rainfall and applied irrigation (FI, 0.65 FI and 0.35 FI) water in 2010-2011.

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 at two different times, i.e., before stem elongation and flowering stage. Soil samples were collected from each plot

149, 189, 223 and 255 days after planting in first year and 186, 226 and 255 days after planting in second year to measure salinity of saturated soil extract (EC_e). Soil samples were taken in 0.3 m increment to depth of 1.2 m to assess the soil salinity in the root zone in two replications. Soil samples were taken from bed of furrow in in-furrow planting and were taken from top of ridge in on-ridge planting method. Salinity of saturated soil extract determinations were measured as described by the U. S. Salinity Laboratory Staff (USDA, 1954).

Before harvest, plant height and after harvest seed yield, aboveground dry matter and 1000-seed weight were determined. Plants from the three central rows with 1.0 m distance from two edges were harvested and seeds were separated from straw and weighed. Furthermore, the oven-dried weight of straw was determined. Samples from the seeds were used to determine the seed protein content (as percent) by multiplying the nitrogen content by 6.25. Seed nitrogen concentration was determined by Kejldahl procedure (Bremner and Mulvaney, 1982). Furthermore, samples from seeds were used to determine the seed oil content by using Soxhlet extraction (Agrawat and Dadlani, 1987).

Yield production function

Relative yield under water and salinity stress was estimated by the following equation (Sepaskhah and Yarami, 2010):

$$\frac{Y_a}{Y_m} = 1 - K_y\left[1 - \frac{K_s ET_c}{ET_c}\right] \tag{6}$$

where Y_a is the actual crop yield (Mg ha^{-1}), Y_m is the maximum expected crop yield (Mg ha^{-1}), K_y is the relative yield response factor at water stress, ET_c is the crop evapotranspiration for standard condition (no water stress, mm d^{-1}) and K_s is the transpiration reduction factor which depends on soil salinity and water stress. It is determined by the following equation as proposed by Allen et al. (1998):

$$K_s = \left[1 - \frac{b}{K_y 100}(EC_e - EC_{e-threshold})\right] \times \left[\frac{TAW - D_r}{(1-P)TAW}\right] \tag{7}$$

where D_r is the root zone water depletion (mm), *TAW* is the total available water in the root zone (mm), *P* is the fraction of *TAW* that a crop can extract water from the root zone without suffering water stress, EC_e is the electrical conductivity of the saturated soil extract (dS m^{-1}), $EC_{e\text{-}threshold}$ is the threshold soil saturated extract electrical conductivity (dS m^{-1}) and *b* is the seed yield reduction per unit saturated soil extract salinity under full irrigation condition. Value of 0.6 is proposed for *P* by Allen et al. (1998) for rapeseed. Application of Equation (7) should usually be restricted to $EC_e < EC_{e\text{-}threshold} + 50/b$ and $K_y \leq 1.0$. For $K_y > 1.0$ it should predict $Y_a=0$ at $K_s=0$. In addition, the K_y values are given for only 23 crops by Doorenbos and Kassam (1979) and where K_y is unknown it is suggested to use $K_y=1$ or may select the K_y for a crop that has similar behavior.

Statistical analysis

The interaction effects between deficit irrigation, salinity and planting method were evaluated by using analysis of variance test and means were compared by using Duncan multiple range test. Before means comparison, normality test was conducted and all of data were normal.

Results and Discussion

Soil water depth

Soil water depths of root zone before last irrigation are shown in Table 3. In the two years, there were no clear differences between the soil water depths of root zone for different salinity levels. With decrease in applied water, soil water depth decreased. In-furrow planting method, soil water depth increased by 3.8 and 1.0 percent in comparison with on-ridge planting for first and second year, respectively due to leaf shading on the wetted surface area and less evaporation from the soil surface.

Evapotranspiration

Deficit irrigation decreased evapotranspiration by 6 and 19% in 0.75 FI and 0.5 FI irrigation treatments in 2009-2010 and 13 and 32% in 0.65 FI and 0.35 FI irrigation treatments in 2010-2011, respectively, compared with full irrigation treatment (Table 3). In two years, there was no difference between evapotranspiration for different salinity levels and two planting methods. With decrease in applied water, evapotranspiration decreased. In the second year in comparison to first year, evapotranspiration was higher due to lower air relative humidity (Figure 1) and more reference evapotranspiration (Figures 2 and 3).

Table 3. Soil water depth, evapotranspiration and electrical conductivities of the saturated soil extract (EC_e) averaged in root zone for two years.

year	Irrigation treatment	Planting method							
		On-ridge planting				In-furrow planting			
Soil water depth, mm									
		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)	193	195	197	194	198	200	203	194
	0.75 FI	178	179	186	190	184	191	195	185
	0.5 FI	150	147	158	155	155	151	168	176
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	8.0	12.0	0.6	4.0	8.0	12.0
2010-2011	FI	194	192	196	197	192	189	196	197
	0.65 FI	167	161	165	170	168	166	168	171
	0.35 FI	140	145	158	146	145	162	140	156
Evapotranspiration, mm									
		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	806	822	816	811	814	811	797	813
	0.75 FI	787	773	757	747	772	769	744	744
	0.5 FI	667	669	657	652	658	660	641	639
		Irrigation water salinity, dS m^{-1}							
		0.6	4.0	8.0	12.0	0.6	4.0	8.0	12.0
2010-2011	FI	859	869	863	862	870	894	891	863
	0.65 FI	757	762	759	756	760	761	757	754
	0.35 FI	601	594	590	591	591	586	590	590
Electrical conductivities of the saturated soil 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	FI	0.60	2.54	5.35	5.79	0.56	2.61	4.20	4.60
	0.75 FI	0.59	2.61	3.68	4.66	0.52	1.86	3.01	3.75
	0.5 FI	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
2010-2011	FI	0.54	2.31	4.25	8.10	0.58	2.22	3.56	7.34
	0.65 FI	0.62	2.88	4.74	5.26	0.58	3.16	3.88	6.19
	0.35 FI	0.64	1.12	2.61	3.45	0.60	1.55	2.90	4.30

Soil salinity

The average electrical conductivities of soil saturation extract (EC_e) in root zone during growing season for each treatment for both years are presented in Table 3. For the full irrigation treatment in the two years and deficit irrigation of 0.75 FI in the first year, salt accumulation was higher in on-ridge planting. However, in other deficit irrigations, salt concentrated higher in-furrow planting due to lower applied water, drier soil in furrow and less salt transfer to the ridge (Table 3). Comparison between the soil salinities of the two planting methods by paired t-test indicated that there was no significant difference between soil salinities of two planting methods.

Plant height

Deficit irrigation in the second year and salinity in the first year and planting method in both years showed significant effect on plant height (Table 4). Deficit irrigation of 0.65 FI and 0.35 FI decreased plant height by 10 and 12%, respectively, only in second year compared with full irrigation treatment. Salinity decreased plant height so that in salinity level of 10.0 and 12.0 dS m^{-1} in first and second year, it was reduced by 12 and 7%, respectively in comparison with no saline water. Plant height in second year was lower than that in first year. This maybe due to frost occurrence at initial vegetative stage of growth in second year. Deficit irrigation and salinity stress decreased plant height as reported by Istanbulluoglu et al. (2010), Shabani et al. (2009) and Mohammadi et al. (2012) for rapeseed. Reduction of plant height may be due to decrease in cell elongation as a result of water stress and salinity. Further, plant growth might have been retarded with lower stomatal conductance, decrease in photosynthesis rate and ion toxicity (Ashraf and McNeilly, 2004; Mohammadi et al., 2012). Comparison of results (Table 4) showed that planting method had significant effect on plant height in two consecutive growing seasons. In all of irrigation treatment, plants of in-furrow planting were taller than those in on-ridge planting. For full irrigation and 0.75 FI treatments, plant height in in-furrow was taller due to higher soil moisture, higher salt leaching and reduction in evaporation from the soil surface. In 0.65 FI, 0.50 FI and 0.35 FI, salt accumulations for these treatments were higher in furrow in comparison with on ridge; however plant height was taller due to higher soil water content that dominated the negative effects of salinity.

Table 4. Mean values of plant characteristics, yield and yield quality in each irrigation treatment, water salinity and planting methods for two years.

Year	Plant height cm		Yield Mg ha^{-1}		Dry matter Mg ha^{-1}		Harvest index		Seed oil content %		Seed protein content %		Oil yield Mg ha^{-1}		Protein yield Mg ha^{-1}		1000-seed weight, g	
	1th	2th	1th	2th	1th	2th	1th	2th	1th	2th	1th	2th	1th	2th	1th	2th	1th	2th
Irrigation treatment																		
FI**	116.6^{a*}	105.5^{a}	2.93^{a}	3.03^{a}	9.8^{a}	8.5^{a}	0.30^{a}	0.35^{a}	31.5^{a}	32.7^{a}	18.8^{a}	20.3^{a}	0.92^{a}	1.0^{a}	0.55^{a}	0.62^{a}	4.6^{a}	3.8^{a}
0.75 FI	117.3^{a}		2.48^{b}		8.9^{ab}		0.28^{a}		32.0^{a}		18.9^{a}		0.80^{b}		0.47^{b}		4.5^{a}	
0.65 FI		94.6^{b}		2.40^{b}		7.4^{a}		0.32^{b}		32.7^{a}		21.0^{a}		0.79^{ab}		0.51^{ab}		3.9^{a}
0.5 FI	115.9^{a}		2.17^{c}		7.4^{b}		0.30^{a}		32.1^{a}		18.2^{a}		0.70^{c}		0.40^{c}		3.6^{b}	
0.35 FI		92.8^{ab}		2.03^{b}		6.9^{a}		0.30^{c}		32.2^{a}		21.2^{a}		0.66^{b}		0.43^{b}		3.7^{a}
Salinity levels dS m^{-1}																		
0.6	126.1^{a}	99.9^{a}	2.69^{a}	2.73^{a}	9.0^{a}	8.0^{a}	0.30^{a}	0.34^{a}	33.4^{a}	33.4^{a}	18.8^{a}	20.6^{a}	0.90^{a}	0.91^{a}	0.50^{a}	0.56^{a}	4.5^{a}	3.9^{a}
4.0	116.3^{b}	99.9^{a}	2.62^{a}	2.68^{a}	9.0^{a}	8.1^{a}	0.30^{a}	0.33^{ab}	32.0^{ab}	32.8^{a}	18.2^{a}	20.4^{a}	0.84^{b}	0.88^{a}	0.48^{a}	0.54^{a}	4.4^{a}	3.8^{a}
7.0	113.3^{bc}		2.43^{b}		8.4^{a}		0.29^{a}		31.0^{b}		18.8^{a}		0.75^{c}		0.46^{a}		3.8^{b}	
8.0		97.4^{a}		2.30^{b}		7.5^{ab}		0.31^{b}		32.0^{a}		21.5^{a}		0.74^{b}		0.49^{b}		3.8^{a}
10.0	110.8^{c}		2.37^{b}		8.4^{a}		0.29^{a}		31.2^{ab}		18.8^{a}		0.74^{c}		0.45^{a}		4.2^{ab}	
12.0		93.3^{a}		2.24^{b}		6.9^{b}		0.32^{ab}		32.1^{a}		20.9^{a}		0.72^{b}		0.47^{b}		3.7^{a}
Planting method																		
On-ridge	115.1^{a}	89.6^{a}	2.46^{a}	2.33^{a}	8.3^{a}	7.3^{a}	0.30^{a}	0.32^{a}	31.8^{a}	32.2^{a}	18.7^{a}	20.7^{a}	0.78^{a}	0.76^{a}	0.46^{a}	0.48^{a}	4.1^{a}	3.8^{a}
In-furrow	118.5^{b}	105.7^{b}	2.59^{b}	2.65^{b}	9.0^{a}	8.0^{b}	0.29^{a}	0.33^{b}	32^{a}	32.9^{a}	18.7^{a}	20.9^{a}	0.83^{b}	0.87^{b}	0.49^{b}	0.55^{b}	4.4^{a}	3.8^{a}

*Mean 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 range test.

**FI: Full irrigation.

There was a significant interaction effect between deficit irrigation (I), salinity levels (S) and planting method (P), (I×S×P), on plant height in first year (Table 5). However, there was no significant effect in second year (data not shown). Similar results were obtained for interaction between I×S, I×P and S×P for two growing seasons (data not presented). Maximum plant height was obtained in first year with full irrigation and water salinity of 0.6 dS m^{-1} at two planting methods, while in the second year the maximum height was occurred in full irrigation and 4.0 dS m^{-1} salinity (data not shown). Therefore, in some cases, water salinity of 4.0 dS m^{-1} may be considered as salinity level for stimulation of plant growth in the vegetative stage.

Seed yield

Deficit irrigation and salinity decreased seed yield of rapeseed in two years (Table 4). Similar results have been reported by Istanbulluoglu et al. (2010), Sinaki et al. (2007), Ahmadi and Niazi-Ardekani (2006) and Gul and Ahmed (2004) for rapeseed. The effect of deficit irrigation on seed yield was significant so that in 0.75 FI and 0.5 FI irrigation treatments, seed yield reduced by 15.0 and 25.9%, respectively and in 0.65 FI and 0.35 FI it decreased by 20.8 and 33.0%, respectively, relative to full irrigation at different salinity levels and planting methods. Figure 4 shows the relationship between seed yield reduction and ratio of deficit irrigation (Table 6). Results indicated that 11% reduction in applied irrigation water can be imposed without seed yield reduction of rapeseed. At different deficit irrigation and planting methods, the seed yields were not statistically different at water salinity levels of 0.6 and 4.0 dS m^{-1} for two years. However, they were statistically higher compared with those obtained at water salinity levels of 7.0-12.0 dS m^{-1}. Furthermore, seed yields were not statistically different at water salinity levels of 7.0 and 10.0 for first year and 8.0 and 12.0 dS m^{-1} for second year (Table 4).

In full irrigation treatment in first year, salinity level of 10 dS m^{-1} resulted in lower seed yield by 18.0 and 6.9% for on-ridge and in-furrow planting method, respectively and in second year these reductions were 18.0 and 14.0%, respectively due to higher salinity level (12.0 dS m^{-1}). Seed yield reduction might be occurred as a result of lower stomatal conductance, depressed specific metabolic process in carbon uptake and reduction in photosynthesis (Ashraf and Mc Neilly, 2004), ion toxicity and change in the balance of available nutrients in saline environment (Mohammadi et al., 2012). Increasing salinity of water to 7.0 dS m^{-1} in first year and to 8.0 dS m^{-1} in second year resulted in significant reduction in seed yield. Because of salt accumulation on ridge in furrow irrigation (Wadleigh and Fireman, 1949) and more leaching and soil water content in furrows, seed yield in-furrow planting method was higher than that in on-ridge planting (Table 4). There was not significant interaction effect between deficit irrigation, water salinity and planting method (I×S×P) on seed yield in first and second year (Table 5). Similar results obtained for interaction between I×S, I×P and S×P for two growing seasons (data not presented). In full irrigation treatment with exception of on-ridge planting in first year, salinity level of 4.0 dS m^{-1} resulted in higher seed yield than that obtained at 0.6 dS m^{-1}, although their difference was not statistically significant. For some crops somewhat higher salinity (i.e. 4.0 dS m^{-1}) stimulated plant growth in vegetative stage as reported by Sepaskhah et al. (2006) for sugerbeet. However, under higher reduction in applied irrigation water due to simultaneous decrease in plant water and osmotic potential, seed yield decreased in higher salinity levels (Table 5).

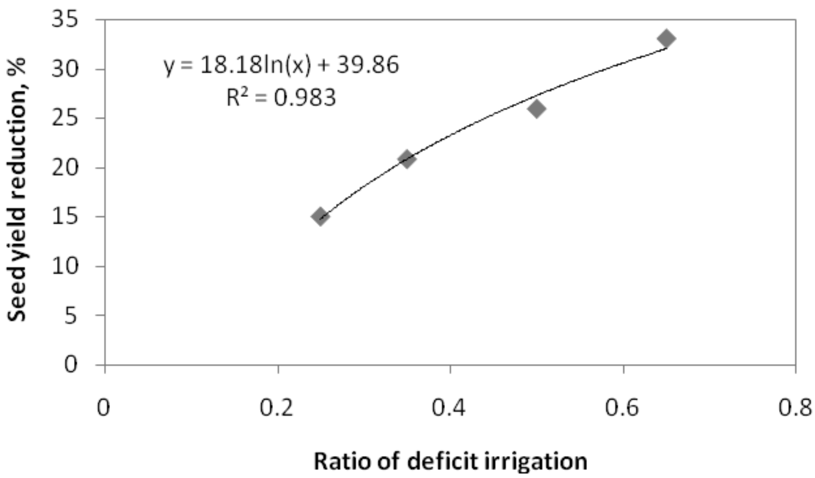

Figure 4. Relationship between seed yield reduction and ratio of deficit irrigation.

Table 5. Mean values of plant characteristics interaction between irrigation, water salinity and planting methods treatments.

		Planting method							
		On-ridge planting				In-furrow planting			
		Plant height, cm							
year	Irrigation** treatment	Salinity level, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
1^{th}	FI	132.8^{a*}	119.0^{def}	108.8^{ij}	107.0^{ij}	133.0^{a}	107.5^{ij}	114.7^{fgh}	110.0^{hij}
	0.75 FI	125.0^{bc}	118.7^{def}	111.0^{ghi}	105.0^{j}	130.0^{a}	120.7^{cd}	118.0^{def}	110.0^{hij}
	0.50 FI	120.0^{de}	106.2^{ij}	109.7^{ij}	117.7^{def}	115.7$^{d\text{-}g}$	125.5^{b}	117.8^{def}	115.0^{efg}
		Seed yield, Mg ha^{-1}							
		Salinity level, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
1^{th}	FI	3.18	3.01	2.76	2.60	3.03	3.12	2.88	2.82
	0.75 FI	2.63	2.49	2.27	2.24	2.83	2.63	2.45	2.29
	0.50 FI	2.13	2.06	1.92	2.19	2.30	2.42	2.28	2.08
		Salinity level, dS m^{-1}							
		0.6	4.0	8.0	12.0	0.6	4.0	8.0	12.0
2^{th}	FI	3.13	3.14	2.57	2.56	3.42	3.51	3.02	2.93
	0.65 FI	2.50	2.36	2.03	2.00	3.03	2.98	2.17	2.14
	0.35 FI	2.04	1.99	1.88	1.77	2.29	2.11	2.15	2.04
		Seed protein, %							
		Salinity level, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
1^{th}	FI	18.68$^{b\text{-}e}$	18.97$^{a\text{-}e}$	17.80^{de}	17.80^{de}	18.68$^{b\text{-}e}$	18.84$^{a\text{-}e}$	20.72^{a}	18.97$^{a\text{-}e}$
	0.75 FI	19.84^{abc}	17.51^{e}	20.31^{ab}	19.55$^{a\text{-}d}$	18.38$^{b\text{-}e}$	18.68$^{b\text{-}e}$	18.26^{cde}	18.97$^{a\text{-}e}$
	0.50 FI	18.38$^{b\text{-}e}$	17.51^{e}	17.80^{de}	19.84^{abc}	18.55$^{b\text{-}e}$	17.96^{cde}	18.09^{cde}	17.80^{de}
		Salinity level, dS m^{-1}							
		0.6	4.0	8.0	12.0	0.6	4.0	8.0	12.0
2^{th}	FI	20.1^{abc}	20.0^{bc}	19.8^{bc}	20.7^{abc}	20.1^{abc}	19.0^{c}	21.3^{abc}	21.3^{abc}
	0.65 FI	19.8^{bc}	20.4^{abc}	23.3^{a}	19.8^{bc}	21.6^{abc}	20.5^{abc}	21.3^{abc}	21.3^{abc}
	0.35 FI	20.7^{abc}	20.0^{bc}	21.3^{abc}	22.8^{ab}	21.5^{abc}	22.5^{ab}	21.9^{abc}	19.0^{c}
		Water use efficiency, kg m^{-3}							
		Salinity level, dS m^{-1}							
		0.6	4.0	7.0	10.0	0.6	4.0	7.0	10.0
1^{th}	FI	0.39	0.37	0.34	0.32	0.37	0.38	0.36	0.35
	0.75 FI	0.33	0.32	0.30	0.30	0.37	0.34	0.33	0.31
	0.50 FI	0.32	0.31	0.29	0.34	0.35	0.37	0.36	0.32
		Salinity level, dS m^{-1}							
		0.6	4.0	8.0	12.0	0.6	4.0	8.0	12.0
2^{th}	FI	0.36	0.36	0.30	0.30	0.39	0.39	0.34	0.34
	0.65 FI	0.33	0.31	0.27	0.26	0.40	0.39	0.29	0.28
	0.35 FI	0.34	0.34	0.32	0.30	0.39	0.36	0.36	0.35

* Mean 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 range test.

** FI: Full irrigation.

Table 6. Relationship between ratio of deficit irrigation (*DI*) (% of reduction in applied water with respect to FI) and percent reduction of seed yield (*SY*) and oil yield (*OY*) and protein yield (*PY*).

Equation	R^2
$SY=18.18 \ln (DI)+39.86$	0.983
$OY= 20.15 \ln (DI)+40.91$	0.938
$PY=17.99 \ln (DI) +38.51$	0.966

Water-salinity-yield production function

Relationships between relative seed yield and relative evapotranspiration (relative to those obtained in full irrigation) for different irrigation water salinities and soil saturation extract salinities [Eq.(6)] determined by regression analysis are shown in Table 7 (numbers 1-4 are displayed with K_{sy} notation for seed yield). Coefficients of Eq. (6) in Table 7 are the growth response factor to water (K_{sy}) for different traits. With increasing salinity higher than 4.0 dS m^{-1} and 2.2 dS m^{-1} for irrigation water salinity and soil saturation extract salinity, respectively, the value of K_{sy} reduced. Results indicated that in low salinities of soil and water the value of K_{sy} was more than 1.0, therefore seed yield of rapeseed was sensitive to reduced water consumption. In high salinities of soil and irrigation water, the sensitivity of rapeseed to water stress reduced due to values of K_{sy} close to 1.0 (Figures 5 and 6).

Table 7. Relationship between relative seed yield (*SY*), dry matter (*DM*), oil yield (*OY*) and protein yield (*PY*) and relative evapotranspiration for different water and soil salinity.

Number	Water salinity level, dS m^{-1}	Soil saturation extract salinity, dS m^{-1}	Equation	R^2
		Seed yield		
1	0.6	0.6	$(1-SY_a/SY_m)=1.23\ (1-ET_a/ET_m)$	0.91
2	4.0	2.2	$(1-SY_a/SY_m)=1.33\ (1-ET_a/ET_m)$	0.93
3	7.0 and 8.0	3.6	$(1-SY_a/SY_m)=1.17\ (1-ET_a/ET_m)$	0.87
4	10.0 and 12.0	5.0	$(1-SY_a/SY_m=1.04\ (1-ET_a/ET_m)$	0.9
		Dry matter		
5	0.6	0.6	$(1-DM_a/DM_m)=0.74\ (1-ET_a/ET_m)$	0.786
6	4.0	2.2	$(1-DM_a/DM_m)=1.00\ (1-ET_a/ET_m)$	0.864
7	7.0 and 8.0	3.6	$(1-DM_a/DM_m)=0.71\ (1-ET_a/ET_m)$	0.696
8	10.0 and 12.0	5.0	$(1-DM_a/DM_m)=0.83\ (1-ET_a/ET_m)$	0.867
		Oil yield		
9	0.6	0.6	$(1-OY_a/OY_m)=1.25\ (1-ET_a/ET_m)$	0.895
10	4.0	2.2	$(1-OY_a/OY_m)=1.33\ (1-ET_a/ET_m)$	0.98
11	7.0 and 8.0	3.6	$(1-OY_a/OY_m)=1.22\ (1-ET_a/ET_m)$	0.88
12	10.0 and 12.0	5.0	$(1-OY_a/OY_m)=1.02\ (1-ET_a/ET_m)$	0.94
		Protein yield		
13	0.6	0.6	$(1-PY_a/PY_m)=1.14\ (1-ET_a/ET_m)$	0.88
14	4.0	2.2	$(1-PY_a/PY_m)=1.25\ (1-ET_a/ET_m)$	0.80
15	7.0 and 8.0	3.6	$(1-PY_a/PY_m)=1.0\ (1-ET_a/ET_m)$	0.85
16	10.0 and 12.0	5.0	$(1-PY_a/PY_m)=0.90\ (1-ET_a/ET_m)$	0.77

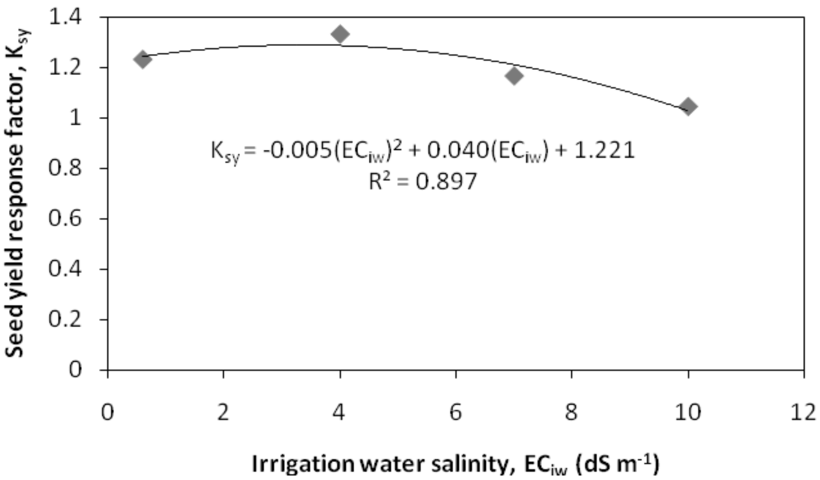

Figure 5. Relationship between growth response factor (K_{sy}) for seed yield and irrigation water salinity (EC_{iw}).

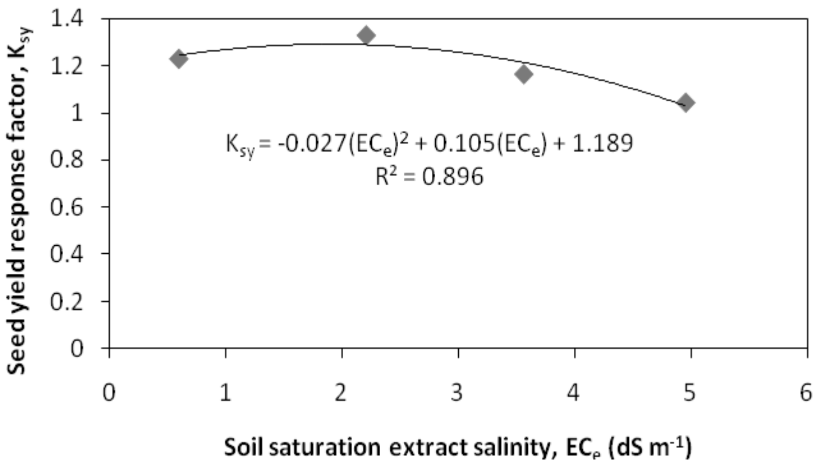

Figure 6. Relationship between growth response factor (K_{sy}) for seed yield and soil saturation extract salinity (EC_e).

Relationship between relative seed yield and salinity of irrigation water determined by regression analysis as follows (Figure 7):

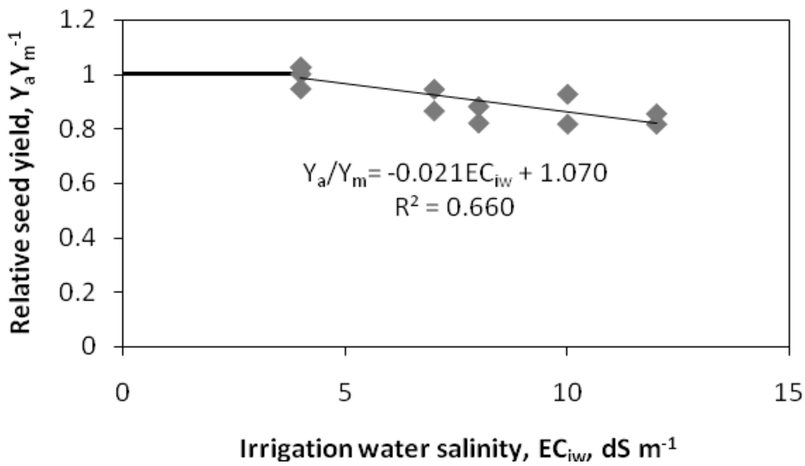

Figure 7. Relationship between relative seed yield and salinity of irrigation water.

$$(Y_a/Y_m)=1-0.021\ (EC_{iw} - 3.33),\ R^2=0.66 \tag{8}$$

where EC_{iw} is the salinity of irrigation water (dS m^{-1}). The value of 3.33 is the EC_{iw} threshold for seed yield. Ahmadi and Niazi-Ardekani (2006) reported EC_{iw} of 5.0 dS m^{-1} as threshold for rapeseed which is higher than that obtained in this study. This might be due to differences in cultivars (Falcon, Shirali and ACSNI) with different salt tolerances. The slope (2.1%) in Eq. (8) indicates a reduction of seed yield per unit increase in irrigation water salinity. This coefficient is similar to that reported by Sepaskhah and Beirouti (2009) for madder as a salt tolerant plant.

Figure 8 shows the relationship between relative seed yield and soil saturation extract salinity in root zone. The relationship is as follows:

$$(Y_a/Y_m)=1-0.032\ (EC_e - 1.75),\ R^2=0.63 \tag{9}$$

where EC_e is the soil saturation extract salinity (dS m^{-1}). Equation (9) indicates that the soil EC_e threshold for reduction of seed yield is 1.75 dS m^{-1} and the slope of the reduction of seed yield is 3.2% per unit EC_e. The EC_e threshold and rate of yield decline at EC_e above the thresholds is lower than other crops, as listed by Allen et al. (1998). Francois (1994) and Ashraf and McNeilly (2004) reported that rapeseed is a salt tolerant plant. Furthermore, EC_e threshold was less than EC_{iw} threshold. This is due to the fact that before irrigation, the soil was not saline and rainfall in winter decreased irrigation requirement, therefore soil salinity was not high.

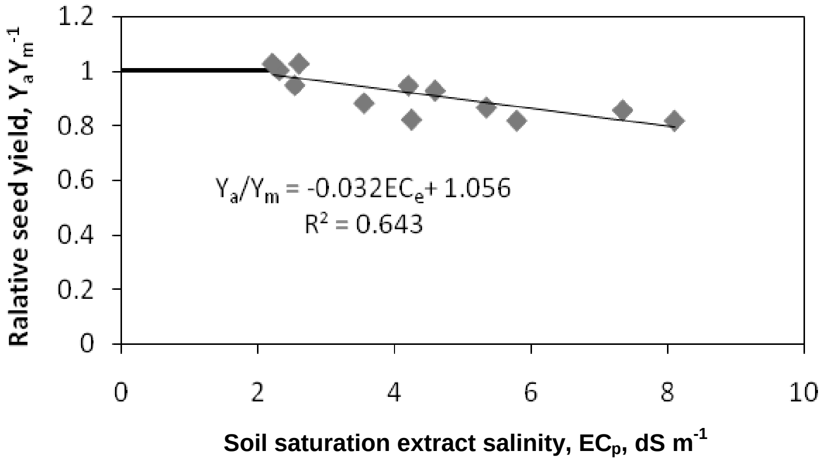

Figure 8. Relationship between relative seed yield and soil saturation extract salinity.

The seed yield was predicted by using Eq. (6) while K_y=1.23 (Table 7). K_s in Eq. (6) was calculated by Eq. (7). The relationships between the predicted seed yield and the measured values are shown in Figure 9. Comparison between this relationship and line of 1:1 showed that slope and intercept were not significantly different from 1.0 and 0, respectively ($P<0.05$). Therefore, Eqs. (6) and (7) resulted in good estimation of seed yield.

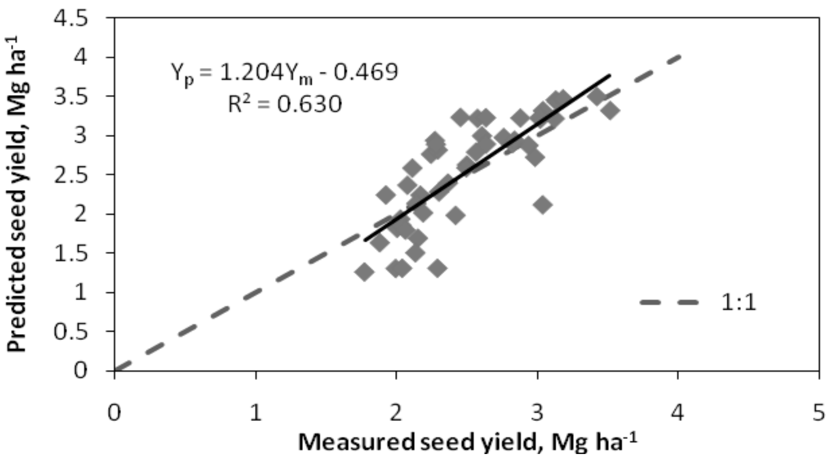

Figure 9. Relationship between predicted and measured seed yield.

Dry Matter

Means comparison showed that deficit irrigation in first year and water salinity and planting method in second year had significant effect on dry matter (Table 4). At different water salinity levels and planting methods, deficit irrigation resulted in decrease in dry matter by 9.2 and 24.5% for 0.75 FI and 0.50 FI, respectively in first year and by 13 and 18.8% for 0.65 FI and 0.35 FI, respectively in second year in comparison with full irrigation. Dry matter decreased in second year in comparison with first year, due to frost occurrence as concluded for plant height reduction, too. There was no interaction effect between deficit irrigation and water salinity and planting method (I×S×P) on dry matter in two years (data not presented). Similar to plant height and seed yield, salinity level of 4.0 dS m^{-1} in full irrigation treatment resulted in higher dry matter compared with salinity level of 0.6 dS m^{-1}. However, there was no significant difference between these salinity levels. Similar results were observed for rice and sugerbeet by Sepaskhah and Yousofi-Falakdehi (2009) and Sepaskhah et al., (2006), respectively. Minimum dry matter observed in lowest applied water and highest salinity level in two planting methods in two years (Table 4).

Relationships between relative dry matter and relative evapotranspiration (relative to those obtained in full irrigation) for different irrigation water salinities and salinity of soil saturation extract determined by regression analysis are shown in Table 7 (numbers 5-8). Coefficients of equations are the growth response factor to water (K_{dm}) for dry matter. Similar to seed yield, the value of K_{dm} reduced with increasing salinity higher than 4.0 dS m^{-1} for irrigation water and 2.2 dS m^{-1} for soil saturation extract.

Harvest index

Harvest index (HI) obtained by seed yield divided by aboveground dry matter. In contrast to the second year, first year results indicated no significant differences in HI in different irrigation treatments. These results were repeated for salinity levels and planting methods (Table 4). For HI, there was not significant interaction effect between deficit irrigation and salinity levels and planting method (data not presented). There was no clear pattern in HI variation between deficit irrigation, salinity and planting methods in two years. In contrast, Ali et al. (1988) observed an increased HI by increase in water stress and Wright et al. (1995) and Shabani et al. (2010) obtained reduction in HI with increase in water stress.

Yield quality

Seed oil content

In first year, seed oil content was statistically different among water salinity levels (Table 4). However, there was no significant difference between effect of deficit irrigation and planting methods on seed oil content. Furthermore, in second year, there was no significant difference between all treatments on seed oil content that is in accordance with those reported by Ahmadi and Niazi-Ardekani (2006) for similar irrigation water salinity. Seed oil content that obtained in this study is lower than that reported by Ahmadi and Niazi-Ardekani (2006) and Ghobadi et al. (2006) for rapeseed and is similar to amounts reported by Shabani et al. (2010). This might be due to differences in cultivars with different salt tolerance. Increasing salinity of water resulted in decrease in seed oil content as reported by Sinaki et al. (2007). There was no significant interaction effect between salinity levels, deficit irrigation and planting method on seed oil content in two years (data not presented).

Seed protein content

In two years, there was no significant difference between effects of deficit irrigation and salinity and planting methods on seed protein content (Table 4). Similar results were also observed by Champolivier and Merrien (1996) and Bouchereau et al. (1996) for rapeseed. In water and salinity stress conditions, due to osmotic adjustment, protein content in plant usually increases as reported by Ghobadi et al. (2006). However, this did not occur in our study. In second year, enhancement of deficit irrigation and water salinity levels resulted in higher seed protein content in comparison with first year. There was a statistically significant interaction effect between deficit irrigation and salinity and planting method on seed protein content (Table 5). For on-ridge planting method, maximum seed protein content observed in salinity level of 7.0 and deficit irrigation of 0.75 FI in first year and in salinity level of 8.0 dS m^{-1} and deficit irrigation of 0.65 FI in second year. For in-furrow planting method, maximum seed protein content observed in treatment of FI and 7.0 dS m^{-1} in first year and 0.35 FI and 4.0 dS m^{-1} in second year.

Protein and oil yields

Oil and protein production is ultimate purpose of rapeseed cultivation. Except the salinity level in first year, there were significant differences between the effects of deficit irrigation, salinity and planting methods on protein and oil yields in two years (Table 4) that are in accordance to those reported by Sepaskhah and Tafteh (2012); Ghobadi et al. (2006) and Shabani et al. (2010). At different water salinities and planting methods, deficit irrigation treatments resulted in decrease in oil yield by 13.0 and 23.9% in 0.75 FI and 0.5 FI, respectively and 21.0 and 34.0% in 0.65 FI and 0.35 FI, respectively, in comparison with full irrigation. For protein yield, deficit irrigation treatments resulted in decrease by 14.5 and 27.2% in 0.75 FI and 0.5 FI, respectively and 17.7 and 30.6% in 0.65 FI and 0.35 FI, respectively in comparison with full irrigation. Relationship between oil and protein yields reduction and ratio of deficit irrigation determined by regression analysis are shown in Table 6. Results indicated that 13.1 and 11.8% deficit irrigation can be imposed without oil and protein yields reduction, respectively. In two years, in-furrow planting method increased oil and protein yields compared with that on-ridge planting method. For both traits, there was no significant interaction effect between deficit irrigation, water salinity and planting method (I×S×P) on oil and protein yields in first and second year (Data not presented).

Relationships between relative oil and protein yields and relative evapotranspiration (relative to those obtained in full irrigation) for different irrigation water salinities and soil saturation extract salinities determined by regression analysis are shown in Table 7 (numbers 9-16). Coefficients of equations are the growth response factor to water for oil (K_{oy}) and protein (K_{py}) yields. With increasing salinity higher than 4.0 dS m^{-1} and 2.2 dS m^{-1} for irrigation water salinity and soil saturation extract salinity, respectively, the values of K_{oy} and K_{py} reduced. Results indicated that in low salinities of soil and water K_{oy} and K_{py} were more than 1.0, therefore oil and protein yields of rapeseed was sensitive to reduced water consumption. In high salinities of soil and irrigation water, this sensitivity reduced due to K_{oy} and K_{py} that were close to 1.0. Relationships between the K_{oy} and K_{py} and irrigation water salinity and soil saturation extract salinity are presented in Table 8. These relationships are quadratic and show an increase of K_{oy} and K_{py} with salinity to a maximum and decrease K_{oy} and K_{py} afterwards.

Table 8. Relationship between the growth response factor to water for seed yield (K_{sy}) and oil (K_{oy}) and protein (K_{py}) yields and irrigation water salinity (EC_{iw}) and soil saturation extract salinity (EC_e).

yield	Equation (Irrigation water)	R^2	Equation (Soil saturation extract)	R^2
Seed yield	K_{sy}=-0.005 $(EC_{iw})^2$ + 0.040 (EC_{iw}) + 1.221	0.897	K_{sy}=-0.027$(EC_e)^2$ + 0.105(EC_e) + 1.189	0.896
Oil yield	K_{oy}= -0.007 $(EC_{iw})^2$ + 0.051 (EC_{iw}) + 1.228	0.997	K_{oy}=-0.034$(EC_{iw})^2$ + 0.134(EC_{iw}) + 1.188	0.996
Protein yield	K_{py}=-0.005 $(EC_{iw})^2$ + 0.031 (EC_{iw}) + 1.145	0.814	K_{py} = -0.027$(EC_e)^2$ + 0.087(EC_e) + 1.119	0.811

1000-seed weight

Planting method had no significant effect on 1000-seed weight in two years. Furthermore, deficit irrigation and salinity had significant effect only in first year (Table 4). There was no significant interaction effect between deficit irrigation, salinity and planting method on 1000-seed weight in two years (data not presented). Deficit irrigation and salinity decreased the 1000-seed weight. Decrease in seed weight probably was related to prevention of assimilate transport to the seeds and decrease in growth during seed filling stage (Zamani et al., 2010). Diepenbrock (2000) reviewed the findings of other investigators and stated that there was negative relationship between seed weight and number of seed per silique. In general, increase in the number of seed per silique was the reason for reduction of 1000-seed weight in second year compared with first year (data not shown).

Water use efficiency

In deficit irrigation due to decrease in irrigation water, evapotranspiration and water loss decreased that resulted in enhancement of water use efficiency (Table 5). At different applied water and salinity levels, the average water use efficiency of in-furrow planting method increased by 7.0 and 13.2% in comparison with on-ridge planting method for first and second year, respectively. Increase of salinity level at the same deficit irrigation treatment and planting method decreased water use efficiency. Therefore, deficit irrigation and in-furrow planting method strategies can be selected to increase water use efficiency in scarce water conditions. Relationship between relative water use efficiency and salinity of irrigation water determined by regression analysis as follows (Figure 10):

$$(WUE_a/WUE_m)=1-0.019\ (EC_{iw} - 2.74),\ R^2=0.66 \quad (10)$$

where WUE_a is the actual water use efficiency, WUE_m is the maximum expected water use efficiency. The value of 2.74 is the EC_{iw} threshold for water use efficiency. The slope (1.9%) in Eq. (10) indicates a reduction of water use efficiency per unit increase in irrigation water salinity.

Figure 11 shows the relationship between relative water use efficiency and soil saturation extract salinity in root zone. The relationship is as follows:

$$(WUE_a/WUE_m)=1-0.029\ (EC_e - 1.31),\ R^2=0.63 \quad (11)$$

Equation (11) indicated that the soil EC_e threshold for reduction of water use efficiency is 1.31 dS m^{-1} and the slope of the reduction of water use efficiency is 2.9% per unit EC_e. The threshold of EC_{iw} and EC_e for water use efficiency was lower than threshold of EC_{iw} and EC_e for seed yield. However, comparison between Eqs. 8 and 10 and between Eqs. 9 and 11 by F-test indicated that there was no significant difference between the slopes and intercepts those equations.

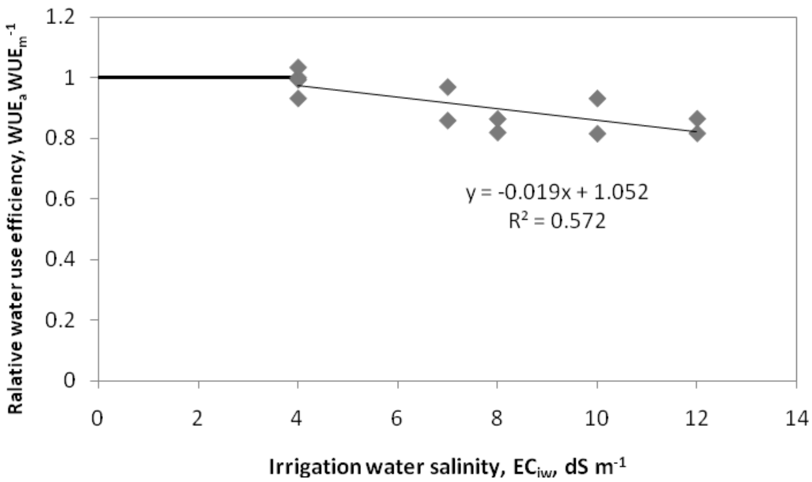

Figure 10. Relationship between relative water use efficiency and irrigation water salinity.

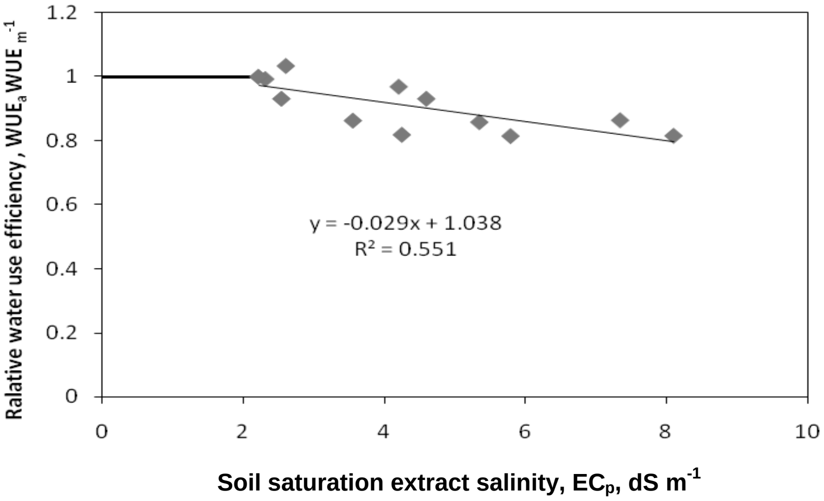

Figure 11. Relationship between relative water use efficiency and soil saturation extract salinity.

Conclusions

Deficit irrigation and salinity decreased yield and dry matter of rapeseed and in-furrow planting resulted in higher seed yield and dry matter compared to on-ridge planting. In-furrow planting increased yield and dry matter by 5.3 and 7.8%, respectively at first year and 13.7 and 10%, respectively at second year compared to on-ridge planting. Deficit irrigation and salinity decreased dry matter, plant height, seed oil content, oil and protein yields and 1000-seed weight. There was significant interaction effect between salinity levels, deficit irrigation and planting methods on plant height and seed protein. Results indicated that 11.0, 11.7, 13.1 and 11.8% of deficit irrigation can be imposed without seed yield, dry matter and oil and protein yields reduction of rapeseed, respectively. In-furrow planting increased water use efficiency compared with on-ridge planting. Increase of salinity level at same conditions of deficit irrigation and planting method decreased water use efficiency. Threshold of irrigation water salinity and soil saturation extract salinity for water use efficiency were 2.74 and 1.31 dS m^{-1}, respectively. Therefore, deficit irrigation and in-furrow planting method strategies can be used to increase water use efficiency in water scarce conditions.

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