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Saline irrigation water management strategies for better yield of safflower (*Carthamus tinctorius* L.) in an arid region

Mohammad Feizi[1*], Mohammad A. Hajabbasi[2] and Behrouz Mostafazadeh-Fard[3]

[1]Isfahan Agricultural and Natural Resources Research Center, and PhD Student, College of Agriculture, Isfahan University of Technology, P.O.BOX 81785-199 Isfahan, Iran
[2]Soil Sciences Department, College of Agriculture, Isfahan University of Technology, Isfahan 84156-83111, Iran
[3]Irrigation Department, College of Agriculture, Isfahan University of Technology, Isfahan 84156-83111, Iran

***Corresponding author:** Feizimohammad@gmail.com

Abstract:

Water quality and irrigation strategies are important factors effecting crop production, especially in arid/saline soils. The effects of irrigation water salinity and irrigation management on safflower yield was studied in a field experiment in Isfahan province (central Iran). Three irrigation water salinity levels of 3.4, 8.8 and 11.2 dS m^{-1}, two irrigation water managements and two leaching levels of without leaching and with leaching levels of 6, 17, and 28.5 %, were used in a completely randomized block design, arranged as Split-Split plots with four replications for each treatment. The results showed that with higher levels of water salinity the yield components such as seed yield, biomass yield (dry weight), number of plant per hectare, 1000- seed weight, plant height, number of capitula per plant and capitula weight per plant were significantly decreased. Although, irrigation with high amount of salt in water (11.2 dS m^{-1}) during the entire growth period reduced the yield, irrigating with water salinity of 3.4 dS m^{-1} , until plant emergence and then applying high irrigation water salinity levels significantly increased the yield components. Leaching application caused a significant increase in the yield and yield components, too. The salinity threshold value of 6.4 dS m^{-1} was obtained for safflower seed yield.

Keywords: Irrigation management; Leaching; Safflower; Salinity tolerance; Arid regions

Introduction

Salinity is an important index of low soil quality reducing crop production and gradually decreases the area under cultivation. Irrigated agriculture using saline water in the arid and semi-arid region can lead to salt accumulation in soil profile, reduction in yield and deterioration in soil resource, if proper management practices are not adapted (Ould et al., 2007). To prevent yield loss, soil salinity must be controlled at a concentration level below which might affect the yield (Ayers and Westcot, 1985). Using poor quality irrigation groundwater has become unavoidable to compensate rapidly increasing water demands of competition between human and industrial water use, especially in arid and semi-arid regions (Katerji et al., 2000). To resolve this, researchers recommended methods such as use of fresh water at the initial stage of plant growth, mixing agricultural drainage water with good quality irrigation water, plant breeding (developing salt tolerant cultivars) and alternating good quality irrigation water with saline water (Khosla et al., 1979 ; Pasternak and De Malach, 1993; Abdel Gawad and Ghaibeh, 2001; Yurtseven et al., 2005; Feizi 2003, Feizi 2004). Another effective method of reducing the salinity hazard is application of proper leaching and irrigation management. The leaching requirement depends on salinity level of irrigation water and crop salt tolerance and careful considerations should be given to the selection of leaching level (Mostafazadeh-Fard et al., 2009). Several researchers such as Feizi (1993), Garcia-Sanchez et al. (2003), Mostafazadeh-Fard et al., (2007) and Mostafazadeh-Fard et al. (2008) reported advantageous effects of leaching on improvement of soil salinity and crop yield and some other researchers such as Kolahchi and Jalali (2007) reported the disadvantages of soil salt leaching due to the movement of soil nutrients to groundwater . Salinity of soil and water resources is a serious threat to many parts of Iran. Estimated land area affected by salinity varies between 16 to 23 million ha (Dewan et al., 1964; Kovda, 1970; Roozitalab, 1987; Siadat et al., 1997). The main difficulty in exact estimation of these figures is the temporal variations of salinity during the growing season. The main rivers in Iran have a low salt load (an electrical conductivity of about 0.3-0.7 dS m^{-1}), but, variations along the stream occur as these rivers receive drainage water of the neighboring farmlands and industries especially at the down streams sections. Besides, with the decrease in flow rate during the summer months, salts concentration may increase to limiting levels. Reports also mention that salinity of the ground waters is more serious than the surface waters (Siadat, 1998). Considering the fact that nearly half of the water used in Iran's agricultural lands comes from the ground water, the threat of salinity effects on the sustainability of crop production in the country becomes evident (Siadat, 1998). In Isfahan province, it is estimated that about 320000 ha of potentially suitable lands for crop production are facing saline or saline-sodic hazards . After all, the effects of salinity of irrigation water and soil on crop yield and yield components are site specific (Cullu, 2003; Dang et al., 2004; Katerji et al., 2005; Feizi, 2002 and Maas and Hoffman, 1977). Several experiments have already been conducted in the region to study the effect of saline water on

Table 1. Average values of chemical characteristics of the irrigation water for the irrigation Season

Treatment	Water source	ECiw (dS m^{-1})	TDS (mg L^{-1})	pH	Ions (mg L^{-1})					SAR
					HCO_3^-	Cl^-	SO_4^-	Ca^{2+}+Mg^{2+}	Na^+	
S_1	River	3.4	2144	7.8	4.4	25	61	14	31	11.7
S_2	Well	8.8	7016	7.6	4.9	50	41	26	96.6	19.3
S_3	Drainage	11.2	8968	7.7	5.2	73	52	35	15.2	22.8

TDS, total dissolved solids; SAR, sodium adsorption ratio.

crops such as wheat, sunflower, cotton and barley. Some results show that saline irrigation water management strategies such as alternative use of drainage water and fresh river water, and use of fresh water at the initial stage of growth could save 50 to 80 percent of fresh water while producing profitable crops yields (Feizi, 2002, 2003, 2004, 2009). Concern of producing safflower *(Carthamus tinctorius* L.*)*, as an important and economically efficient oil crop in the country is getting increased (Tuncturk and Yildirim 2004). Although limited regional and global research is available on safflower production under saline irrigated conditions, but safflower is known to be moderately tolerant to salinity (Bassil and Kaffka, 2002b). The objectives of this study were to evaluate the effects of different irrigation water salinity, leaching and water use management on soil salinity and consequently safflower yield for a typical clay soil of an arid region in the central Iran.

Materials and methods

The experiment was conveyed in Rudasht Research Experiment Station of Isfahan Agricultural and Natural Resource Research Center (32.29/N, 52.11/E and elevation of about 1510 m above the sea level) located 65 km southeast of Isfahan city, central part of Iran. Three irrigation water salinity levels of 3.4, 8.8 and 11.2 dS m^{-1} (S_1, S_2 and S_3), with two irrigation management strategies (GS and GU) and two leaching levels of without leaching (LR_0) and with leaching (LR_1) including leaching levels of 6, 17, and 28.5% were used in four replications. Experimental plots of 5 m width and 25 m length were used to collect data. Selected chemical characteristics of irrigation water are presented in Table 1. The irrigation water managements were i) the plots with above irrigation water salinity levels from planting to the end of growing season (GS) and ii) irrigating plots with EC_{iw} of 3.4 dS m^{-1} (Zayandeh Rud river running through the area as the source of fresh water resource) from planting time up to the emergence, thereafter, applying the above irrigation water salinity levels (GU). The above leaching levels were determined based on the following equation (Ayers and Westcot 1985):

$$LR = EC_{iw}/((5EC_e) - EC_{iw}) \qquad (1)$$

Where LR = leaching level, EC_{iw} = EC of irrigation water (dS m^{-1}), and EC_e = EC of saturated extract dS m^{-1}. For example, for EC_e = 12 dS m^{-1} and EC_{iw} = 3.4 dS m^{-1}, the LR value is 6%, for EC_{iw} = 8.8 dS m^{-1}, the LR value is 17%, and for the EC_{iw} = 11.2 dS m^{-1}, the LR value is 23%.

The experiment was laid out in a Split-Split plot with completely random blocks design with four replications. Prior to the planting, the plots (5m×25m) were plowed and leveled. The safflower Esfahan cultivar was planted in rows, spaced 0.5 m apart, and 0.05 m within rows spacing. The N.P.K fertilizer was applied base on soil test recommended rates. Triple superphosphate (100 kg ha^{-1}) , potassium sulfate (50 kg ha^{-1}), and zinc sulfate (40 kg ha^{-1}) was applied before planting and urea (350 kg ha^{-1}) fertilizer was used as a split (half at sowing and half at late vegetation) during growing season. Safflower seed cultivated in late May, 2008 and harvested in late September 2008. At harvest time the total weight of some agronomic traits such as plant and seed weight and yield components were measured. The samples were taken from four central rows, with five meter length in the center of each sub-plot. The fresh harvested samples (shoots) were oven dried at 65 °C for 3 days to bring moisture content of about 10 % and recorded as biomass. To irrigate the plots, water was delivered by the main line from the local water reservoir or source of water used for specific treatment and distributed to the sub-main hoses. A valve and a volumetric discharge measurement device were installed at the location where the sub-main hoses enter each plot to control and measure the exact amount of water needed for each plot. The plots were irrigated six times during the growing season. The measured volume of water was applied according to crop requirement using class A of evaporation pan. The irrigation intervals were based on about 100 mm evaporation from the pan. The precipitation data was taken from the weather station located in the site. The total rainfall during the experiment was 8 mm. Some of soil physical and chemical properties at the planting time are presented in Tables 2 and 3, respectively. For each plot, soil was sampled at the beginning, germination and emergence, middle and end of growing season. Soil samples were taken at the depths of 0-30, 30-60 and 60-90 cm at the beginning and the end of growing season and at germination and middle stage at the depths of 0-30 and 30-60 cm. Soil samples were analyzed to determine saturated soil paste pH (pHs), saturated paste extract EC (ECe), Ca^{2+} + Mg^{2+}, Cl^-, Na^+, bulk density, moisture content at field capacity, moisture content at wilting point and soil texture using standard methods. The SAR of the samples was also calculated. The ECe was determined by an EC meter in the soil saturated paste extract. The cations and anions such as Ca^{2+} + Mg^{2+}, CO_3^{2-}, HCO_3^-, Cl^-, and Na^+ were measured using standard methods. The plant data were statistically analyzed and means were compared using Least Significant Difference test (LSD). Linear yield decrement due to soil salinity was determined using the following equation (Mass and Hoffman, 1977):

$$Yr = 100 - B\ (ECe - A) \qquad (2)$$

Where Yr = relative yield (%); A = salinity threshold value above which a yield decrement occurs (dS m^{-1}); B = slope of the yield decrement line (%) yield reduction/unit of salinity; and ECe = electrical conductivity of the saturation extract (dS m^{-1}).

Results and discussion

Seed yield

The analysis of variance for safflower seed yield and other trait at salinity, management, leaching and the interactions

Table 2. Physical characteristics of soil

Depth (cm)	Clay	Silt	Sand	Texture	FC	WP	p_b
		(%)			(%)		(gr. cm^{-3})
0–30	51	36.4	12.6	Clay	28.1	18.3	1.45
30–60	59.2	31.2	9.8	Clay	28.8	19.5	1.6
60–90	59	35	6	Clay	30	18	1.75

FC, soil moisture at field capacity; WP, soil moisture at wilting point; p_b, soil bulk density.

Table 3. Average chemical characteristics of soil

Soil depth (cm)	ECe (dS m^{-1})	pH	Ions(meq L^{-1})					SAR
			HCO_3^-	Cl^-	SO_4^-	$Ca^{2+}+Mg^{2+}$	Na^+	
0-30	7.7	8.15	2.94	40.8	39.4	36.4	47.14	11
30-60	9.8	8.00	2.41	51.8	49.1	43.0	60.5	13
60-90	8.8	8.08	3.37	51.83	39.4	38.4	55.95	12.8

are shown in Table 4. The salinity of irrigation water caused the seed yield to be significantly reduced in all treatments (Table 5). However, leaching caused the seed yield to be increased (Table 5). Management of irrigation water showed the significant increases in the seed yield (Table 4). The interaction of irrigation water salinity and irrigation management on the seed yield was also significant (Table 4) .The GU irrigation management treatment resulted in higher seed yield as compared to LR_1 leaching treatment (Table 5). The crop yield as affected by irrigation water salinity is highly depended on the initial stage of growth. The results are consistent with the results obtained by Sharma and Rao (1998). Francois and Bernstein, 1964; Francois et al. 1964; Yermanos et al. 1964; Rains et al. 1987; Irving et al. 1988; Beke and Volkmar , 1995 stated that although safflower regarded as moderately tolerant to salinity, yield have been reduced by high levels of soil salinity. The interaction of irrigation water salinity and irrigation water management shows that in S_2GU treatment the seed yield increased 36 % as compared to S_2GQ (Table 6). This increase was due to using low salinity irrigation water at the germination and emergence period. In S_3GQ treatment in which the drainage saline irrigation water was applied throughout the growing season, the seed germinated and established during the first irrigation, but after the second irrigation, leaves seriously injured due to direct contact to saline irrigation water and almost all newly developed plants died. Under this condition, the plants were severely affected, such that they were not even worth to harvest. Goyal et al. (1999) also concluded similar results that stand establishment appeared to be the most sensitive to salinity and was perhaps the main reason for yield reduction at the germination and stand establishment time. Meantime, the S_3GU treatment had relatively good yield (Table 6). In such cases the first and second irrigation should be heavy enough to maintain sufficient moisture in the root zone, so that the leaves expand enough to tolerate irrigation water salts. Delaying irrigation to the end of late vegetative growth stage may have less harm to the yield. The most serious effect of irrigation water salinity and leaching interaction was observed in S_3LR_1 treatment by 26.0 % seed yield increase as compared to S_3LR_0 treatment (Table 6). The interaction of irrigation water management and leaching was significant (Table 4). The leaching caused increase in seed yield about 19.4 % in $GULR_1$ treatment as compared to $GULR_0$ treatment and 9.5 % in $GQLR_1$ treatment as compared to $GQLR_0$ treatment (Table 6) indicating that the $GULR_1$ treatment was more effective in increasing seed yield as compared to $GQLR_1$ treatment. Comparing to the other treatments, the GQ had higher soil salinity. This resulted in less root expansion, less water use and finally lowers yields (Bassil and Kaffka,2002a).

Biomass yield

As shown in Table 4, all treatments including the salinity of irrigation water, the irrigation water management, leaching treatments and the interactions had significant effects on biomass yield (dry). The biomass yield (shoots) was decreased 44.2 and 71.1 % in S_2 and S_3 treatments as compared to S_1 (Table 5). The irrigation water management of GU increased the biomass yield up to 22.8 %. Application of leaching caused 15.2 % increase in the biomass yield in LR_1 treatment (Table 5). The interaction of irrigation water salinity and irrigation water management showed 32% increase in biomass yield of S_2GU treatment as compared to S_2GQ (Table 6). For the GU treatment this positive effect was highly significant as it was for the seed yield. The biomass yield increased 17.7 % in S_1LR_1 and 19.7 % in S_1LR_o treatment as respectively compared to the S_2LR_1 and S_2LR_0 (Table 5). In S_3LR_1 treatment, the biomass yield also was increased significantly about 15 % as compared to the S_3LR_0. The biomass yield in $GQLR_1$ and $GULR_1$ treatments were 15.3 and 21.3 % increased, as respectively compared to the $GQLR_0$ and $GULR_0$ (Table 6). In general, the effect of all treatments on biomass yield followed similar of the seed yield. The declination of biomass yield in this study was less than the results obtained by Bassil and Kaffka (2002b).

Number of plant per hectare

There was negative correlation between the salinity level of irrigation water and the number of plants per hectare which significantly decreased for all treatments as the level of salt increased (Table 4). The number of plants per hectare was respectively reduced by 29.8% and 63.6% for S_2 and S_3 as compared to the S_1 treatment (Table 5). The GU treatment caused almost 37% increases in the number of plant per hectare as compared to GQ treatment (Table 5). The leaching treatment also significantly increased the number of plant per hectare (Table 4). In LR_1 treatment, 10.8 % increase was observed in the number of plant per hectare as compared to LR_0 treatment (Table 5). Although the interaction of leaching and management significantly affects the number of plant per hectare, but the effect of irrigation water management treatment was higher than the interaction effect. The interaction effect of Irrigation water salinity and irrigation water management and interaction of water management and leaching were highly significant (Table 4). The Application of S_2GU treatment showed 21.2 % increase in the number of plant per hectare as compared to S_2GQ treatment (Table 6). In S_3GQ almost no plant stand recorded whereas in S_3GU good stand was observed. Rains et al. 1987 also reported poor germination and emergence in salinized plots.

Table 4. Variance analysis of safflower yield components

S.O.V	Mean square							
	df	Seed yield	Biomass yield	1000 seed weight	Number of plant per hectare	Plant height	Number of capitula per plant	Weight of capitula per plant
Replication	3	6540.39 ^{ns}	12148 ^{ns}	0.16 ^{ns}	61899999 ^{ns}	2.09 ^{ns}	0.21^{ns}	0.97^{ns}
Salinity (S)	2	21767488**	222922350**	1774.4**	259068515625**	6506.92**	234.29**	610.73**
Error (Ea)		28036.6	139442	0.44	350335416	2.6	0.21	0.52
Management (M)	1	17076752**	130282283**	1949.2**	226969531249**	5580.96**	201.0**	516.00**
S×M	1	5260308**	43662877**	1921.2**	107532031250**	3328.06**	143.65**	427.78**
Error (Eb)		28724.5	151826	0.17	366614583	2.01	0.14	0.253
Leaching (LR)	1	802157**	11984628**	0.42 ^{ns}	7706571428**	21.42**	3.19**	28.05**
S×LR	2	23683^{ns}	1994976**	0.125 ^{ns}	538807291*	8.30*	0.90*	13.23**
M×LR	1	203777*	2099369**	0.003 ^{ns}	3938281249**	3.92 ^{ns}	0.72^{ns}	0.5^{ns}
Error (Residual)		33451.32	174192	0.78	129025000	1.36	0.21	0.34
C.V. (%)		9.2	7	3.4	4.6	2.9	5.8	4.53

Ns, * and ** are non – significant and significant at 5% and 1% probability level, respectively ; S.O.V,source of variations ;df ,degrees of freedom ; C.V ,coefficient of variation

Table 5. Comparison of yield components for salinity, management and leaching treatments

Treatment	Seed yield (Kg ha^{-1})	Biomass yield (Kg ha^{-1})	1000 seed weight (gr)	Number of plant per hectare	Plant height (cm)	Number of capitula per plant	Weight of capitula per plant (gr)
S_1	3488.4 a	11041.2 a	31.4 b	390500 a	61.9 a	11.7 a	19.5 a
S_2	2112.8 b	6162.9 b	32.6 a	274000 b	46.9 b	9.5 b	15.1 b
S_3	1135.9 c	3185.9 c	15.5 c	142188 c	23.2 c	4.6 c	7.7 c
LSD(P≤0.05)	167.3	373	0.66	18698	1.6	0.46	0.72
GU	2354.9 a	6692.1 a	31.9 a	292313 a	48.3 a	9.5 a	15.4 a
GQ	1758.7 b	5451.5 b	21.3 b	212750 b	35.2 b	6.9 b	11.4 b
LSD(P≤0.05)	133.8	307.7	0.32	15121	1.12	0.28	0.39
LR_0	1866.1 b	5458.0 b	25.4 a	232100 b	39.8 b	7.8 b	12.2 b
LR1	2128.3 a	6437.5 a	25.6 a	257050 a	41.1 a	8.3 a	13.7 a
LSD(P≤0.05)	123.3	281.3	0.59	7656	0.79	0.316	0.397

Values followed by the same letter(s) within the same column do not differ significantly at 5 % probability according to least significant difference test

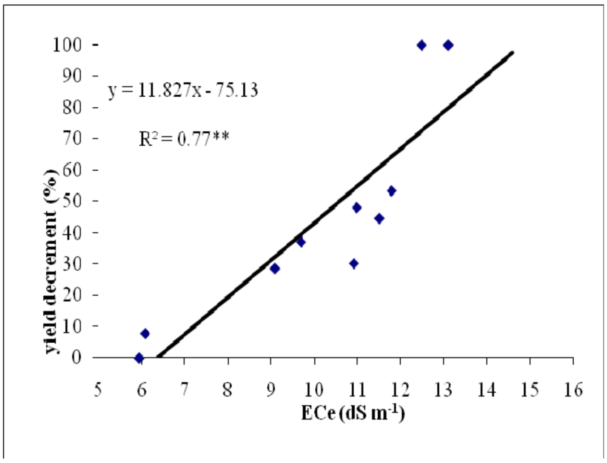
The number of plant per hectare in S_1LR_1, S_2LR_1 and S3LR_1 treatments increased 5.8%, 13.4% and 12.6% as compared to S_1LR_0, S_2LR_0 and S_3LR_0 treatments respectively (Table 6). The $GQLR_1$ and $GULR_1$ treatments caused 4.7 and 17.8% increase in the number of plant per hectare respectively, as compared to $GQLR_0$ and $GULR_0$ treatments (Table 6).

The 1000- seed weight

The salinity of irrigation water, irrigation water management and their interaction showed significant effect on 1000 seed weight (Table 4). In S_2 and S_3 treatments about 3.7% and 52.3% reduction of 1000 seed weight was respectively observed as compared to S_1 (Table 5). Application of GU treatment resulted in 49.6 % increase in 1000 seed weight as compared to GQ treatment (Table 5). For the LR_1 treatment the 1000 seed weight slightly increased as compared to the LR_0 treatment (Table 5), but the difference was not significant.

Plant height

The salinity level of irrigation water, irrigation water management and leaching treatments were significantly affected the crop height (Table 4). The plant height decreased 24.2 and 62.43% in S_2 and S_3 treatments as compared to S_1 treatment (Table 5). For the GU treatment the crop height increased 37.2 % as compared to the GQ treatment (Table 5). Leaching resulted in about 3.2 % increase in crop height (Table 5). However, the irrigation water management treatment was more effective on crop height as compared to the leaching treatment. The interaction effect of irrigation water salinity and irrigation management for S_2GU treatment as compared to S_2GQ treatment caused 14.5% increase in crop height (Table 6). Application of the S_3GU treatment caused to have good crop emergence stand and significantly (Table 4) affected crop height as compared to S_3GQ treatment, in which no yield was obtained (Table 6). The interaction of irrigation water salinity and leaching treatment was significant (Table 4), but the effect of irrigation water salinity and management treatment was more effective (Table



** Significant at 1% probability level

Fig 1. Safflower seed yield decrement due to soil salinity

Table 6. Comparison of yield components for interaction effects of the treatment

Treatment	Seed yield (Kg ha^{-1})	Biomass yield (Kg ha^{-1})	1000 grain weight (gr)	Number of plant per hectare	Plant height (cm)	Number of capitula per plant	Weight of capitula per plant (gr)
S_1GQ	3488.4 a	11041.2 a	31.4 b	390500 a	61.9 a	11.7 a	19.5 a
S_2GQ	1787.7 c	5313.2 d	32.6 a	247750 d	43.7 d	9.1 c	14.7 c
S_2GU	2437.9 b	7012.5 b	32.7 a	300250 b	50.0 b	9.9 b	15.5 b
S_3GQ	0 d	0 e	0 c	0 e	0 e	0 d	0 d
S_3GU	2271.9 b	6371.7 c	31.0 b	284375 c	46.5 c	9.2 bc	15.3 bc
LSD(P≤0.05)	206.76	476.73	0.5	23426.57	1.73	0.45	0.61
S_1LR_0	3345.9 b	10143.9 b	31.1 d	379500 b	60.3 b	11.3 b	16.9 b
S_1LR_1	3630.9 a	11938.6 a	31.6 c	401500 a	63.4 a	12.2 a	22.0 a
S_2LR_0	1987.2 d	5610.7 d	32. b	256750 d	46.1 d	9.2 d	14.5 d
S_2LR_1	2238.4 c	6715.0 c	32.7 a	291250 c	47.7 c	9.9 c	15.7 c
S_3LR_0	1004.9 e	2962.3 e	15.5 f	133750 f	23.2 e	4.6 e	7.7 e
S_3LR_1	1266.9 e	3409.4 e	15.5 e	150625 e	23.3 e	4.7 e	7.7 e
LSD(P≤0.05)	194.87	444.7	0.94	12102.92	1.24	0.48	0.62
$GQLR_0$	1678.9 d	5064.5 c	21.2 d	207917 d	34.6 c	6.8 c	10.3 c
$GQLR_1$	1838.5 c	5838.4 b	21.4 c	217583 c	35.7 b	7.1 b	12.5 b
$GULR_0$	2146.8 b	6048.1 b	31.8 b	268375 b	47.5 a	9.2 a	15.2 a
$GULR_1$	2562.9 a	7336.1 a	31.9 a	316250 a	49.0 a	9.9 a	15.6 a
LSD(P≤0.05)	174.3	397.75	0.84	10825.18	1.11	0.43	0.55

Values followed by the same letter(s) within the same column do not differ significantly at 5 % probability according to least significant difference

6). Yaron and Frenkel (1994) and Bassil and Kaffka (2002b) also reported reductions in the safflower plant height with increase of irrigation water salinity.

Number of capitula per plant

The number of capitula per plant in S_2 and S_3 treatment were decreased about 18.8 and 60.4% as compared to S_1 treatment (Table 5). The GU treatment increased the number of capitula per plant to 39.1% as compared to GQ treatment (Table 5). Leaching caused 6.4 % increase in number of capitula per plant. The interaction of irrigation water salinity and irrigation water management on the number of capitula per plant was significant (Table 4). For S_2GU treatment 9 % increase was observed in the number of capitula per plant as compared to S_2GQ treatment (Table 6). As other measured parameters S_3GQ treatment was zero. Low saline irrigation water application during germination and emergence period (S_3GU treatment) resulted significantly increase in the number of capitula per plant. The interaction of salinity of irrigation water and leaching shows significant (Table 4) increase in the number of capitula per plant. In S_1LR_1 treatment the number of capitula per plant increased 8 % as compared to S_1LR_0 treatment (Table 6). Similarly the increase in S_2LR_1 as compared to S_2LR_0 was 7.6 %. In S_3LR_1 treatment small increase of 2.2% was observed in number of capitula per plant as compared to S3 LR0. Bassil and Kaffka (2002b) research finding is similar to our results. Francois and Bernstein (1964); Yermanos et al. (1964) and Irving et al. (1988) also concluded reduced number of capitula (flower heads) per plant and seed number per capitula.

Capitula weight per plant

As the salinity level of irrigation water increased the capitula weight per plant decreased (Table 5). The reduction of capitula weight per plant in S_2 and S_3 treatment as compared to S_1 was respectively 22.4 and 60.4%. The GU irrigation water management treatment increased 35.2 % in the capitula weight per plant as compared to GQ treatment (Table 5). The LR_1 leaching treatment increases 12.3% in the capitula weight per plant as compared to LR_0 treatment. The interaction of irrigation water salinity and irrigation management treatment on capitula weight per plant was significant (Table 4).The largest effect of irrigation water salinity and irrigation management in capitula weight per plant was observed in S_3GU treatment as followed other yield parameters (Table 6). The interaction between the irrigation water salinity and leaching had also significant effect on capitula weight per plant (Table 4). For S_1LR_1, S_2LR_1 and S_3LR_1 treatments the capitula weight per plant increased 30%, 8.5% and 0.3% as compared to S_1LR_0, S_2LR_0 and S_3LR_0 respectively (Table 6). The decreases in capitulate weight per plant by increase of salinity also observed by Bassil and Kaffka (2002b).

Safflower salt tolerance

In this study safflower salt tolerance was determined based on average soil salinity during the growth periods. The highest yield was belonged to the lowest soil salinity which resulted from Q_1GQLR_1 treatment. In Fig.1, the result of the linear regression analysis of the relationship between seed relative yield and ECe is presented according to the Maas and Hoffman (1977) equation. Ten levels of soil EC and the relative yields in Fig.1 are the results of interaction effects of different treatments.

Eq. (2) can be rearranged as

$$100 - Yr = B \times ECe - AB \quad (3)$$

When B = slope of the line, and AB = intercept.

The results in Fig.1 shows that the values of B and A are 11.8 and 6.4, respectively with relatively high correlation coefficient (R^2=0.77**). Francois and Bernstein (1964) found that at ECe 7, 11 and 14 dS m^{-1} relative yield reductions were 10, 25, and 50 %, respectively. Ayers and Westcot (1985) reported estimates of 50 % yield decrease on soils with an ECe of 9.9 dS m^{-1}. Bassil and Kaffka (2002b) estimated threshold salinity value of 7.2 dS m^{-1}. In this study, ECe of 7.2, 10.6 and 12.8 dS m^{-1} had 10, 25, and 50 % seed yield reduction, respectively. The results obtained in this research are in agreement to the finding of Bassil and Kaffka (2002b) and Francois and Bernstein (1964). Some genetic variation in tolerance and the effects of other interacting factors including climate, weather and irrigation management are the main reasons for some differences between this study and the values obtained by other researchers.

Conclusions

Increasing salinity levels of irrigation water resulted in decreasing of all measured yield components. Application of low saline irrigation water (EC_{iw} 3.4 dS m^{-1}) at germination and establishment period was the most effective and successful irrigation water management strategy to use high saline irrigation water. In general, the irrigation water management treatment was more effective on yield as compared to the leaching application treatment. The proper irrigation water management and leaching in combination to low saline irrigation water are recommended strategic management to grow sustainable salt-tolerant and moderately salt tolerance agricultural crops such as safflower in arid regions of Iran. The salinity threshold value (A) and the slope of the seed yield decrement line value (B) obtained in this study are 6.4dS.m^{-1} and 11.8 % respectively. Although, about similar results reported by others, but due to different environmental condition and genetic variability some differences in results are justifiable.

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