

# Effects of magnetized water application on soil and maize growth indices under different amounts of salt in the water

Meysam Abedinpour and Ebrahim Rohani

## ABSTRACT

Application of low quality water for irrigation is compulsive in facing water scarcity. Use of a magnetic field is an approach to overcome this challenge. This study examined the impact of magnetic field technology on improving germination under water of different salinity levels. An experiment was conducted to determine the effects of saline water levels, i.e. (S<sub>1</sub>):0.5, (S<sub>2</sub>):2, (S<sub>3</sub>):4 and (S<sub>4</sub>):6 dS/m combined with magnetized technology (with or without) on maize growth. Thus, magnetic treatment was applied by passing the irrigation water through a 1,500 mT magnetic field at 3 litres per minute (lpm) flow rate. Some emergence indices, such as emergence index, emergence rate index (ERI) and mean emergence time, were used to evaluate the germination of maize seed. As for soil properties after plant harvest, the use of magnetically treated irrigation water reduced soil pH but increased soil electrical conductivity and available N and P. ERI increased from 7.6 to 10.2, 9.1 to 11.1, 10.3 to 13.3, and 11.8 to 13.3 when applying the magnetized field for S<sub>1</sub>, S<sub>2</sub>, S<sub>3</sub> and S<sub>4</sub>, respectively. Overall, the growth parameters of maize were improved by using magnetic technology with saline water, while the opposite trend was shown for increasing salinity without magnetic treatment.

**Key words** | germination, magnetic treatment, maize, saline water

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## INTRODUCTION

Agriculture is the main consumer of water resources. However, because of the increase in demand from other sectors, water has become scarce and limited. In Iran, agriculture uses more than 85% of the available water resources. In addition, the processes of urbanization and industrialization and the development of irrigated agriculture to support population growth have raised the demand for water, but at the same time have reduced the supply.

Salinity of soil and water resources is a serious threat in many parts of the country. The main difficulty in this regard is the temporal variations of salinity during the growing season, due to the effects of irrigation water which add or

leach the salts. Salinity of the ground waters is more serious than that of the surface waters in Iran. This has been increasing in recent years due to the overdraft and intrusion of the surrounding saline bodies of water. Considering the fact that nearly half of the water used in Iran's agriculture comes from the groundwater, the threat of salinity effects on the sustainability of crop production in the country has become evident. Magnetic water treatment works on the principle that as water passes through a magnetic water softener, a Lorentz force is exerted on each ion which is in the opposite direction to each other. The redirection of the particles increases the frequency of collisions between ions of opposite sides, combining to form a mineral precipitate or insoluble compound. Magnetic treatment of saline irrigation water can be used as an effective method for soil desalinization. The application of a magnetic field on water decreases

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the hydration of salt ions and colloids, having a positive effect on salt solubility, accelerated coagulation and salt crystallization (Hillal & Hillal 2000a). Field experiments conducted in Egypt showed that sandy loam soil pots irrigated with normal highly saline water of an electrical conductivity (EC) value of 8.2 dS/m retained salts compared to pots irrigated with magnetized saline water (Hillal & Hillal 2000b). Subsequently, it was concluded that magnetized water increased leaching of excess soluble salts, lowered soil alkalinity and dissolved slightly soluble salts. Plants have increasingly become an attractive model system for studying the biological effects of magnetic fields (Racuciu & Creangia 2005). Researchers have reported that 125 and 250 mT magnetic treatment produced a biostimulation on the initial growth stages and increased the germination rate of several seeds such as rice (Carbonell *et al.* 2000; Flórez *et al.* 2004), wheat (Martinez *et al.* 2002) and barley (Martinez *et al.* 2000). Yinan *et al.* (2005) published that the magnetic field pretreatment had a positive effect on cucumber seedlings, such as stimulating seedling growth and development. Tai *et al.* (2008) observed that subjecting water to a magnetic field leads to a modification of its properties, as it becomes more energetic and able to flow, which can be considered as the birth of a new science called magneto biology. They also pointed out that magnetized water prevents uptake by the roots of harmful metals, such as lead and nickel, and hence prevents these from reaching the fruits. However, it increases the percentage of nutrient elements like phosphorus, potassium and zinc in plants. Grewal & Maheshwari (2011) investigated the effects of magnetic treatment of irrigation water on snow pea and Kabuli chickpea seed emergence, early growth and nutrient contents under glasshouse conditions. Hozayn & Qados (2010) studied the application of magnetic water for wheat crop production and found improvements

in quantity and quality of wheat. Therefore, using magnetic water treatment could be a promising technique for agricultural improvements, but extensive research is required on different crops. Maheshwari & Grewal (2009) demonstrated some effects of magnetic water treatment on water productivity and yield of snow pea, celery, and pea plants. Their results pointed out beneficial effects of magnetic treatment, particularly for saline water and recycled water, on the yield and nutrient composition of celery and snow pea plants under irrigation with saline water. Therefore, an attempt was made to understand the applicability of using magnetized saline irrigation water in the evaluation of growth and emergence of maize seeds.

## MATERIALS AND METHODS

A pot experiment was carried out in Kashmar Higher Education Institute, Iran, during the summer season of 2015, to study the effects of different irrigation water saline levels and tap water with or without magnetic field on germination rate, dry weight, plant height and some emergence indices. The experiment was laid in randomized complete block design comprising tap water, i.e. control: S<sub>1</sub>; irrigation with saline water (2 dS/m): S<sub>2</sub>; 4 dS/m: S<sub>3</sub>; and 6 dS/m (S<sub>4</sub>) as main plots and irrigation water with or without magnetic field (M<sub>1</sub> and M<sub>2</sub>), respectively, as subplots. The pots were filled with 15 kg of uniform soil. Some physical and chemical properties of the soil are presented in Table 1.

Germination tests were performed under greenhouse conditions with natural light and the average temperature of 36 ± 2 °C to study the effect of magnetized water on maize seed germination and emergence. Saline water of 1,500 ppm was prepared in the laboratory by adding NaCl. Before applying to the plants, for the magnetized treatments, irrigation water

**Table 1** | Some properties of soil before applying treatments

Soil depth (cm)	Soil texture	FC (%) (v/v)	PWP (%) (v/v)	B <sub>d</sub> (g/cm <sup>3</sup> )	EC (dS/m)	pH	N (g/kg)	P (g/kg)
0–10	Si.C. loam	44.02	23.43	1.25	0.65	7.18	0.82	18.33
10–20	Si.C. loam	41.00	21.67	1.27	0.66	7.20	0.84	18.47
20–30	Clay loam	35.50	18.82	1.32	0.71	7.20	0.84	18.51
30–40	Clay loam	37.50	18.29	1.33	0.70	7.19	0.84	18.51

FC: field capacity, PWP: permanent wilting point, B<sub>d</sub>: bulk density, EC: electrical conductivity.

was treated with a 1,500 mT magnetic field with 5 circulations. The water flow rate was 3 litres per minute (lpm). The magnetic field was produced just before the flow outlet using four pairs of neodymium block magnets, fixed to a wooden frame, with 25 mm distance between pairs. Each magnet measured 45 mm long, 5 mm high and 35 mm wide and a 60 cm pipe length was in contact with the magnets. A schematic design of the magnetic device is shown in Figure 1. The strength of the magnetic field was measured along the longitudinal direction of the pipe with the help of a magnetic flux meter and the maximum magnetic intensity was observed in the center of the entire length of the pipe and the minimum magnetic intensity was observed at the edge of the magnets. The mean parameter values, including EC, pH, N, P, K, Ca<sup>2+</sup> and Mg<sup>2+</sup>, of different water types are presented in Table 2. Uniform size seeds were used for the germination test. Seeds were soaked in magnetized water for 24 hours and 30 seeds were placed in a grid of 3 × 4 cm with uniform intervals and sown at a uniform depth of 20 mm in every pot with the help of marked stick. A measured volume of 500 ml of the different irrigation water types with or without magnetic treatment was applied in specified pots soon after sowing. Maize seeds were grown in pots for 15 days. The number of seedlings which emerged was counted on a daily basis in each pot during the entire duration of the study to determine the germination rate and emergence

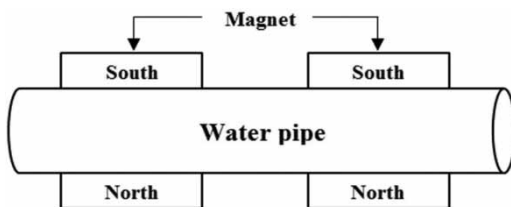


Figure 1 | Schematic design of magnetic device.

Table 2 | Effects of magnetic treatment on EC, pH, N, P, K, Ca and Mg concentration in different water salinity

Water quality	EC (ds/m)		pH		N (mg/l)		P (mg/l)		K (mg/l)		Ca (mg/l)		Mg (mg/l)	
	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>	M <sub>2</sub>	M <sub>1</sub>
S <sub>1</sub>	0.51	0.52	7.1	6.85	0.25	0.27	0.048	0.049	2.19	2.13	0.84	0.91	0.73	0.78
S <sub>2</sub>	2	2.03	7.6	7.2	0.274	0.297	0.053	0.056	2.43	2.43	1.12	1.16	1.26	1.3
S <sub>3</sub>	4	4.05	7.9	7.1	0.288	0.310	0.056	0.058	2.56	2.56	1.46	1.49	2.09	2.17
S <sub>4</sub>	6	5.96	8.3	7.5	0.317	0.331	0.057	0.059	2.64	2.64	2.08	2.14	3.12	3.23

M<sub>2</sub>: non-magnetized; M<sub>1</sub>: magnetized.

percentage. The emergence of seedlings was completed within 15 days of sowing.

### Seedling emergence indices

Some seedling emergence indices were analyzed to evaluate the effectiveness of magnetized water on maize seeds, i.e. emergence index (EI), germination rate, emergence rate index (ERI), seedling height and weight, final emergence percentage (FEP), and mean emergence time (MET). These indices are presented below.

### Final emergence percentage

FEP was estimated after 15 days at the end of the experiment using Equation (1).

$$\text{FEP} = \frac{\text{Total number of seedlings emerged in 15 DAP}}{\text{Total number of seeds planted}} \times 100 \quad (1)$$

where DAP is days after planting.

### Mean emergence time

MET is presented in Equation (2) according to Ellis & Roberts (1981).

$$\text{MET} = \frac{\sum D_n}{\sum n} \quad (2)$$

where  $D$  = number of days counted from the beginning of emergence,  $n$  = number of seeds emerged on day  $D$ .

## Emergence index

Speed of germination index was calculated using Equation (3) as described by association of official seed analysis (AOSA) (1983):

$$EI = \frac{N_{es}}{D_{first\ count}} + \dots + \frac{N_{es}}{D_{final\ count}} \quad (3)$$

where  $N_{es}$  is the number of emerged seeds and  $D$  is days.

## Emergence rate index

Emerged seeds were counted daily and used to calculate ERI using Equation (4).

$$ERI = \sum_{nf}^{nl} \frac{[\%_0n - \%_0(n-1)]}{n} \quad (4)$$

where  $\%_0n$  = percent of plants emerged on day  $n$ ;  $\%_0(n-1)$  = percent of plants emerged on day  $n-1$ ;  $n$  = number of days after planting;  $f$  = first day any plants emerged,  $l$  = last counting day (emergence complete).

## RESULTS AND DISCUSSION

### Soil properties at the end of the experiment

The results showed that the magnetic treatment of all types of water led to no significant difference on the soil EC

values, but the magnetic treatment of all irrigation water varied significantly and affected soil pH at the end of the experiment (Table 3). Also, soil pH decreased with magnetically treated different saline irrigation water. Furthermore, available soil N and P significantly increased with magnetic treatment when compared with the control (non-magnetized). However, the magnetic treatment of the control ( $S_1$ : tap water) had no significant effect on the values for available soil N and P (Table 3). One explanation for this is that, magnetic treatment of water may be affecting desorption of N and P from soil adsorbed P on the colloidal complex, thus increasing its availability to plants, and thus resulting in an improved plant growth. Noran *et al.* (1996) observed differences in the concentrations of N, P, K and Ca + Mg in soil irrigated with magnetically treated water when compared to a control. Moreover, decrease of soil alkalinity, increase in mobile forms of fertilizers and earlier vegetation periods can be achieved with magnetized water treatment (Cakmak *et al.* 2009).

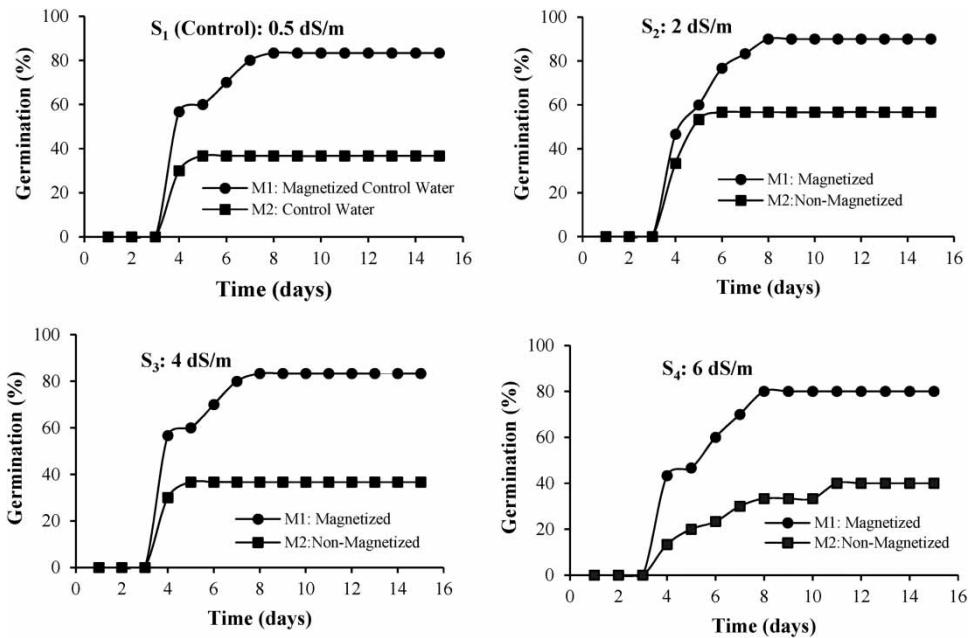
### Vegetative growth (germination rate)

Experiment results of maize seed germination with the application of different levels of magnetized saline water in contrast to non-magnetized saline water are shown in Figure 2. It was observed that seed germination started one to two days earlier with the application of magnetized water as compared to non-magnetized water for all treatments. The highest percent germination occurred after 6 to 8 days and remained constant onward (Figure 2). Results

**Table 3** | Effects of magnetic treatment on mean values of soil EC, pH, N, P, K at the end of the experiment

Water quality	EC (dS/m)			pH			N (mg/kg)			P (mg/kg)		
	M <sub>2</sub>	M <sub>1</sub>	Mean	M <sub>2</sub>	M <sub>1</sub>	Mean	M <sub>2</sub>	M <sub>1</sub>	Mean	M <sub>2</sub>	M <sub>1</sub>	Mean
S <sub>1</sub>	0.65	0.66	0.655	7.18	7.05	7.105	0.87	0.88	0.875	18.31	18.29	18.3
S <sub>2</sub>	0.98	1.03	1.005	7.72	7.35	7.535	1.02	0.94	0.98	18.84	20.17	19.505
S <sub>3</sub>	1.51	1.53	1.52	7.51	7.28	7.395	1.14	1.17	1.155	19.27	22.33	20.785
S <sub>4</sub>	2.26	2.21	2.235	7.87	7.39	7.63	0.79	0.81	0.80	20.40	23.61	22.0
Mean	1.35	1.36	1.345	7.57	7.26	7.42	0.95	0.96	0.95	19.21	21.1	20.148
LSD 0.05 water		0.08			0.09			0.04			0.64	
LSD 0.05 magnetic		NS			0.07			NS			0.41	
LSD 0.05 water × magnetic		0.11			0.13			NS			0.93	

M<sub>2</sub>: non-magnetized; M<sub>1</sub>: Magnetized; LSD: Least significant difference; NS: Not significant.

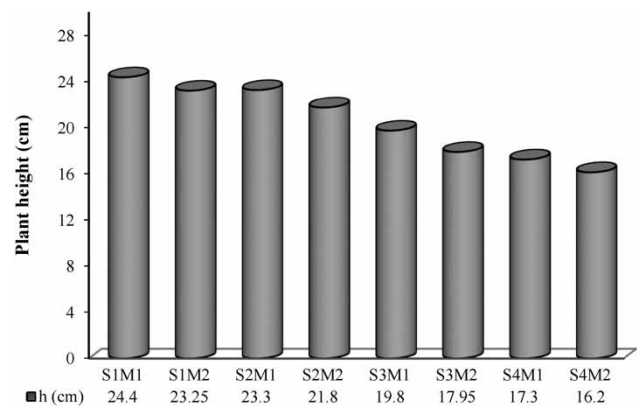


**Figure 2** | Percent germination of maize seeds under different magnetized and non-magnetized tap water and different levels of saline water.

revealed that overall germination rate was higher with all treatments of magnetized water in comparison with non-magnetized water. Results are in agreement with the germination data of maize seeds obtained by Mahmood & Usman (2014) that marked the positive effect of magnetic treatment on the germination and emergence of maize seeds in sand culture. The higher germination rate may be due to the effect of the magnetic treatment on the amount and rate of water absorption in the maize seed compared with the non-magnetized water. A magnetic field induces changes in ionic concentration and osmotic pressure, which regulates the entrance of water into the seeds. These positive effects of magnetic treatment may be due to some alterations within plant systematic biochemical levels and their possible effects at cell level and are mainly due to increased water content. External electric and magnetic fields have been reported to influence both the activation of ions and polarization of dipoles in living cells (Moon & Chung 2000).

### Seedling height and weight

The average height of the maize seedlings measured after 15 days is presented in Figure 3. With the application of magnetized water, the maize seedling grew taller and heavier as compared



**Figure 3** | Maize height when subjected to varying magnetized (M<sub>1</sub>) and non-magnetized (M<sub>2</sub>) levels of saline water compared to the control treatment (tap water).

to non-magnetized treatments. The results of Table 4 show increases of 13.95, 10.61, 9.76 and 9.33% in seedling weight with magnetized tap water (S<sub>1</sub>), S<sub>2</sub>, S<sub>3</sub> and S<sub>4</sub>, in comparison to the non-magnetized water.

This increase in seedling height and weight may be due to earlier emergence of maize seedlings irrigated with magnetized water in contrast to the control (S<sub>1</sub>) and, as a result, seedlings had two to three more days for growth compared with the control treatment. Seedling emergence indices were examined including EI, FEP, ERI and MET.

**Table 4** | Maize seedling weight when subjected to varying magnetized (M<sub>1</sub>) and non-magnetized (M<sub>2</sub>) levels of saline water compared to the control treatment (tap water)

Water salinity (dS/m)	Seedling growing parameters				
	Treatment	Fresh weight (g)		Dry weight (g)	
		Measured	Increase (%)	Measured	Increase (%)
S <sub>1</sub> : 0.5	M <sub>1</sub>	9.58	7.2	0.98	13.95
	M <sub>2</sub>	8.9		0.86	
S <sub>2</sub> : 2	M <sub>1</sub>	8.4	1.85	0.90	10.61
	M <sub>2</sub>	8.25		0.80	
S <sub>3</sub> : 4	M <sub>1</sub>	8.82	1.68	0.82	9.76
	M <sub>2</sub>	8.8		0.74	
S <sub>4</sub> : 6	M <sub>1</sub>	6.66	2.48	0.75	9.33
	M <sub>2</sub>	6.49		0.68	

Table 5 shows that the magnetized waters have potential for MET reduction and rapid emergence for maize seeds (Table 5). It was observed that magnetically treated water had significant effects on emergence indicators for various water types. FEP with magnetically treated canal water was less as compared to the control, whereas magnetized tap water had no effect on FEP (Mahmood & Usman 2014). Higher values of EI and ERI symbolized uniform and quick emergence. Results reported in Table 5 substantiate the significant increase in EI and ERI that clearly indicate rapid and uniform seed emergence. ERI increased from 7.6 to 10.2, 9.1 to 11.1, 10.3 to 13.3, and 11.8 to 13.3, whereas EI increased from 4.75 to 5.26, 5.1 to 5.66, 5.78 to 6.4, and 6.1 to 7.3 with magnetically treated tap water (S<sub>1</sub>), S<sub>2</sub>: (2 dS/m), S<sub>3</sub>: (4 dS/m), and S<sub>4</sub>: (6 dS/m), respectively. Also, MET index data implying the time required for emergence is presented in Table 5. Higher MET values indicate more time required for seed emergence. The application of magnetic treatment to water of different salinity levels for maize seed irrigation has significant results on MET (Table 5). Magnetically treated water reduced the MET from 5.7 to 5.3, 6.6 to 5.9, 8.3 to 7.6 and from 8.4 to 7.2 for tap, S<sub>2</sub>, S<sub>3</sub>, and S<sub>4</sub>, respectively. Present findings are in agreement with Mahmood & Usman (2014) who reported the beneficial effects of magnetic treatment on maize seed germination in which MET was reduced by 17.90% for magnetized sewerage water in contrast to

**Table 5** | Effect of different irrigation waters on the seedling emergence indicators

Irrigation water salinity (dS/m)	Treatment	Seedling emergence indicators			
		MET (days)	EI	FEP (%)	ERI
S <sub>1</sub> : 0.5	M <sub>1</sub>	5.3	4.75	100	7.6
	M <sub>2</sub>	5.7	5.26	95	10.2
S <sub>2</sub> : 2	M <sub>1</sub>	5.9	5.1	90	9.1
	M <sub>2</sub>	6.6	5.66	56	11.1
S <sub>3</sub> : 4	M <sub>1</sub>	7.6	5.78	83	10.3
	M <sub>2</sub>	8.3	6.4	46.5	13.3
S <sub>4</sub> : 6	M <sub>1</sub>	8.4	6.1	70	11.8
	M <sub>2</sub>	7.2	7.3	40	15.2

non-magnetized. Smirnov (2003) indicted that water can receive signals produced from magnetic forces that have a direct effect on living cells and their vital action. Table 3 presents the percent increase or decrease due to the application of magnetized water compared with control water. Furthermore, FEP increased from 40% to 70% in S<sub>4</sub>M<sub>2</sub> treatment in comparison with S<sub>4</sub>M<sub>1</sub> treatment. Overall, it is concluded that magnetic treatment of saline water had beneficial effects.

Irrigation with magnetically treated water may be responsible for activation of enzymes and hormones involved in the germination process and mobilization of nutrients. As a result, there is probably an enhancement in the mobilization and transportation of nutrients to the embryonic axis and a resultant increase in speed of emergence and germination rate of maize seedlings.

## CONCLUSIONS

Results of the experiment revealed some beneficial effects of magnetically treated water for maize seed germination. Irrigation with magnetically treated water increased the vegetative growth of maize seeds in all treatments. Application of magnetized saline water for maize seed emergence reduced the MET as compared with non-magnetized water. Although magnetic water treatment is an environmentally friendly technique and easy to handle, further research is required to understand the ambiguous mechanism of the magnetic field in order to turn it into a technology for sustainable farming.



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