# Chapter 11
# Do Cultivating Methods Improve Crop Yield Under Saline Conditions in Semi-Arid Areas

**Fatemeh Razzaghi, Ali Shabani, and Ali Reza Sepaskhah**

**Abstract** Soil and water salinities in agricultural land increase osmotic pressure and the toxic effect of some ions, disturb the nutrient uptake, restrict plant growth and ultimately, reduce crop yields. During the growing season, the osmotic potential in plant root zone varies due to spatial and temporal variations of salt and water distribution in the soil profile. Planting methods and irrigation regimes are two effective ways to affect salt and water distributions in the soil profile. There are different planting methods including on-ridge planting (single row bed, double row bed, single row sloping bed, double row sloping bed), in-furrow planting and basin planting. Under conditions of irrigation water and soil salinities and in each planting method and irrigation regime, the level of damage caused by salinity stress on plant growth depends on plant position relative to salt accumulation place and soil water content distribution. On the other hand, the variation of salt distribution in the soil results in partial root-zone salinity stress that affects plant growth. Therefore, in this chapter, the effects of different planting methods on improvement or reduction of salinity stress on salt accumulation in soil and on yield, water productivity and relations between yield and soil saturated electrical conductivity of wheat, rapeseed and saffron plants are discussed. Results show that the in-furrow planting method resulted in higher winter wheat, rapeseed grain and saffron yields, higher water productivity and generally higher ECe threshold and ECe for 50% yield reduction compared with on-ridge and basin planting methods under water and salinity stress conditions.

**Keywords** Wheat · Rapeseed · Saffron · In-furrow planting · On-ridge planting · Water productivity

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## 1 Introduction

Salinity and water stress are the two major constraints for crop growth and production (Ashraf et al. 2008). It is stated in the literature that around 20% of the total cultivated land and 33% of the irrigated agricultural areas in the world have been affected by high salinity (Jamil et al. 2011; Shahid et al. 2018). Arid and semi-arid regions, which cover one-third of the total world area, face water stress, low precipitation and uneven distribution of rainfall (Mesgaran et al. 2017). The largest area of the world's saline soils is found in the arid and semi-arid regions, where precipitation is lower than evapotranspiration (Nachshon 2018). Iran, as an arid to semi-arid region, is faced with both salinity and water stress due to limited and low quality water resources, low precipitation, low soil quality and high evaporation demand (Ahmadikhah 2009). The rate of agricultural production was already in decline before 2005 (Mousavi 2005). Thirty percent of irrigated land in Iran is salt-affected (Hussain et al. 2019). When water stresses occur, soil water potential, root water uptake, plant photosynthesis and finally crop growth and production are negatively influenced. Hence, finding solutions to overcome this problem is of utmost importance. The most appropriate solutions are: (i) selecting crops tolerant to salinity and water stress, (ii) appropriate planting methods and (iii) managing irrigation amounts and methods.

Irrigation water and soil salinities result in depressed specific metabolic processes and reduced crop growth and yield due to: (1) increase in osmotic stress that limits water uptake by plant roots and (2) ionic toxicity that promotes the imbalance in plant nutrient uptake (Rajpar et al. 2006). As reported by Cebas-Csic et al. (1997), higher salt concentration in soil and higher toxic ions like Na and Cl ions decrease nutrient ions uptake like Ca, K and Mg (Grattan and Grieve 1992). On the other hand, there are spatial and temporal variations of salt and water distribution in the soil profile during the growing season (Liu et al. 2013). These variations resulted from two factors including planting method and irrigation regimes and methods. Some of the planting methods are on-ridge planting (single row bed, double row bed, single row sloping bed, double row sloping bed), in-furrow and basin planting (Fig. 1) (Fahong et al. 2004; Qin et al. 2019; Li et al. 2010). The temporal variation of osmotic potential is related to the soil water-soluble salt concentration variation, which results from soil water content variation between two irrigation events. The level of damage caused by salinity stress on plant growth depends on plant position relative to the salt accumulation place and soil water content distribution (Paranychianakis and Chartzoulakis 2005; Machado and Serralheiro 2017). On the other hand, variation of salt distribution in soils can result in partial root-zone salinity stress that affects plant growth. Planting in-furrow causes salt to accumulate on the ridge and provides a better microclimate for plant growth, due to higher soil water content and lower soil evaporation from soil surface due to canopy cover. In addition, the result of using different planting patterns such as basin, on-ridge and in-furrow showed that the in-furrow planting method stores the rainfall in the soil and enhances water use efficiency (Li et al. 2010).

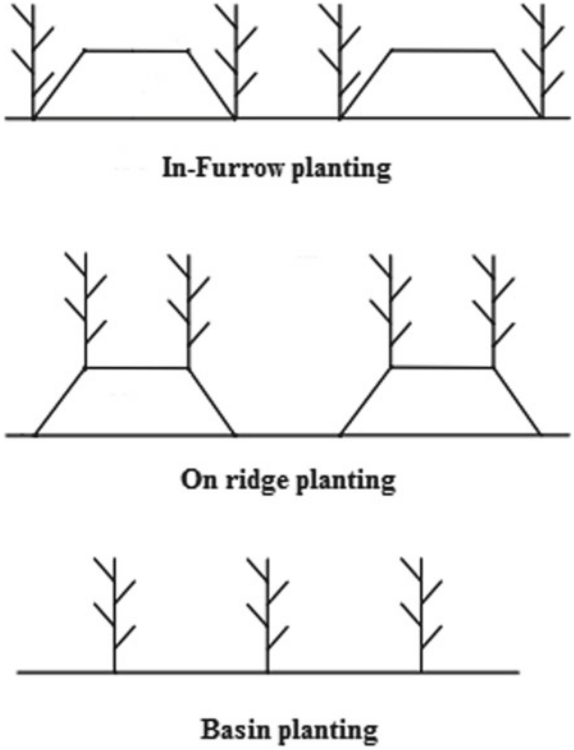



**Fig. 1** Schematic of in-furrow, on-ridge and basin planting method (Li et al. 2010)

Application of appropriate levels of amendments in forms of manure, chemical fertilizer and other nutritional residue mitigates the negative effect of salt stress on crop production, increases soil water holding capacity and hydraulic conductivity and enhances water uptake and crop growth and yield (Kanber et al. 2019; Chávez-García and Siebe 2019). However, if the electrical conductivity of the amendment is high, its application with saline irrigation water is not recommended.

In this chapter, the results of 8-year field experiments on the effect of different planting methods and salinity levels on yield and threshold electrical conductivity of rapeseed, saffron and winter wheat are discussed.

## 2 Materials and Methods

### *2.1 Site Description*

Different experiments were conducted during growing seasons from 2009 to 2017 (Table 1), at the Experimental Station of Agricultural College, Shiraz University, Iran (Fig. 2). The soil at the experimental site is silty clay loam in the 0–1.2 m depth

(Table 2). Cumulative seasonal rainfall depth, irrigation depths for full irrigation and reference evapotranspiration ($ET_o$) in all growing seasons are shown in Table 3. Reference evapotranspiration ($ET_o$) was calculated using meteorological data from a standard weather station near the experimental fields and the modified Penman–Monteith equation (Razzaghi and Sepaskhah 2012).

## *2.2 Experimental Design and Treatments*

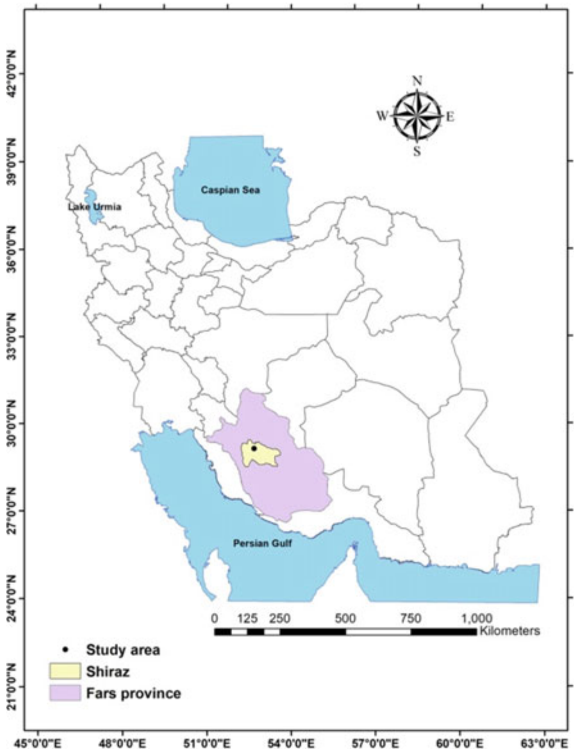
Four different experiments were conducted using rapeseed (Exp 1; Shabani et al. 2013), saffron (Exp 2; Yarami and Sepaskhah 2015), winter wheat (Exp 3; Mosaffa and Sepaskhah 2019) and saffron (Exp 4; Dastranj and Sepaskhah 2019) to investigate whether the planting method mitigates the negative effect of salt stress on plant growth and yield. Hence, different treatments were applied, including different planting methods, irrigation water salinities, and different irrigation regimes and/or fertilizer levels (Table 4). In all experiments, experimental design was a split-split plot arrangement in a randomized complete block design with three replications. In Exp 1, irrigation treatments, water salinity levels and planting methods were considered as the main plot, subplot and sup-subplot, respectively. In Exp 2, salinity levels of irrigation water, cow manure levels and planting methods were arranged as the main plot, subplot and sub-subplot, respectively. In Exp 3, irrigation treatments, salinity levels of irrigation water and planting methods were considered as the main plot, subplot and sub-subplot, respectively. In-furrow planting had two rows at the bottom of each furrow, and on-ridge planting had two rows on top of each ridge with a spacing of 0.15 m. Finally in Exp 4, salinity levels of irrigation water, irrigation water amount and planting methods were performed as the main plot, subplot and sub-subplot, respectively.

In order to prevent water transfer from one plot to another, a 1.0 m distance was considered between two adjacent plots in all experiments. Appropriate fertilizers were added to the soil of each experiment according to performed soil analyses prior to crop cultivation. The saline water in all experiments was obtained by addition of NaCl and $CaCl_2$ to the well water in equal equivalent proportions. In addition, full irrigation was initially applied to all experimental crops to ensure full germination and crop establishment and the saline water and irrigation regimes were initiated afterward.

**Table 1** Different experiments that are used in this study

| Crop | Years | Code |
|---|---|---|
| Rapeseed | 2009–2011 and 2010–2011 | Exp 1 |
| Saffron | 2011–2012 and 2012–2013 | Exp 2 |
| Winter wheat | 2011–2012 and 2012–2013 | Exp 3 |
| Saffron | 2015–2016 and 2016–2017 | Exp 4 |

**Fig. 2** Location of the experimental site




## *2.3 Soil Water Content*

Soil water content was measured by the neutron scattering method at different depths for each irrigation event, in all experiments. The irrigation depth was calculated according to the following equation:

$$I = \sum_{i=1}^{n} (\theta_{FCi} - \theta_i) \times \Delta Z_i \quad (1)$$

where I is the irrigation water depth ($m$), $\theta_{\mathrm{FC}i}$ is the volumetric soil water content in layer i at field capacity ($m^3\ m^{-3}$), $\theta_i$ is the soil water content in layer i before each irrigation event ($m^3\ m^{-3}$), $\Delta z_i$ is the soil layer depth ($m$) and n is the number of soil layers. Twenty percent, 15, 20 and 15% leaching fraction was added to full irrigation to prevent salt accumulation in root zone in Exp 1, Exp 2, Exp 3 and Exp 4, respectively.

**Table 2** Physical and chemical properties of the soil in the experimental site (Shabani et al. 2013)

| Properties | Soil depth (cm) | | | | |
|---|---|---|---|---|---|
| | 0–10 | 10–30 | 30–60 | 60–90 | 90–120 |
| $\theta_{FC}$[a] ($cm^3\ cm^{-3}$) | 0.30 | 0.32 | 0.33 | 0.33 | 0.33 |
| $\theta_{PWP}$ ($cm^3\ cm^{-3}$) | 0.16 | 0.16 | 0.19 | 0.19 | 0.19 |
| $\rho_b$ ($g\ cm^{-3}$) | 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 | | | | |
| $EC_e$ ($dS\ m^{-1}$) | 0.65 | 0.63 | 0.6 | 0.57 | 0.53 |
| Na ($meq\ l^{-1}$) | 0.93 | 0.85 | 0.83 | 0.8 | 0.76 |
| Ca ($meq\ l^{-1}$) | 3.71 | 3.68 | 3.72 | 3.41 | 3.23 |
| Cl ($meq\ l^{-1}$) | 3.23 | 3.04 | 2.71 | 2.3 | 2.12 |
| Mg ($meq\ l^{-1}$) | 3.17 | 3.11 | 2.69 | 2.85 | 2.71 |

[a] $\theta_{FC}$, $\theta_{PWP}$, $\rho_b$ and $EC_e$ indicates soil water content at field capacity, soil water content at permanent wilting point, soil bulk density and soil saturated electrical conductivity, respectively

**Table 3** Average temperature and relative humidity ($T_{ave}$ and $RH_{ave}$, respectively), initial salinity of saturated soil extract ($EC_e$), non-saline water EC, seasonal rainfall, $ET_0$ and applied full irrigation for different experiments (Exp)

| Crop | Exp | $T_{ave}$ (°C) | $RH_{ave}$ (%) | Initial soil ECe ($dS\ m^{-1}$) | Non-saline water EC ($dS\ m^{-1}$) | Applied full irrigation (mm) | Rainfall (mm) | $ET_0$ (mm) |
|---|---|---|---|---|---|---|---|---|
| Rapeseed | 1 | 11.3 | 62 | 0.57 | 0.60 | 807 | 298 | 988 |
| | | 6.1 | 42 | 0.57 | 0.60 | 935 | 258 | 1048 |
| Saffron | 2 | 8 | 45 | 0.58 | 0.45 | 207 | 363 | 556 |
| | | 7 | 55 | 0.58 | 0.45 | 263 | 445 | 531 |
| Winter wheat | 3 | 10 | 44 | 0.58 | 0.60 | 562 | 363 | na |
| | | 10 | 53 | 0.58 | 0.60 | 525 | 439 | na |
| Saffron | 4 | na | na | 0.64 | 0.45 | 324 | 266 | na |
| | | na | na | 0.64 | 0.45 | 317 | 367 | na |

*na* not available

## 2.4 Yield and Water Productivity

The crop grain for rapeseed, winter wheat and flowers (stigmas and styles) for saffron and the above-ground dry matter of each crop was harvested and dried [in oven for rapeseed and winter wheat and air-dried for saffron] for each plot and treatment in all four experiments. Water productivity was defined as the ratio of grain or saffron yield to the applied irrigation water.

## 2.5 Relationship Between Relative Yield and Average Root-Zone Salinity of Soil Saturation Extract

Soil samples were taken from different soil depths after harvest to measure electrical conductivity in soil saturation extract ($EC_e$). The relationship between relative yield and average root-zone salinity of soil saturation extract was determined by the following equation (Maas and Hoffman 1977):

$$\frac{Y_a}{Y_m} = 1 - b(EC_e - EC_{e\,threshold} \tag{2}$$

in which $Y_a$ is the actual yield, $Y_m$ is the maximum yield, $EC_e$ is the average root-zone salinity of soil saturation extract (dS $m^{-1}$), $EC_{e\ threshold}$ is the $EC_e$ value for 100 percent yield potential (dS $m^{-1}$) and b is the growth reduction coefficient of relative yield (% per dS $m^{-1}$).

**Table 4** Treatments used in different experiments

| | Treatment | | |
|---|---|---|---|
| | Planting method | Irrigation water salinity, dS $m^{-1}$ | Irrigation water regimes/ fertilizer levels |
| Rapeseed | On-ridge and in-furrow | 0.6, 4.0, 7.0 and 10.0 in first year and 0.6, 4.0, 8.0 and 12.0 in second year | FI, 0.75 FI and 0.5 FI in first year and FI, 0.65 FI and 0.35 FI in second year |
| Saffron | Basin and in-furrow | 0.45, 1.0, 2.0, and 3.0 | 30 and 60 Mg $ha^{-1}$ of cow manure |
| Winter wheat | On-ridge and in-furrow | 0.6, 5.0, 7.5, and 10.0 | FI, 0.65 FI and 0.35 FI |
| Saffron | Basin and in-furrow | 0.45, 1.0, 2.0 and 3.0 | FI, 0.75 FI and 0.5 FI |

*FI* full irrigation

# 3 Results

## 3.1 Grain Yield/Saffron Yield

The amount of winter wheat and rapeseed grain and saffron yields for different treatments in each study was reported and discussed in previously published articles (Shabani et al. 2013; Yarami and Sepaskhah 2015; Mosaffa and Sepaskhah 2019; Dastranj and Sepaskhah 2019). The maximum and minimum grain yield/saffron yield for different planting methods (averaged over two other treatments: salinity levels and irrigation levels/fertilizer levels) for different growing seasons are presented in Table 5. For rapeseed, in the first year of the experiment, the maximum grain yield in the in-furrow planting method (3.12 Mg $ha^{-1}$) was similar ($P$ value > 0.05) to that in the on-ridge planting method (3.18 Mg $ha^{-1}$), while the minimum values of rapeseed yield were higher in the in-furrow planting method in comparison with that in the on-ridge planting method; however, the difference was not statistically significant ($P > 0.05$). In contrast, in the second year of the rapeseed experiment, the maximum yield was higher in the in-furrow planting (3.5 Mg $ha^{-1}$) method in comparison with that in the on-ridge planting (3.13 Mg $ha^{-1}$), although the difference was not statistically significant ($P > 0.05$). Similarly to the first year, the minimum rapeseed yield in the on-ridge planting method (1.77 Mg $ha^{-1}$) was lower than that in the in-furrow planting method (2.04 Mg $ha^{-1}$); however, the difference was not statistically significant ($P > 0.5$).

Figure 3a and b shows the difference between the rapeseed grain yield of the on-ridge and in-furrow planting methods for different irrigation regimes and salinity levels. In the first year of the rapeseed experiment (Exp 1), the rapeseed grain yield for the on-ridge planting method was higher than in the in-furrow planting method in full irrigation and 0.5 dS $m^{-1}$ salinity level and in 0.35 FI and 10 dS $m^{-1}$ salinity levels (negative values), while for other treatments, the in-furrow planting method had higher rapeseed grain yield than in the on-ridge planting method. In the second year of Exp 1, all treatments had higher rapeseed grain yield under the in-furrow planting method. In general, with an increase in irrigation water salinity and water stress levels, the percent difference between rapeseed grain yield of the in-furrow and on-ridge planting methods was increased (more distance from center, Fig. 3a and b). In other words, under high water and salinity stress conditions, yield reduction in the on-ridge planting method was higher in comparison with the in-furrow planting method. Therefore, the in-furrow planting method provides better conditions for plant growth due to lower salt accumulation, higher soil water content and salt leaching in the plant root zone in the furrow (Zhang et al. 2007; Shabani et al. 2013).

Winter wheat grain yield in the first and second year of experiment (Exp 3) showed a higher value under the in-furrow planting method than under the on-ridge planting (Table 4). The latter results confirmed that the in-furrow planting method produced higher yield than that in the on-ridge planting methods for all interactions of salinity and irrigation levels (Fig. 3e and f). Similar to the results obtained for rapeseed,

**Table 5** Maximum and minimum of seed yield/saffron yield for different planting methods in two years of experiments

| | | Rapeseed Mg ha$^{-1}$ (Exp 1) | | Saffron kg ha$^{-1}$ (Exp 2) | |
|---|---|---|---|---|---|
| | | First year | Second year | First year | Second year |
| In-Furrow | Max | 3.12a[a] (4 dS m$^{-1}$ + FI) | 3.5a (4 dS m$^{-1}$ + FI) | 12.07a (60 t ha$^{-1}$ + 1 dS m$^{-1}$) | 17.34a (60 t ha$^{-1}$ + 1 dS m$^{-1}$) |
| | Min | 2.05b (10 dS m$^{-1}$ + 0.5FI) | 2.04b (12 dS m$^{-1}$ + 0.35FI) | 7.12b (30 t ha$^{-1}$ + 3 dS m$^{-1}$) | 9.40b (30 t ha$^{-1}$ + 3 dS m$^{-1}$) |
| On ridge | Max | 3.18a (0.5 dS m$^{-1}$ + FI) | 3.13a (4 dS m$^{-1}$ + FI) | 3.89c (60 t ha$^{-1}$ + 0.45 dS m$^{-1}$) | 7.35c (60 t ha$^{-1}$ + 0.45 dS m$^{-1}$) |
| | Min | 1.92b (7 dS m$^{-1}$ + 0.5FI) | 1.77b (12 dS m$^{-1}$ + 0.35FI) | 1.18d (30 t ha$^{-1}$ + 2 dS m$^{-1}$) | 1.41d (30 t ha$^{-1}$ + 2 dS m$^{-1}$) |
| In-Furrow | | Winter wheat Mg ha$^{-1}$ (Exp 3) | | Saffron kg ha$^{-1}$ (Exp 4) | |
| | | First year | Second year | First year | Second year |
| | Max | 5.41a (0.6 dS m$^{-1}$ + FI) | 5.08a (0.6 dS m$^{-1}$ + FI) | 10.28a (0.45 dS m$^{-1}$ + FI) | 17.27a (0.45 dS m$^{-1}$ + FI) |
| | Min | 2.90b (10 dS m$^{-1}$ + 0.35FI) | 2.98b (10 dS m$^{-1}$ + 0.35FI) | 5.73c (3 dS m$^{-1}$ + 0.5FI) | 7.24c (3 dS m$^{-1}$ + 0.5FI) |
| Basin | Max | 5.30a (0.6 dS m$^{-1}$ + FI) | 4.92a (0.6 dS m$^{-1}$ + FI) | 6.37b (0.45 dS m$^{-1}$ + FI) | 10.2b (0.45 dS m$^{-1}$ + FI) |
| | Min | 2.87b (10 dS m$^{-1}$ + 0.35FI) | 2.78b (10 dS m$^{-1}$ + 0.35FI) | 1.78d (3 dS m$^{-1}$ + 0.5FI) | 3.37d (3 dS m$^{-1}$ + 0.5FI) |

*FI* full irrigation

[a]Means followed by the same letters in columns for each year are not significantly different at 5% level of probability, using Duncan's multiple range test

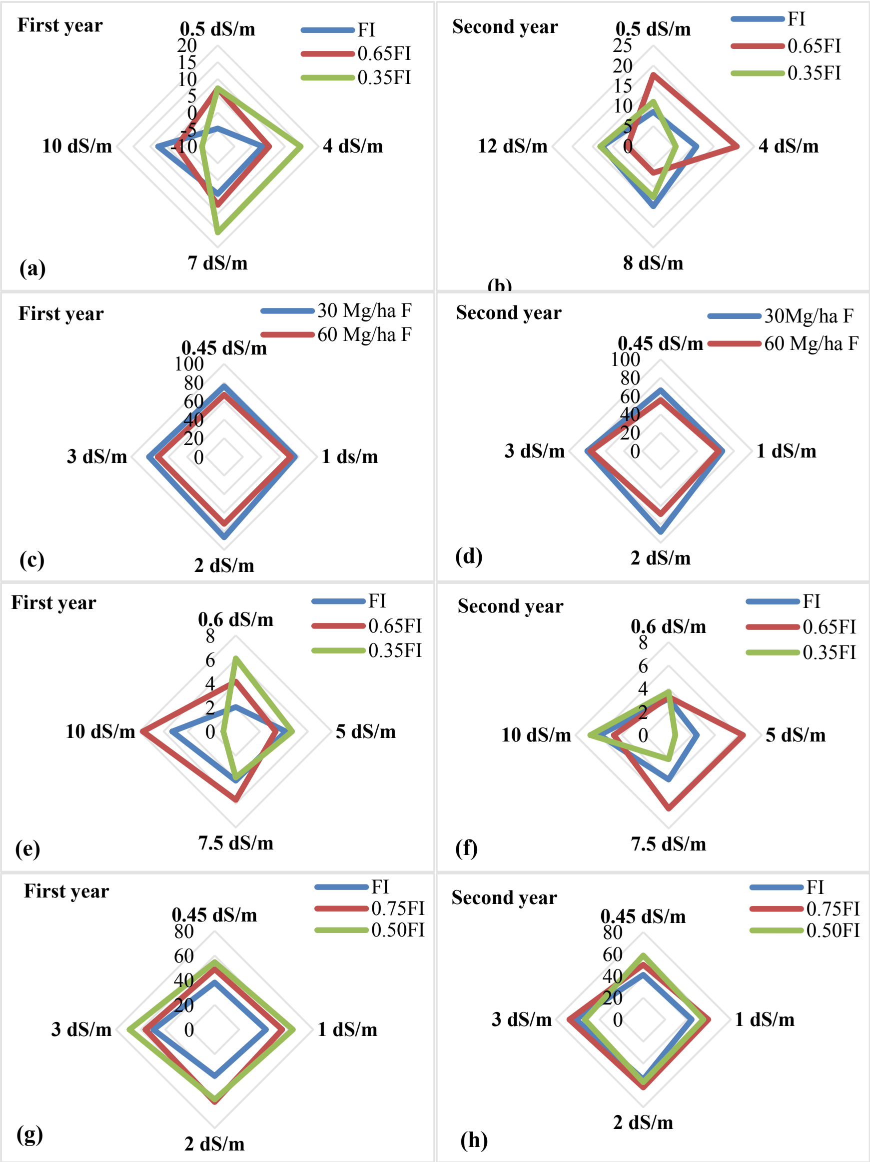



**Fig. 3** Percent difference in crop yield for rapeseed (a, b) and winter wheat (e, f) grain yield between the in-furrow and the on-ridge planting methods and for saffron yield and in the in-furrow and the basin planting methods for different irrigation/fertilizer (c, d) and salinity levels (g, h) in two years of the field experiment

differences between the in-furrow and the on-ridge planting methods were larger with higher irrigation water salinity compared with lower irrigation water salinity.

Considering Exp 2 and Exp 4, both maximum and minimum values of saffron yield were higher under the in-furrow planting method than under basin condition in both years of the experiments (Table 5). The percentage difference in saffron yield between the in-furrow and basin planting methods for different salinities and fertilizer levels is shown in Fig. 3. The result showed that saffron yield differences between the in-furrow and the basin planting method were higher for the 30 Mg ha$^{-1}$ fertilizer application and at all salinity levels (Fig. 3c and d). Specifically in the second year, the differences between the in-furrow and basin planting methods were higher for the 2 and 3 dS m$^{-1}$ irrigation water salinity compared with the 0.45 and 1.0 dS m$^{-1}$ irrigation water salinity. This may have been the result of better plant growth conditions in the in-furrow planting method. Figure 3 shows the percent difference in saffron yield under the in-furrow and the on-ridge planting methods, and the results indicate that for all interactions between irrigation and salinity levels, the in-furrow planting produced higher saffron yield than that on the ridge planting method (Fig. 3g and h). Similar to Exp 1 and Exp 2, at higher irrigation water salinity (3 dS m$^{-1}$), the difference between the in-furrow and on-ridge planting methods was larger. This difference was clearly higher under more severe water stresses in the first year (0.5FI and 0.75FI). The results indicate that salinity stress is more detrimental to saffron yield in in-furrow planting compared with on-ridge planting.

## 3.2 *Water Productivity*

Maximum water productivity (WP) for rapeseed in the first year was 0.47 kg m$^{-3}$ for 4.0 dS m$^{-1}$ salinity and 0.35 FI for the in-furrow planting and 0.42 kg m$^{-3}$ for 10.0 dS m$^{-1}$ and 0.35 FI for the on-ridge planting method (Exp 1), while in the second year, 0.45 and 0.4 kg m$^{-3}$ were obtained for 0.5 dS m$^{-1}$ salinity and 0.35 FI for the in-furrow and the on-ridge planting methods, respectively. Figure 4a and b shows that the average WP for the in-furrow plants was higher than for the on-ridge planting method for all irrigation and salinity levels in both years. There is no clear pattern for the effect of salinity and water regimes on the percent difference between rapeseed WP in the in-furrow and the on-ridge planting method.

Application of 30 Mg ha$^{-1}$ manure fertilizer led to higher saffron WP under the in-furrow planting method in comparison with that in the basin in both years of the study (Fig. 4c and d). However, the maximum WP for saffron yield in the first year was 5.83 g m$^{-3}$ for 60 Mg ha$^{-1}$ manure fertilizer and 1.0 dS m$^{-1}$ salinity under the in-furrow and 1.88 g m$^{-3}$ for 60 Mg ha$^{-1}$ manure fertilizer and 0.45 dS m$^{-1}$ salinity under the basin planting. In the second year, the WP was 6.32 and 2.81 g m$^{-3}$ for 60 Mg ha$^{-1}$ manure fertilizer and 0.45 dS m$^{-1}$ salinity under the in-furrow and the basin planting methods, respectively (Exp 2). In both years, for application of

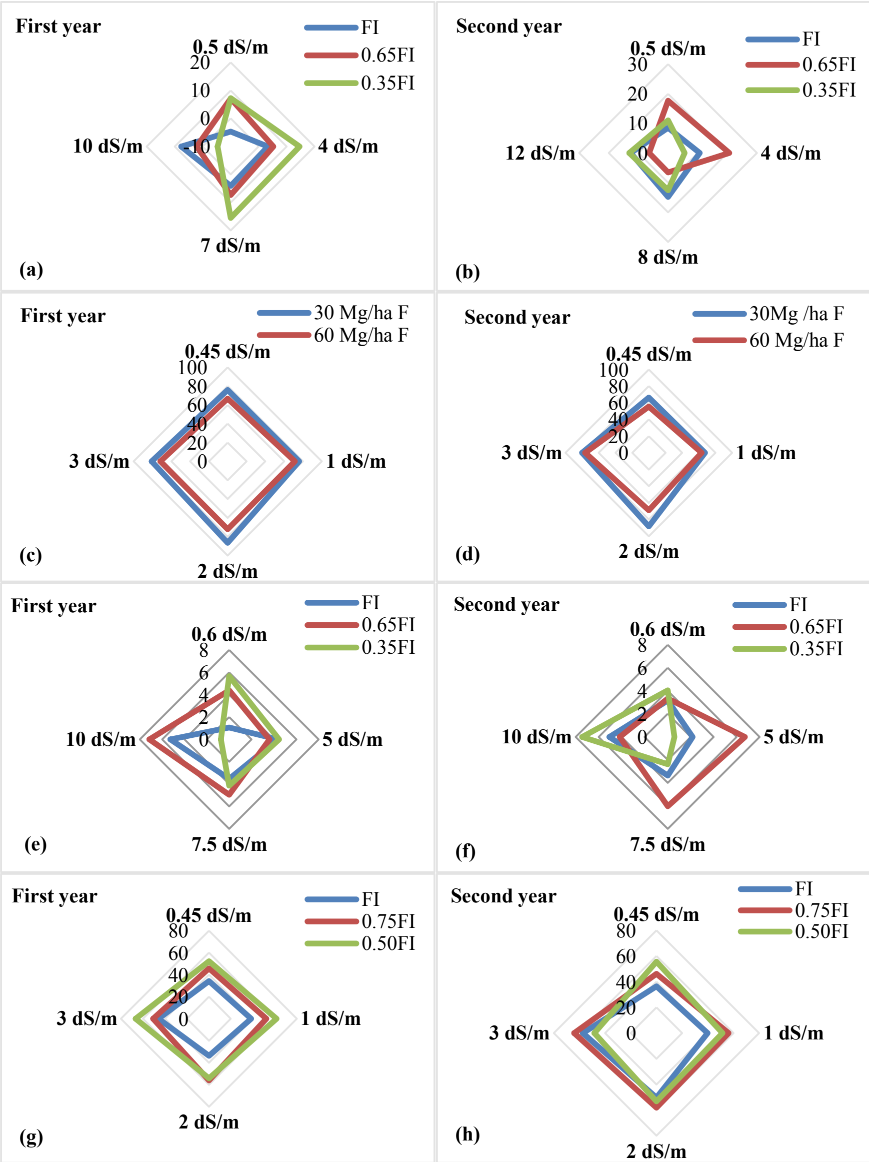



**Fig. 4** The differences in water productivity between in-furrow and on-ridge planting methods for rapeseed (a, b) and winter wheat (e, f) and between in-furrow and basin planting methods for saffron for different irrigation/fertilizer (c, d) and salinity levels (e, f) for the 2-year experiments

30 Mg ha$^{-1}$ manure fertilizer, the percent difference between saffron WP in the in-furrow and the basin planting method for 2.0 dS m$^{-1}$ salinity level was higher than values in other salinity levels.

Maximum winter wheat WP in the first year was 1.50 kg m$^{-3}$ for both 0.6 and 5.0 dS m$^{-1}$ salinity levels and 0.35 FI under the on-ridge planting method, and 1.59 kg m$^{-3}$ for 0.6 dS m$^{-1}$ and 0.35 FI in the in-furrow planting method (Exp 3). In addition, in the second year, the WP of 1.69 kg m$^{-3}$ (for 5.0 dS m$^{-1}$ and 0.35 FI) and 1.73 kg m$^{-3}$ (for 0.6 dS m$^{-1}$ and 0.35 FI) for the on-ridge and the in-furrow planting method was obtained, respectively. Considering all interactions, the on-ridge planting method showed higher WP than the in-furrow planting method (Fig. 4e and f).

Saffron reached its maximum WP of 4.61 and 2.2 g m$^{-3}$ in the first year and 7.93 and 3.75 g m$^{-3}$ in the second year (average of salinity and irrigation levels) in the in-furrow and the basin planting methods, respectively (Exp 4). In addition, the percentage of difference between WP in the in-furrow and the basin planting methods clearly showed that saffron had a higher WP in the in-furrow planting method (Fig. 4g and h). These differences were higher with the 2.0 and 3.0 dS m$^{-1}$ irrigation water salinity.

## 3.3 Relations Between Yield Ratios and Soil Saturated Electrical Conductivity

The relationships between $\frac{Y_a}{Y_m}$ (actual yield/maximum yield) versus the mean soil saturated electrical conductivity for different crops and the planting methods in full irrigation regime were drawn and the threshold $EC_e$ ($EC_{e\ threshold}$), the $EC_e$ for 50% yield reduction and the yield reduction coefficient were determined (Table 6). The results showed that the $EC_{e\ threshold}$ of rapeseed (Exp 1) for the in-furrow planting method was higher than that in the on-ridge planting method. The amount of $EC_e$ to have 50% rapeseed yield reduction was 18.0 dS m$^{-1}$ for the in-furrow planting method, while it was 17.7 dS m$^{-1}$ for the on-ridge planting method, indicating that a higher ECe should be obtained in soil to have 50% yield reduction in the in-furrow planting method compared with the on-ridge method. In addition, the yield reduction coefficient for rapeseed was 3.2% per dS m$^{-1}$ for the in-furrow, while a lower value was obtained for the on-ridge planting method (2.9% per dS m$^{-1}$). For winter wheat, the in-furrow planting method had a lower $EC_{e\ threshold}$ in comparison with that in the on-ridge planting method (Exp 3). A similar trend was observed for the yield reduction coefficient with 5.2 and 5.4% per dS m$^{-1}$ for the in-furrow and the on-ridge planting methods, respectively.

For the saffron experiments (Exps 2 and 4), the results showed that $EC_{e\ threshold}$ in the in-furrow planting method was higher than that in the basin method. In addition, the percent yield reduction per increase in $EC_e$ was lower in the in-furrow planting method in comparison with that in the basin planting method. Furthermore, a higher

**Table 6** Threshold $EC_e$, $EC_e$ for 50% yield reduction and yield reduction coefficient for different planting methods and crops in full irrigation regime

| Planting method/Crop | Rapeseed (Exp 1) | Winter wheat (Exp 3) |
|---|---|---|
| | Threshold $EC_e$ (dS $m^{-1}$) | |
| On ridge | 1.02 | 1.84 |
| In-furrow | 1.08 | 1.56 |
| *$EC_e$ for 50% yield reduction (dS $m^{-1}$)* | | |
| On ridge | 17.66 | 11.12 |
| In-furrow | 18.04 | 11.16 |
| *Yield reduction coefficient (% per dS $m^{-1}$)* | | |
| On ridge | 2.9 | 5.4 |
| In-furrow | 3.2 | 5.2 |
| | Saffron (Exp 2) | Saffron (Exp 4) |
| *Threshold $EC_e$ (dS $m^{-1}$)* | | |
| Basin | 0.76 | 0.77 |
| In-furrow | 0.87 | 0.86 |
| $EC_e$ for 50% yield reduction (dS $m^{-1}$) | | |
| Basin | 1.64 | 1.90 |
| In-furrow | 2.02 | 2.27 |
| *Yield reduction coefficient (% per dS $m^{-1}$)* | | |
| Basin | 63 | 44 |
| In-furrow | 46 | 35 |

$EC_e$ should be reached in soil to have a 50% reduction in saffron yield in the in-furrow planting method compared to the basin method. The latter results showed that saffron sensitivity to saline soil is lower in the in-furrow planting method.

Moreover, the $\frac{Y_a}{Y_m}$ versus the mean soil saturated electrical conductivity equations for winter wheat (Exp 3) and saffron (Exp 4) under different irrigation regimes were determined (Table 7). These equations were not provided for rapeseed (Exp 1) due to different treatments performed in two years of experiment and for saffron (Exp 2), due to use of single irrigation regime. The result showed that application of deficit irrigation under saline conditions reduced the $EC_{e\ \text{threshold}}$ and increased the yield reduction coefficients for both winter wheat and saffron. The latter result occurred due to a decline in soil water potential as a result of both the matric and osmotic potential and hence the sensitivity of crop to saline condition increased under deficit irrigation (Ma et al. 2020).

**Table 7** Relationship between $\frac{Y_a}{Y_m}$ fraction versus the mean soil saturated electrical conductivity (dS $m^{-1}$) for winter wheat (Exp 3) and saffron (Exp 4) under different irrigation regimes

| Crop | Treatment | Equations |
|---|---|---|
| Winter wheat (Exp 3) | FI | $\frac{Y_a}{Y_m} = 1 - 0.052(EC_e - 1.67)$ |
| | 0.65FI | $\frac{Y_a}{Y_m} = 1 - 0.093(EC_e - 1.71)$ |
| | 0.35FI | $\frac{Y_a}{Y_m} = 1 - 0.095(EC_e - 1.07)$ |
| Saffron (Exp 4) | FI | $\frac{Y_a}{Y_m} = 1 - 0.39(EC_e - 0.82)$ |
| | 0.75FI | $\frac{Y_a}{Y_m} = 1 - 0.59(EC_e - 0.74)$ |
| | 0.5FI | $\frac{Y_a}{Y_m} = 1 - 0.84(EC_e - 0.64)$ |

# 4 Conclusions

The in-furrow planting method resulted in a higher amount of winter wheat and rapeseed grain and saffron yields, higher water productivity and generally higher $EC_{e\ threshold}$ and $EC_e$ for 50% yield reduction compared with on-ridge and basin planting methods under water and salinity stress conditions. These results are explained by higher soil water content, salt leaching and increases in osmotic potential (lower osmotic pressure) in the plant root zone. Therefore, the in-furrow planting method can be used as a strategy to ameliorate salt and water stress. However, there are some challenges to this planting method such as an increase in roughness coefficient, a decrease in speed of water advances down the furrows and ultimately, an increase in depth of infiltrated water near the furrow inlet and water loss. Solving this problem requires changing the in-furrow irrigation design factors such as furrow length or water discharge to furrows.

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