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Research paper

Crop response and water productivity of sunflower (*Helianthus annuus* L.) drip-irrigated with magnetically treated and non-magnetically treated water with variable salinity

Mohsen Dastorani[1], **Mohammad Albaji**[1] **and Saeed Boroomand Nasab**[1]

[1]*Department of Irrigation and Drainage, Faculty of Water and Environmental Engineering, Shahid Chamran University of Ahvaz, Ahvaz, Iran*

To compare the effect of magnetic drip irrigation and conventional irrigation with different salinity levels on water productivity and yield of sunflower (*Helianthus annuus* L.), a factorial experiment was conducted using a completely randomized design with 6 treatments and 3 replicates at the Research Station of the Faculty of Water Sciences Engineering, Shahid Chamran University of Ahvaz, Iran. The experiment was executed over the crop year 2018–19. The treatment variables consisted of 2 types of water (magnetically treated and non-magnetically treated) and 3 salinity levels (Karun River water (S1), 4 dS/m (S2), and 6 dS/m (S3)). The use of magnetically treated irrigation water increased the biomass water use efficiency, and the weight of 100 seeds by 13.9%, and 5.48%, respectively. With the conventional irrigation method, increased salinity reduced the seed yield. The highest seed yield and irrigation water productivity were observed at 4 459 kg/ha and 0.73 kg/m^3 for grain yield at a water salinity level of S1 (the control treatment). The application of water with salinity of 4 dS/m and 6 dS/m (S2 and S3) caused a reduction in seed yield by 9.3 and 21.8%, respectively, in comparison to that of the control treatment. Moreover, irrigation water productivity for the biomass yield decreased by 14.57 and 29.23%, respectively. Based on the results of this study, the use of magnetically treated water can reduce the effects of salinity stress under conditions of salt stress. Therefore, magnetically treated water can increase the yield and productivity of irrigation water.

CORRESPONDENCE
Mohammad Albaji

EMAIL
m.albaji@scu.ac.ir
m_albaji2000@yahoo.co.uk

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INTRODUCTION

In arid and semi-arid regions such as Iran, a limiting factor in the irrigation sector is the scarcity of water resources, which can be compensated by developing initiatives to effectively save water (Chegah et al., 2013; Albaji et al., 2014; Abyaneh et al., 2017; Neissi et al., 2020). On the other hand, salinity is one of the most essential and most common criteria for determining the quality of irrigation water. The term salinity refers to the concentration of total ions and soluble molecules in any type of water (e.g. irrigation water, drainage water, and urban runoff) (Naseri et al., 2009; Albaji et al., 2009). Salinity causes an alteration in the plant's germination, leaf size, number and size of stomata, leaf thickness, wooded length, physiological processes such as respiration and photosynthesis, water use efficiency, evapotranspiration, stomatal conductance, and ultimately plant growth. It also alters the plant structure, especially cell chloroplasts (Abedi et al., 2002). Salinity reduces the absorption of potassium, phosphorus and calcium, and affects the transfer of calcium ions into the plant's growth regions. (Fazelipour, 2011).

Consequently, the use of saline water or brackish water in agriculture without proper management reduces the quantity and quality of plant yields. To this end, one of the methods that have been used in recent years in saline water management for irrigation is the passing of irrigation water through a magnetic field. This causes changes in the physical and chemical parameters of water. In general, the water that passes through the magnetometer develops a uniform structure with some changes in important characteristics, such as odour, flavour, electrostatic polar force or surface adhesion, water solubility feature, specific gravity, water–surface contact angle, viscosity, salinity and hardness (Ahmadi, 2010). Since magnetic treatment of water does not add or remove any substance in the water itself, it is considered a harmless and environmentally friendly technology.

Dehghani et al. (2007) conducted field experiments at Yazd Agricultural Research Center and found that irrigation with magnetically treated water had no significant effect on wheat crop yield and water productivity. Maheshwari and Grewal (2009) studied the effects of magnetic treatment on different irrigation water types, focusing on water productivity and yield of snow pea, celery, and pea plants. The magnetic treatment of recycled water and 3 000 mg/kg saline water increased celery yield by 12% and 23% and water productivity by 12% and 24%, respectively. For snow peas, there were 7.8%, 5.9%, and 6.0% increases in pod yield with magnetically treated potable water, recycled water, and 1 000 mg/kg saline water, respectively. The water productivity of snow peas increased by 12%, 7.5%, and 13%, respectively, for magnetically treated potable water, recycled water, and 1 000 mg/kg saline water.

Nikbakht et al. (2011) investigated the effect of deficit irrigation with magnetically treated water on the yield and water use efficiency of maize. The total dry weight and water use efficiency of plants irrigated with magnetically treated water increased significantly, by 17.8% and 9%, respectively. The total fresh weights of the plant and water use efficiency based on total fresh weight were 31.56 t/ha and 14.22 kg/m^3, respectively, whereas for non-magnetically treated water treatment these values were 28.94 t/ha and 12.94 kg/m^3, respectively.

Banjad et al. (2013) investigated the interaction effects of magnetically treated water and salinity on the yield and yield components of basil. The treatments included water type (magnetically treated and non-magnetically treated) and salinity at 3 levels (3.57, 5.3, and 5.76 dS/m). The results showed that magnetically treated water had the greatest effect on increasing performance factors. The interaction effects of water type and salinity level showed a 33% and 23% increase in fresh and dry weight in magnetically treated distilled water as compared to non-magnetically treated distilled water, respectively.

To investigate the effects of magnetically treated water on the growth and production of total dry matter in chickpeas, an experiment was conducted by Mahmodi et al. (2014). The results showed that placing the seeds in a magnetic field significantly increased dry matter content by 26% as compared with seeds not subjected to a magnetic field. The application of a magnetic field to irrigation water and chickpea seeds resulted in a 27% and 19% increase in grain yield, respectively.

Mohammadian et al. (2014) investigated the effect of saline water passing through a magnetic field on growth characteristics and yield components of green pepper plants. The treatments included 2 types of water (magnetically treated and non-magnetically treated) and salinity at 3 levels (0.3, 2.3, and 4.2 dS/m). Their study showed that water which had passed through a magnetic field increased total fruit yields by 12, 19, and 33%, for water having salinities of 0.3, 3.2, and 4.2 dS/m, respectively.

Surendran et al. (2016) investigated the impacts of magnetic treatment of irrigation water on plant, water, and soil characteristics. The results showed that the magnetic treatment of irrigation water led to an improvement in crop growth and yield parameters of cowpea. Magnetic treatments tend to reduce electrical conductivity, total dissolved solids, and salinity levels of all solutions except normal, non-saline irrigation water, whereas a definite trend of increase in pH was noticed for all treatments.

Aghamir and Bahrami (2018) showed that the electromagnetic field has no significant effect on the chemical properties of water. Due to the properties of the soil before and after harvest, magnetically treated water had a significant effect only on the concentrations of soluble and exchangeable sodium, chlorine, calcium, and magnesium. Also, with increasing salinity, absorption of high-consumption nutrients and protein percentage decrease, and absorption of low-consumption nutrients and sodium increase.

El-Gindy et al. (2018) showed that the irrigation with magnetically treated water increased plant growth characteristics significantly. It was observed that protein levels increased when the crop was irrigated with non-magnetically treated water as compared to magnetically treated water in both seasons. In most cases, the growth parameters (shoot and root) of pear seedlings were improved significantly using water treated by magnetic technology, especially with low salinity irrigation water at 1 000 mg/kg (canal water), while the opposite trend was recorded when the salinity was increased to 4 000 and 5 000 mg/kg without being treated by magnetic technology in both seasons.

Abdel Kareem (2018) evaluated the effect of magnetizing irrigation water on the enhancement of yield and water productivity for some crops. The results showed significant increases in water productivity for the magnetically treated water when compared with non-magnetically treated water, amounting to 1.65, 1.88, and 1.78 kg/m^3 for eggplant, faba beans, and tomato, respectively. It was also observed that the MTW affected the amounts of irrigation water required to be added to different crops during their growing period. The water savings were 11%, 13.5%, and 14.2% for eggplant, faba beans, and tomato, respectively. As a result, net return increased by 1.97, 3.0, and 2.45 kg/m^3 for the three crops, respectively.

In this paper, we have attempted to compare functional indices and water productivity of sunflower (*Helianthus annuus* L.) in the Ahvaz region of Khuzestan Province, Iran, when drip-irrigated with magnetically treated and non-magnetically treated water of variable salinity.

MATERIALS AND METHODS

Experimental site location

This research was carried out at Research Farm No. 1 (latitude 31°18'18", longitude 48°39'68" and elevation 20 m amsl) of the Shahid Chamran University of Ahvaz, Iran, in the 2018/19 growing season. The farm is located in an arid climate as indicated by some meteorological data for the 2018/19 growing season (Table 1).

Experimental layout and treatments

A factorial experiment using a randomized complete block design with 2 irrigation water treatments (magnetically treated, W1, and non-magnetically treated, W2) as the main plots and 3 salinity treatments (2.2 dS/m, S1; 4 dS/m, S2, and 6 dS/m, S3) as the sub-plots, in 3 replication sets (Fig. 1).

Agronomic practices

The cultivar Hysun 25 was planted manually with 3 to 4 seed clumps at 3 to 5 cm depth, with a 30 cm spacing in the rows. The intervals between the 6 m long rows were 75 cm. To bring the plants to the desired density level, thinning was done at the 4–6 foliage stage. Weeding was done manually from emergence until harvest.

Table 1. Mean air temperature, relative humidity, and total monthly rainfall and evaporation during 2018/19 growing season at Ahvaz

Month	Feb	Mar	Apr	May	June	July	Average	Total
Temperature (°C)	13.20	18.35	24.40	32.50	36.30	39.55	27.38	---
Relative humidity (%)	54	48	44	30	28	34	39.67	---
Rainfall (mm)	6.00	24.90	24.50	0.80	0.00	0.00	9.37	56.20

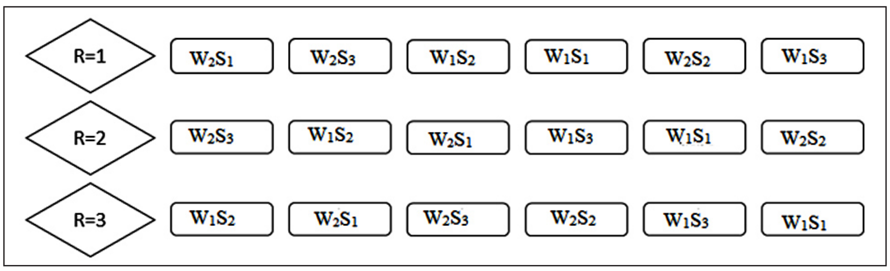

Figure 1. Schematic diagram showing the arrangement of treatments

However, single spraying with Diazinon was done at a ratio of 1:1 000 to eliminate pests such as aphids. It should be noted that to prevent damage by birds such as sparrows and parrots, the field was covered with a reticulated mesh (2.5 × 2.5 cm). 100 kg/ha of triple superphosphate fertilizer and 200 kg/ha of potassium sulfate fertilizer were applied to the soil before planting and then disk operation was performed to crush the lumps and mix the fertilizer with the soil. Urea fertilizer (150 kg/ha) was applied during the stem and pre-flowering stage. Urea is applied as granules on the entire soil surface. The amount of N applied as urea each time was 35 kg/ha. Moreover, fertigation at 5 kg/ha was given once. The nutrient analysis for fertigation was as follows: humic and folic acid – 13%; total nitrogen (N) – 6%; phosphorus (P_2O_5) – 0.2%; potassium (K_2O) – 2%; zinc chelate – 250 mg/kg; iron chelate – 100 mg/kg; manganese chelate – 150 mg/kg; copper chelate – 70 mg/kg; sulfur – 0.25%.

The mean characteristics of the different irrigation water treatment combinations during the testing period are presented in Table 2.

The amount of water required for drip irrigation to sustain the growth and development of the sunflower plants was estimated from evaporation data measured with an American Class A evaporation pan installed by the Faculty of Water Engineering near the experimental site. Equations 1 to 6 were used to calculate the net water requirement by taking, for example, the leaching requirement and application efficiency into account. The drip irrigation per event was kept constant over 2 days.

$$\mathrm{ET}_0 = K_\mathrm{P} \times E_\mathrm{P} \tag{1}$$

where ET_0 is reference evapotranspiration (mm/day); K_P is pan coefficient; E_P is evaporation of the pan (mm).

$$\mathrm{ET}_\mathrm{C} = \mathrm{ET}_0 \times K_\mathrm{C} \tag{2}$$

where ET_C is crop evapotranspiration (mm/day); ET_0 is reference evapotranspiration (mm/day), K_C is vegetation factor.

According to Eqs 1 and 2, the maximum daily water requirement of the plant was calculated from the FAO proposed relationship as follows:

$$T_\mathrm{C} = [P_s + 0.15 \times (1 - P_s)] \times \mathrm{ET_c} \tag{3}$$

where T_C is maximum daily water requirement (mm/d), $\mathrm{ET_c}$ is maximum daily evapotranspiration (mm/d), P_s is maximum percentage of canopy (%).

$$\mathrm{LR} = \frac{\mathrm{EC}_W}{2\mathrm{EC}_\mathrm{E}(\mathrm{MAX})} \tag{4}$$

where LR is the need for leaching $\mathrm{EC_w}$, electric conductivity of irrigation water (dS/m); $\mathrm{EC_E}$ is the electrical conductivity of the soil saturation extract in such a way that the percentage of production is zero (dS/m)

$$d_g = \frac{d_n}{(1 - LR) \times E_a} \tag{5}$$

where d_g is gross irrigation requirement (mm) d_n is net irrigation required (mm) E_a is irrigation application efficiency.

$$V = d_\mathrm{g} \times A \times f \tag{6}$$

where V is gross volume of irrigation water (L), A is surface of each row (m^2), f is coefficient of the surface soaked.

The water was transmitted by canal to a pool and then pumped to 3 tanks (two with 1 000 L and one with 2 500 L capacity) in the field via a floating pump. The 2 500 L tank was used for the 2.2 dS/m (S1) water from the nearby Karun River, and the two 1 000 L tanks for the 4 dS/m (S2) and 6 dS/m (S3) water, respectively.

To prepare irrigation water for the different salinity treatments, Karun River water was mixed with agricultural saline agricultural drainage water. The mixing ratio was determined using Eq. 7.

$$\mathrm{EC_{adj}} = \frac{(V_1 \times \mathrm{EC}_1) + (V_2 \times \mathrm{EC}_2)}{V_1 + V_2} \tag{7}$$

where $\mathrm{EC_{adj}}$ is adjustment electric conductivity (dS/m), V_1 is drainage water volume (lit), V_2 is treatment water volume (lit), EC_1 is electric conductivity of drainage water (dS/m), EC_2 is electric conductivity of treatment water (dS/m).

An irrigation system consisting of a pump, grating filter, pressure gauge, and volumetric flow meter with a distribution system that included a set of pipes, fittings, and droplets was used. An Aqua Correct Magnetic Device (Table 3) was fitted to the distribution system at relevant positions for the magnetic treatment of the water.

Soil measurements

To determine the physical and chemical characteristics of the soil, standard procedures (Black, 1965) were used. Before cultivation in February 2018, three field points were sampled at depths of 0–30, 30–60, and 60–90 cm, respectively. The samples were composited and analysed in the drainage laboratory of the Engineering Science Faculty of the Shahid Chamran University of Ahvaz, and several of the chief physical and chemical characteristics which were determined, are presented in Table 4.

Table 2. Mean characteristics of the water used in the treatment combinations during the testing period

Treatment	EC (dS/m)	pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
			(Meq/L)						
S1	2.2	8.30	8.50	6	9.21	0.01	5.5	10	8.98
S2	4	8.69	11.50	9	24.37	0.06	5.5	25	11.87
S3	6	8.56	17.00	13	38.67	0.13	5.5	41.5	16.04

Table 3. Specifications of the magnetic device used for magnetic treatment of irrigation water

Device name	Installation type	Magnetic field intensity	Maximum discharge flow	Size	Length	Manufacturer	Model
Aqua correct	Inside the path	6 500 Gauss	0.7 m^3/h	1.27 cm	20 cm	Germany H.S.P	AC 2

Table 4. Physical and chemical soil characteristics

Depth (cm)	PWP (%)	FC (%)	pH	(dS/m) EC	Bulk density (g/cm^3)	Soil texture
0–30	16.07	31.13	7.66	5.62	1.46	Loam
30–60	15.67	23.59	7.72	5.84	1.44	Loam
60–90	15.67	28.58	7.62	6.35	1.44	Loam

Plant measurements

After physiological maturity, 30 plants (the first 5 plants from each side of a row) were manually sampled from all treatment combinations and immediately transferred to a laboratory for determining wet biomass. The different parts of each plant were then separated (i.e., leaves, stems, heads and seeds) and each of the components was weighed. Stem height was determined with a measuring tape, stem diameter with a caliper, and head diameter with a ruler. Leaf area was calculated using an equation based on the leaf weight. Stem, head, and seed samples of each treatment were placed individually in a paper bag and heated in an oven at 70°C for 48 h and dry weight of the samples was measured. The number of grains in the head were counted and the weight of each 100 grains was measured. The seeds were then peeled and the kernel weight of each 100 seeds was determined. Seed and biomass yields were calculated per hectare. Crude oil percentage was determined via the Soxhlet extraction technique to calculate oil yield as a function of seed yield and crude oil percentage (Pomeranz and Clifton, 1994).

Data processing and analyses

By using relevant measured data, the harvest index (HI = grain yield/biomass yield), biomass water productivity (biomass yield/irrigation volume), and seed water productivity (seed yield/irrigation volume) were calculated. All measured and calculated parameters were subject to analyses of variance using SPSS software. Duncan's test at the 5% level was used to compare means where necessary. Microsoft Excel was applied to draw charts.

RESULTS

Crop response

Leaf area index

The results indicated a significant difference between the two irrigation treatments, W1 and W2. Irrigation with magnetically treated water increased leaf area index compared to the control by 15.7%.

Weight of 100 seeds

There was a significant difference in 100-seed weight between the different irrigation treatments. Irrigation with magnetically treated water increased 100-seed weight by 3.4% compared to the control (Table 5). The maximum 100-seed weight resulted from magnetically treated water (6.55 g) while the minimum 100-seed weight occurred with non-magnetically treated water (6.33 g) (Table 5).

A significant difference was found among the different salinity treatments. Salinity reduced the 100-seed weight. The highest 100 seed weight, of 6.98 g, was observed for the S1 treatment and the lowest 100-seed weight of 5.89 g was observed for the S3 treatment. The application of water with S2 and S3 salinity levels reduced 7.7% and 15.6% of the seed yield, respectively (Table 5), which in itself resulted in a decrease in the 100-seed weight.

100-seed kernel weight

The results showed that magnetically treated and non-magnetically treated water resulted in significantly different 100-seed kernel weight (Table 5). The maximum 100-seed kernel weight occurred with magnetically treated water (4.67 g) and the minimum 100-seed weight with non-magnetically treated water (4.41 g).

A significant difference in 100-seed kernel weight was observed between water salinity levels. A maximum 100-seed kernel weight of 5.00 g was realized with the S1 treatment and a minimum 100-seed kernel weight of 4.03 g with the S3 treatment. The application of water with salinity levels of S2 and S3 decreased 100-seed kernel weight by 8.3% and 19.3%, respectively (Table 5).

Stem height

Stem height differed significantly between the W1 and W2 treatments. Magnetically treated water increased the stem height by 7.8% compared to non-magnetically treated water.

Application of water with higher salinity levels increased stem height significantly. The maximum stem height was recorded with the S1 treatment (191.8 cm), followed by the S2 treatment (185.9 cm) and the S3 treatment (162.78 cm).

Stem diameter

A significant difference was found between magnetically treated and non-magnetically treated water (Table 5). The diameter of the stems for magnetically treated water was larger than that for non-magnetically treated water. The maximum stem diameter was 22.22 mm (W1) and the minimum was 20.78 mm (W2).

With increasing salinity, the stem diameter decreased. The largest stem diameter was 21.9 mm for the S1 treatment and the smallest stem diameter was 19.38 mm for the S3 treatment.

Biomass yield

The application of magnetically treated vs. non-magnetically treated water gave no significant difference in dry weight of the stem, leaf, and head. However, stem weight (3 776 vs 3 595 kg/ha), leaf weight (4 544 vs 4 272 kg/ha) and head weight (4 127 vs 3 834 kg/ha) were slightly higher when magnetically treated instead of non-magnetically treated water was applied.

Harvest index

Neither magnetization nor salinization of water influenced HI significantly (Table 5). The maximum HI was 0.255 with the S3 treatment and the minimum HI was 0.246 with either the S1 and S2 treatments (Table 5).

Table 5. Comparison of average sunflower seed traits

Treatments	Leaf area index	Harvest index	Irrigation water productivity for biomass yield (kg/m^3)	Irrigation water productivity for grain yield (kg/m^3)	Oil yield (kg/ha)	Oil percentages (%)	The 100-seed kernel weight (g)	Weight of 100 seeds (g)	Grain yield (kg/ha)
Magnetically treated water	4.41 a	0.246 a	3.14 a	0.67 a	1 682 a	40.44 a	4.67 a	6.55 a	4 046 a
Non-magnetically treated water	3.72 b	0.252 a	2.82 b	0.64 b	1 576 a	40.00 a	4.41 b	6.33 b	3 931 b
S1 – Salinity: 2.2 dS/m	4.63 a	0.246 a	3.53 a	0.73 a	1 769 a	39.67 a	5.00 a	6.99 a	4 459 a
S2 – Salinity: 4 dS/m	4.21 a	0.246 a	3.02 b	0.66 b	1 683 a	41.50 a	4.58 b	6.45 b	4 044 b
S3 – Salinity: 6 dS/m	3.35 b	0.255 a	2.40 c	0.57 c	1 436 a	41.00 a	4.03 c	5.90 c	3 489 c

Values with the same letter are statistically homogeneous in the Duncan test.

Oil percentages

The oil percentages were not influenced significantly by either the magnetic treatment or salinization of the water (Table 5). The maximum oil percentage was realized for the S2 treatment (41.5%) and, the minimum oil percentage for the S1 treatment (39.47%).

Oil yield

Oil yield was not affected significantly by any of the treatments (Table 5). The maximum oil yield was realized for the S1 treatment (1 769 kg/ha), followed by the S2 treatment (1 683 kg/ha) and the S3 irrigation treatment (1 436 kg/ha).

Grain yield water productivity

Water productivity for grain yield increased significantly from 0.64 to 0.67 kg/m^3 due to magnetic treatment (Table 5). This parameter decreased with increasing water salinity: 0.73 kg/m^3 for S1, 0.66 kg/m^3 for S2 and 0.57 kg/m^3 for S3.

Biomass yield water productivity

Irrigation with magnetically treated water increased water productivity for biomass yield by 10.51% from 2.82 kg/m^3 to 3.14 kg/m^3 (Table 5). The highest water productivity for biomass yield was 3.53 kg/m^3 for the S1 treatment and the lowest was 2.5 kg/m^3 for the S3 treatment.

Grain yield

Irrigating with magnetically treated water increased the grain yield of sunflowers by 3.2% when compared with that for non-magnetically treated water (Table 5). The highest grain yield (4 459 kg/ha) was observed for the S1 treatment and the lowest grain yield (3 489 kg/ ha) was observed for the S3 treatment. The application of water with salinity levels of S2 and S3 reduced grain yield by 9.3% and 21.8%, respectively (Table 5).

DISCUSSION

Irrigation with magnetically treated water increases plant water absorption (Ahmadi, 2010). Probably, with increased water absorption, cellular swelling and consequently potential water pressure in the cell are elevated, so cell division in the leaf tissue increases, which increases the leaf area and thus leaf area index. The leaf area index of sunflower (*Helianthus annuus* L.) plants grown with saline irrigation water (S3) significantly decreased relative to plants grown with non-saline irrigation water (Table 5). The maximum leaf area index was 4.63 in the control treatment (S1). Increasing the salinity level of irrigation water to S2 decreased the leaf area index by 8.9% compared with the control treatment (4.21), but no significant difference in LAI was observed between these two treatments. The minimum leaf area index was 3.35, for S3 (Table 5).

Since grain weights develop by concurrent photosynthesis and resin storage in the plant, irrigation with magnetically treated water may increase photosynthesis and, eventually, enhance the plant storage. Sarmarzadeh Vojdehfar et al. (2010) reported that irrigation with magnetically treated water increased seed weight per head by 14.72% compared to irrigation with normal water. The 100-seed weight reduction under salinity stress conditions seem to be an effect of the reduction in water and nutrient absorption by plants which reduces the production and transfer of photosynthetic materials and processed sap to the seeds. In other words, salinity stress reduces 100-seed weight through a decrease in leaf area. The consistency of salinity stress in irrigation treatments is likely to negatively affect the transfer of photosynthetic materials, which would eventually adversely affect the transfer of nutrients to seeds, resulting in wrinkling and reduced seed weight. The findings of the present study supported those of previous studies (e.g., Shobeiri, 2004; Rafiae et al., 2002; Kalhori et al., 2002) that reported a decrease in the production of photosynthetic materials affected by moisture. Furthermore, salinity stress resulted in the seeds remaining half-filled. As shown in Table 5, magnetically treated water increased 100-seed kernel weight, recorded as about 4.67 g for the control, by 5.75%. Efficient water use (in the magnetically treated water irrigation treatment) increased leaf area and thus photosynthesis, leading to an increase in seed kernel weight. The higher seed kernel yield in the S1 treatment was chiefly due to the durability of high leaf areas during the reproductive process, quick physiologic growth and the transfer of sufficient photosynthetic materials to reproductive organs.

Stem height decreased as irrigation water salinity level increased. Stem height reduction in irrigation with saline water conditions can be attributed to a reduction in the growth period. Likely, salinity stress led to a reduction in stem cells' water potential to a level lower than that needed for cell elongation and consequently resulted in shorter internodes and stem height. These findings were in good agreement with the observations made by Aziz (1992), who reported that salinity at all concentration ranges caused a significant decrease in the height of rosella plants. The negative effect of salinity on the plants was due to the osmotic potential created by salt in the soil solution, which reduced the water uptake by plant cells. Therefore, the uptake of some nutrients dissolved in water was also restricted. Thus, the growth and development of plants is inhibited due to defects occurring in metabolism (De Lacerdaet et al., 2003).

Karam et al. (2004) stated that irrigation insufficiency did not result in any remarkable increase in the harvest index (HI), ranging from 0.24 to 0.27 ($p > 0.05$), confirming the results obtained in the current study. The harvest index in this study ranged from 0.25 to 0.29. Mozafari et al. (1996) stated that drought stress affects sunflower oil percentage. However, the percentage of oil in the plant seed would not necessarily be reduced by drought stress because seed oil is a quantitative feature influenced by the plants' genetic profile. Demir et al. (2006) observed that deficit irrigation of sunflower did not cause any significant difference in seed oil percentage between various irrigation treatments. The results of the current research closely parallel those reported by Tan et al. (2000) and Flagella et al. (2002), who found that the plant seed oil percentage did not vary as irrigation was increased. Karaata (1991) reported that the seed oil percentage did not significantly increase as the amount of irrigation water increased, but increased with additional irrigation applied at the flowering and milk ripening stages. Since the seed oil percentage is influenced by several environmental factors (especially temperature) as well as genotypic effects, it is likely that the conflicting results reported in various studies were mainly due to environmental conditions.

Since oil yield is determined by multiplying the seed yield by oil percentage, and particularly with the seed yield variations reported in this study, the difference in the oil yield between different irrigation treatments seems to be due to the seed yield differences (because no significant difference was observed in the seed oil percentage). The oil yield was reduced as water quality was reduced and salinity stress was applied at different levels. Adequate fresh irrigation, particularly during sunflower seed filling, can be helpful to increase seed weights (seed yield) and increase oil supply.

Using magnetically treated water in irrigation operations increases plant productivity and ultimately boosts water use efficiency (Durate Diaz et al., 1997). Maheshwari and Grewal (2009) reported that the use of magnetically treated water for irrigation increased the water use efficiency of snowflake and celery plants. The minimum yield water productivity (WP (Ir) Y)) occurred with the S3 treatment and averaged 0.57 kg/m^3. Reductions in grain yields due to an increase in salinity led to a decrease in irrigation water productivity for grain yield (Table 5). The effect of salt stress has been reported to reduce the water productivity of maize (Heydarinia, 2016; Saeedi Nia, 2015; Nasrollahi, 2014). As already mentioned, water flow crossing a magnetic field results in increased plant water absorption. The magnetic field causes the hydrogen bonds and Van der Waals force between the water molecules to weaken (Maheshwari and Grewal, 2009). As a result, the surface tension of the water decreases, and the solubility of nutrients increases. The above factors increase the absorption of water, salts and nutrients in the roots. By increasing the absorption of nutrients by the roots, the capacity of the plant for photosynthesis and production of food increases, and ultimately the plant yield and fresh weight increases (Khande Royan, 2013). Ghadami Firouzabadi et al. (2016) reported that irrigation with magnetic water caused an increase of 9.35%, on average, in water use efficiency. Magnetically treated water increased the yield of soybean seeds by 10.77% as compared to non-magnetically treated water (Ghadami Firouzabadi et al., 2016). Salinity disrupts the absorption of nutrients and plant metabolic activity, causing early aging and decreasing the photosynthetic activity of the plant, especially the photosynthesis by leaves, which have a major contribution to seed production, and which when affected will reduce grain yield (Fried and Ehsanzadeh, 2006).

Balanced water consumption during different development processes like flowering and seeding seems to improve sunflower seed yield because two important components of seed yield (seed numbers in the head and 100-seed weight) are formed during these processes, while enough irrigation in the vegetative process leads to a desired development of the leaf area. It can, therefore, be concluded that the reason for attaining a desirable seed yield in conventional irrigation (with freshwater) is the assignment of more photosynthetic materials to enhance the general reproductive and seed-filling process. Due to salinity, improper irrigation treatment accelerates leaf aging and reduces production levels, in addition to decreasing leaf area and the amount of photosynthesis. Feyzi (2005) reported that irrigation with salinity levels of 6.1 and 10.5 dS/m during the cropping season of sunflowers, as compared to irrigation with salinity levels of 2.6 dS/m, reduced sunflower seed yield by 38% and 80%, respectively.

Due to the increased solubility of sodium salts in magnetically treated water, irrigation (leaching) with magnetically treated water increased sodium leaching. The amount of leaching in the magnetic treatment was 27.7% higher than in the control treatment. The use of magnetically treated water reduced the amount of calcium leaching by 13%. It was also shown that increasing the intensity of the magnetic field resulted in an increase in the amount of solute leaching, in turn reducing soil EC. Increased sodium leaching and decreased calcium leaching with magnetic water treatment results in increased calcium and decreased sodium in the soil. Accordingly, the flocculation of soil particles increases and ultimately the permeability of the soil increases.

Finally, the interaction of water type (magnetically treated and non-magnetically treated) and salinity was not significant in any of the evaluated traits. As a result, it can be said that the effect of the interaction between water type and salinity is less than the sum of the effects of each of these stresses.

CONCLUSION

Analysis of variance of different traits measured in the experiment showed that irrigation water type had a significant effect on stem height, stem diameter, 100-seed kernel weight, and irrigation water productivity for biomass yield (p < 0.01) and the leaf area index, grain yield, 100-seed weight and irrigation water productivity for grain yield (p < 0.05). However, irrigation water type had no significant effect on other variables. The use of magnetically treated water for irrigation increased the irrigation water productivity for biomass yield, stem height, and 100-seed kernel weight by 9.13%, 7.8%, and 5.48%, respectively, compared to plants irrigated with normal water.

Furthermore, irrigation water salinity had a significant impact on all traits except oil percentage, oil yield, and harvest index (p < 0.01). However, the interaction effect of water type and salinity was not significant for any of the measured traits. Salinity reduced grain yield. The highest grain yield and irrigation water productivity for grain yield were observed with S1 salinity (control treatment), with 4 459 kg/ha and 0.73 kg/m^3, respectively. The application of 4 and 6 dS/m salinity (S2 and S3) reduced grain yield by 9.3% and 21.8%, respectively. Irrigation water productivity for biomass yield was reduced by 14.57% and 23.23%, respectively. Following these findings, it can be argued that the use of magnetically treated water can reduce the adverse effects of salinity stress.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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