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Effect of Magnetic Treatment of Water or Seeds on Germination and Productivity of Tomato Plants under Salinity Stress

Nezar Husein Samarah *, Mu'awia Muhsen Ibrahim Bany Hani and Ibrahim Mahmoud Makhadmeh

Department of Plant Production, Faculty of Agriculture, Jordan University of Science and Technology, P.O. Box 3030, Irbid 22110, Jordan; mmbanyhani@just.edu.jo (M.M.I.B.H.); ibrahimm@just.edu.jo (I.M.M.)
* Correspondence: nsamarah@just.edu.jo

Abstract: Salinity is an abiotic stress that reduces the seed germination and productivity of tomatoes. Magnetic treatment has been shown to have a positive effect on the seed germination, seedling growth, and productivity of various crop species. Therefore, three experiments were conducted to evaluate whether treating saline water or seeds with a magnetic field can improve the seed germination and productivity of tomatoes (*Solanum lycopersicum*) under salinity stress. To evaluate seed germination and seedling growth in response to a magnetic field, two laboratory experiments were carried out by passing four saline water solutions of NaCl (0, 5, 10, and 15 dS/m) through a magnetic field (3.5–136 mT) or exposing tomato seeds to the same magnetic field for 20 min before sowing. In a greenhouse experiment, plants were irrigated with different magnetically-treated and untreated saline water solutions to evaluate plant growth. Magnetic treatment of water or seeds improved seed germination percentage, speed of germination (lower mean time to germination), and seedling length and dry weight in the two laboratory experiments, especially under salinity stress of 5 and 10 dS/m. As the salinity level increased, germination performance and plant growth were significantly decreased. Irrigating tomato plants with magnetically-treated water improved plant height, stem diameter, and fruit yield per plant compared to untreated water, especially under salinity of 0 and 5 dS/m. In conclusion, magnetic treatment of saline water or seeds improved germination performance, plant growth, and fruit yield of tomatoes under saline conditions.

Keywords: salinity; NaCl; magnetic field; seed germination; fruit yield

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1. Introduction

The tomato is an important and strategic crop grown in Jordan under irrigation, where the poor quantity and quality of irrigation water may negatively affect seed performance and crop productivity [1]. Magnetic treatment has been proposed to have a positive effect on the seed germination, seedling growth, and productivity of various crop species [2–4]. Magnetic treatment is defined as passing water through or exposure of seeds to a magnetic field [5].

Many researchers have reported that a magnetic field applied to either the seeds or the water improved the seed germination and seedling growth of crop species [6,7]. Magnetic treatment of seeds had a positive effect on the seed germination, seedling growth and reproduction, and growth of meristem cells [2,8]. Studies carried out with tomato (*Solanum lycopersicum*) [3,5], cucumber (*Cucumis sativus*) [9,10], and sunflower (*Helianthus annuus*) [11] have shown that there was an enhancement of germination and plant growth when irrigation water or planted seeds were exposed to a magnetic field. Magnetic treatment had a positive effect on seedling length, dry weight, and seedling vigor [12]. There was an increase in seedling length after application of magnetically-treated irrigation water to the seedlings of chickpea (*Cicer arietinum* L.), where the lengths of the seedlings irrigated with magnetically-treated water 18 d after sowing were taller by 2.67 cm than seedlings irrigated with untreated tap water [13]. Other studies have shown that magnetic treatment improved the quantity and quality of sunflowers [14]. Irrigation with magnetically-treated water improved the productivity of various crops such as apricot (*Prunus armeniaca*), peach (*Prunus persica*), flame seedless grape (*Vitis vinifera*), and Thompson seedless grape (*Vitis vinifera*) as compared to those irrigated with untreated water [15].

To our knowledge, not much information is available about the effect of magnetization of seeds or water on the ability of tomato seeds to germinate under different salinity levels. More research is also needed to test whether irrigating tomato plants with magnetically-treated saline solutions may improve plant growth and productivity under greenhouse conditions. Therefore, the objective of this study was to evaluate whether treating saline water or seeds with a magnetic field improved seed germination percentage, mean time to germination, seedling growth, plant growth and development, and fruit number and yield of tomato.

2. Materials and Methods

2.1. Plant Materials and Magnetic Treatment

Tomato seeds (*Solanum lycopersicum* cv. Thuraya) were used in this study. 'Thuraya' is a determinate F1 hybrid variety, medium to late in maturity (requiring 80–90 days after transplanting). Seeds were obtained from Trust Seeds Co. Ltd. Jordan. The seeds were stored at 5 °C until experimentation. A magnetic device (Omni Environmental Group, Sydney, Australia) was used to treat water or seeds with a stationary magnetic field. The magnetic induction of the device was in a range of 3.5–136 mT. The magnetic device for treating water or seeds consists of a 100 mm long polycarbonate pipe with an internal diameter of 22 mm. It contains two permanent magnets that are 50 mm in length, separated by a distance of 24 mm. A static nonuniform magnetic field was generated between the two permanent magnets.

2.2. Magnetic Treatment of Saline Water and Seed Germination

Two laboratory experiments were conducted in the Seed Science and Technology Lab at Jordan University of Science and Technology, Irbid, Jordan, to study the effect of treating saline water or seeds with a magnetic field on seed germination percentage, mean time to germination, seedling fresh and dry weight, and seedling and shoot length. Four concentrations of saline solutions (0, 5, 10, and 15 dS/m) were prepared by mixing sodium chloride (NaCl) (Fisher Scientific UK Ltd., Loughborough, UK) with distilled water to reach the targeted electrical conductivity, which was measured by using an electrical conductivity meter (Cyberscan 510, International Trade Links Instrumentation Pvt. Ltd., Singapore, Malaysia).

In the first experiment, saline water solutions of 0, 5, 10, or 15 dS/m were either exposed to a magnetic field by passing the solutions through a magnetic device or left untreated. The magnetically-treated and untreated saline solutions were used to study the effect of salinity and magnetic treatments on seed germination of tomato. The standard seed germination test was conducted for tomatoes as described by the International Seed Testing Association (ISTA) [16]. Four replicates of 50 seeds were placed on three layers of filter papers in 12 cm glass Petri dishes. The germination papers were moistened with 8 mL of different magnetically-treated and untreated saline solutions (0, 5, 10, and 15 dS/m). The Petri dishes were covered with lids, enclosed in plastic bags, and distributed randomly inside an incubator set at 25 °C for 11 days. Seeds with radicle protrusions were counted on 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11 days after planting to calculate mean time to germination using the following Equation (1):

$$\mathrm{MTG} = \sum(\mathrm{ni} \times \mathrm{ti}) / \sum \mathrm{ni}, \quad (1)$$

where ni is the number of seeds with radicle protrusion at time ti, ti is the number of days from the beginning of germination, and Σ ni is the total number of germinated seeds. At the end of the germination test (11 d after planting), the final germination percentage was calculated, and seedling fresh and dry weight, seedling length, and shoot length were measured.

In the second experiment, tomato seeds were either treated with a magnetic field by placing them inside a magnetic device for 20 min or left untreated. The magnetically-treated and untreated seeds were evaluated under different salinity levels (0, 5, 10, and 15 dS/m). A seed standard germination test was conducted for the tomato seeds as described by the International Seed Testing Association [16].

2.3. Magnetic Treatment of Water and Plant Performance under Salinity

Tomato seeds were planted in polystyrene trays filled with peat moss and perlite at a ratio of 2:1 at a vegetable nursery, Jordan Valley, Jordan. After 33 days, young seedlings were transplanted into plastic pots (30 cm in diameter, and a 25 cm depth) filled with a mixture of 2:1 of peat moss and perlite at a rate of one seedling per pot. Experiments were performed as a split-plot arrangement in a randomized complete block design (RCBD) with four blocks, 4×4 rows in each block, and two pots for each treatment. The plants were irrigated using 8 different treatment combinations (magnetically-treated and untreated saline (NaCl) solutions of 0, 5, 10, and 15 dS/m). Pest and weed control and fertilizer application were performed following the recommended practices for commercially-grown tomatoes and as needed throughout the experiment.

Electrical conductivity (EC) and pH of irrigation water were measured before and after magnetic treatments.

2.4. Growing Medium Measurements

Growing medium EC and pH were measured at 72 days after transplanting (at the end of the experiment) for a 1:5 growing medium: water suspension by weighing 10 g air-dried growing medium from each pot in a glass beaker and adding 50 mL distilled water using a graduated cylinder. Then, the suspension was mixed well for 30 min to dissolve soluble salts. After 30 min, the pH for the mixture was recorded by putting a pH probe inside the mixture. The water solution was collected from the mixture by filtration to measure EC. The probes of the pH and EC electrodes were rinsed thoroughly before and after each measurement of the samples using distilled water.

2.5. Plant Growth Measurements

Plant measurements were taken during and at the end of the growing season including plant height, stem diameter, shoot fresh weight and dry weight, and crop yield per plant (fruit number and fresh weight). Plant height was measured from the base of the plant to the growing tip, and the average of two plants was taken for each treatment at 10, 17, 24, 30, 37, 43, 50, 57, 64, and 72 d after transplanting. Plant diameter was measured for the plants at the end of growing season using a caliper to measure the average of tip, mid, and crown diameters from each plant and reported as an average of two plants per treatment per replicate. Shoot fresh and dry weight were taken at the end of the growing season by cutting the plants from the base and weighing them before and after oven-drying at 75 °C for 48 h. Fruit number and fresh weight were measured for fruits harvested throughout the experiment.

2.6. Statistical Analysis

For each laboratory experiment, data were statistically analyzed using analysis of variance (ANOVA) of two-factor factorial in a completely randomized design using JUMP software. In the greenhouse experiment, data were analyzed as a split-plot arrangement in a randomized complete block design with 4 replications. Probabilities of significance among treatments and their interactions and Student's *t*-test ($p \leq 0.05$) were used to compare means within and among treatments in the laboratory experiments. The Least Significant Difference (LSD) at $p \leq 0.05$ was used to compare the means of plant height among salinity or magnetic treatments at each sample date in the greenhouse experiment.

3. Results

3.1. Magnetic Treatment of Water and Seed Germination under Salinity

Seed germination percentage, mean time to germination, seedling fresh weight, seedling dry weight, seedling length, and shoot length in standard germination exhibited significant responses to treatment combinations of different salinity levels and magnetic field treatments. The highest germination percentage was 94% in magnetically-treated water and zero salinity with no significant difference from untreated water (90%) and magnetically-treated water at 5 dS/m salinity (91%). On the other hand, the lowest germination percentage was 69% in the untreated 15 dS/m salinity water. However, the magnetically-treated 15 dS/m treatment combination had a higher germination percentage (77%) compared with untreated at same level of salinity (Table 1). Generally, seeds incubated with magnetically-treated water had a higher average germination percentage (88%) than those incubated with untreated water (80%). In addition, germination percentage decreased in response to increasing salinity level.

Table 1. Effect of magnetically-treated water at different levels of water salinity on tomato seed germination percentage, mean time to germination, seedling fresh weight, seedling dry weight, seedling length, and shoot length in a standard germination test at 25 °C.

Salinity Level	Magnetic Treatment	GP [z]	MTG	Trait FW	DW	SL	SHL
dS/m		**(%)**	**(Days)**	**(mg/Seedling)**	**(mg/Seedling)**	**(cm)**	**(cm)**
0	Untreated	90 ab [y]	3.7 f	1465 a	45 a	16.2 b	8.9 bc
	Magnetically-treated	94 a	3.1 g	1561 a	47 a	18.0 a	10.1 a
5	Untreated	81 c	4.9 e	1669 a	23 c	15.4 b	8.5 c
	Magnetically-treated	91 ab	3.7 f	1521 a	30 b	15.0 b	9.7 ab
10	Untreated	80 c	6.5 c	972 b	16 d	9.2 d	5.2 e
	Magnetically-treated	88 b	5.9 d	1072 b	29 b	12.6 c	7.2 d
15	Untreated	69 d	9.0 a	488 c	9 e	3.8 e	2.0 f
	Magnetically-treated	77 c	8.4 b	476 c	13 ed	4.7 e	2.8 f
Main Effects							
0		92 a	3.4 d	1513 a	46 a	17.1 a	9.5 a
5		86 b	4.3 c	1595 a	26 b	15.2 b	9.1 a
10		84 b	6.2 b	1022 b	23 b	10.9 c	6.2 b
15		73 c	8.7 a	482 c	11 c	4.2 d	2.4 c
Untreated		80 b	6.0 a	1149 a	23 b	11.2 b	6.1 b
Magnetically-treated		88 a	5.3 b	1158 a	29 a	12.6 a	7.4 a

[z] GP: Seed germination percentage; MTG: Mean time to germination; FW: Seedling fresh weight; DW: Seedling dry weight; SL: Seedling length; SHL: Seedling shoot length. [y] Means followed by same letters are not significantly different at $p \leq 0.05$ according to Student's *t*-test.

The effects of magnetic treatment of water and salinity level on mean time to germination (MTG) was shown for both factors. Magnetic treatment of water significantly accelerated germination by decreasing MTG (faster germination) at all levels of salinity compared to untreated water (Table 1).

There was no significant difference in seedling fresh weight between seeds incubated with magnetically-treated water and untreated water (Table 2). For seedling dry weight, there was an interaction between the magnetic treatment of water and salinity level. There was no significant difference in seedling dry weight between seeds incubated with magnetically-treated and untreated water at 0 dS/m, while the difference was significant at 5, 10, and 15 dS/m.

Table 2. Seed germination percentage, mean time to germination, seedling fresh weight, seedling dry weight, seedling length, and shoot length in a standard germination test at 25 °C of magnetically-treated tomato seeds watered with different levels of salinity.

Salinity Level	Magnetic Treatment	GP [z]	MTG	Trait FW	DW	SL	SHL
dS/m		(%)	(Days)	(mg/Seedling)	(mg/Seedling)	(cm)	(cm)
0	Untreated	87 ab [y]	4.0 f	1215 b	67 b	15.2 a	7.8 bc
	Magnetically-treated	91 a	2.8 g	1324 b	93 a	15.8 a	8.7 b
5	Untreated	82 b	5.0 e	1636 a	63 b	16.0 a	8.9 ab
	Magnetically-treated	91 a	3.6 f	1581 a	84 a	16.6 a	9.9 a
10	Untreated	72 c	6.8 c	966 c	35 c	11.0 b	5.7 d
	Magnetically-treated	85 ab	5.7 d	976 c	62 b	12.3 b	6.7 cd
15	Untreated	56 d	9.6 a	423 d	39 c	3.1 d	1.5 f
	Magnetically-treated	73 c	9.0 b	336 d	29 c	6.3 c	3.0 e
Main Effects							
0		89 a	3.4 d	1269 b	80 a	15.5 a	8.2 b
5		86 a	4.3 c	1608 a	73 a	16.3 a	9.4 a
10		78 b	6.2 b	971 c	48 b	11.6 b	6.2 c
15		64 c	9.3 a	379 d	34 c	4.7 c	2.3 d
Untreated		74 b	6.3 a	1060 a	51 b	11.3 b	5.9 b
Magnetically-treated		85 a	5.3 b	1054 a	67 a	12.8 a	7.1 a

[z] GP: Seed germination percentage; MTG: Mean time to germination; FW: Seedling fresh weight; DW: Seedling dry weight; SL: Seedling length; SHL: Seedling shoot length. [y] Means followed by same letters are not significantly different at $p \leq 0.05$ according to Student's *t*-test.

For seedling length, there was a significant response with respect to the interaction between magnetic treatment of water and salinity levels. The seedling length of seeds germinated in magnetically-treated water was higher than those germinated in untreated water at 0 and 10 dS/m, while the difference was not significant at 5 or 15 dS/m.

Shoot length was significantly increased when seeds were moistened with magnetically-treated water (7.4 cm) compared to seeds moistened with untreated water (6.1 cm) (Table 1).

3.2. Magnetic Treatment of Seeds and Seed Germination under Salinity

When seeds were exposed to a magnetic field before incubating them in the standard germination test at 25 °C on filter paper moistened with water with different levels of salinity, seed germination percentage was significantly increased by the magnetic treatment for the seeds at 5, 10, or 15 dS/m compared to untreated seeds. However, treating seeds with a magnetic device had no significant effect on seed germination percentage (91%) compared to untreated seeds (87%) (Table 2). The reduction in germination percentage was more pronounced for seeds germinated under saline conditions without exposure to a magnetic field, compared to seeds exposed to a magnetic field.

Magnetic treatment of seeds significantly reduced the mean time to germination (MGT) at 25 °C compared to untreated seeds at 5 and 10 dS/m, but the difference was not significant at 0 or 15 dS/m. Seedling fresh weight was not significantly different between magnetically-treated (1060 mg/seedling) and untreated seeds (1054 mg/seedling).

For seedling dry weight, the effects of magnetic treatment and salinity level were significant. The seedling dry weight was significantly increased when seeds were treated with a magnetic device before incubating them with 0, 5, or 10 dS/m saline solutions compared to untreated seeds, whereas at 15 dS/m, magnetic treatment of seeds did not affect seedling dry weight.

Seedling length increased significantly in response to magnetic treatment of seeds (12.8 cm/seedling) compared to untreated seeds (11.3 cm/seedling).

Seedling shoot length was significantly increased when seeds were exposed to a magnetic field (7.1 cm) compared to untreated seeds (5.9 cm). The shoot length was 7.1 cm/seedling for treated seeds and 5.9 cm/seedling for untreated seeds. The greatest shoot length was 9.4 cm/seedling at 5 dS/m, while the lowest shoot length was 2.3 cm/seedling at 15 dS/m (Table 2).

3.3. Salinity Level and Seed Germination

Regardless of magnetic treatments (water or seeds), the increase in salinity level resulted in significant decreases in seed germination percentage, seedling fresh and dry weight, and seedling and shoot length, and increased MTG (the slower speed of germination). The maximum seed germination and seedling growth were at 0 dS/m, except for shoot length at 5 dS/m, while the minimum was at 15 dS/m.

3.4. Magnetic Treatment of Water and Plant Growth and Yield under Salinity

Plant height was significantly increased when plants were irrigated with magnetically-treated water compared to plants irrigated with untreated water, except for plants measured at days 17 and 24 after transplanting (Figure 1b). The salinity level of the irrigation water had no effect on plant height when plants were measured at days 10, 17, 24, and 30 (Figure 1a). At days 37, 43, and 50, plant height was significantly affected only when plants were irrigated with the highest level of salinity (15 ds m/m). At days 57, 64, and 72, a significantly lower increase in plant height was noticed as the salinity level of irrigation water was increased (Figure 1).

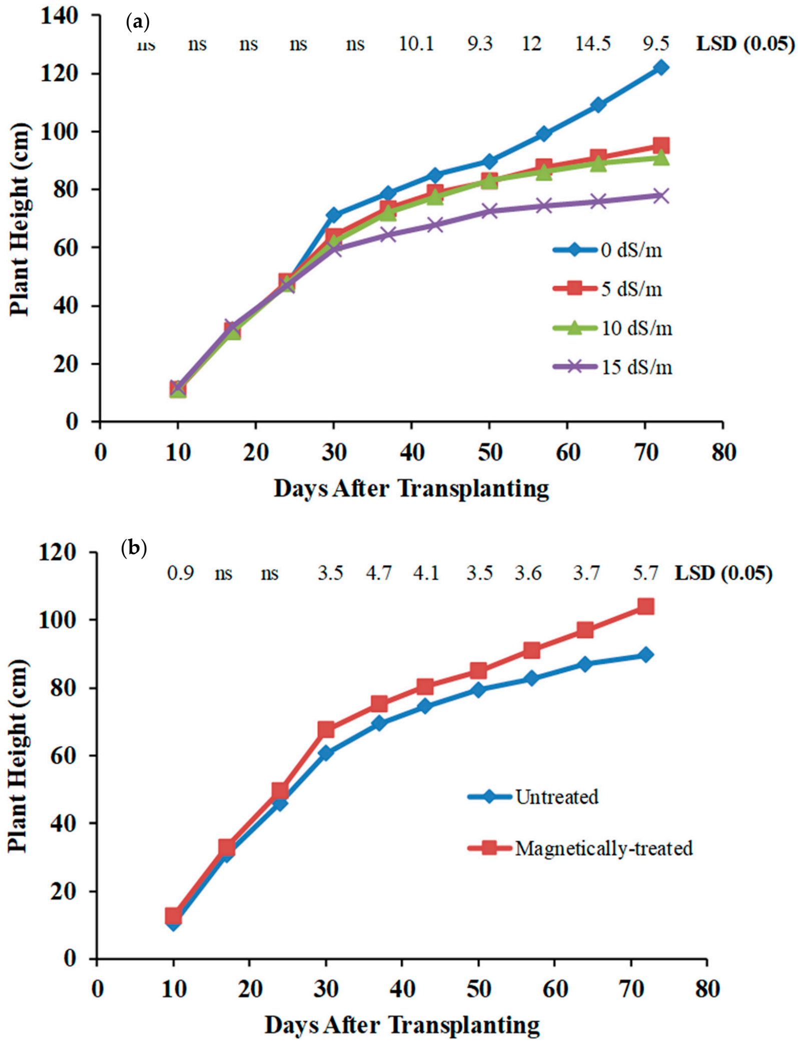

Figure 1. Plant height at different days after transplanting for tomato grown under four levels of salinity (**a**) and for plants grown under magnetically-treated and untreated water (**b**). Numbers at the top of the figures represent the LSD value at $p < 0.05$.

Significant increases in plant stem diameter resulted when irrigating plants with magnetically-treated water (6.9 mm) compared to control plants (5.6 mm) (Table 3). As the salinity level of the irrigation water increased, plant stem diameter at the end of the growing season significantly decreased. The greatest plant stem diameter (8.3 mm) was recorded for the plants irrigated with distilled water (0 dS/m), while the lowest plant stem diameter (4.3 mm) was recorded for the plants irrigated with the highest saline water (15 dS/m) (Table 3).

Table 3. Plant stem diameter, plant fresh and dry weight, fruit number, and fruit yield of tomato plants irrigated with magnetically-treated water at different salinity levels in a greenhouse experiment.

Salinity Level	Magnetic Treatment	Stem Diameter	Plant Fresh Weight	Plant Dry Weight	Fruit Number	Fruit Yield
dS/m		(mm)	(g/Plant)	(g/Plant)	(Number)	(g/Plant)
0	Untreated	7.3 b [z]	231.9 b	68.9 b	14 ab	1603 b
	Magnetically-treated	9.3 a	295.7 a	77.8 a	19 a	2324 a
5	Untreated	6.3 c	110.1 d	32.7 d	12 b	701 c
	Magnetically-treated	7.3 b	169.9 c	39.9 c	15 ab	1106 c
10	Untreated	5.0 d	96.3 de	26.2 de	12 b	321 d
	Magnetically-treated	6.0 c	98.2 de	31.4 cd	11 b	326 d
15	Untreated	3.8 e	52.2 e	17.1 e	10 b	216 d
	Magnetically-treated	5.0 d	61.4 de	19.0 e	9 b	201 d
	Main Effect					
0		8.3 a	263.8 a	73.4 a	17 a	1964 a
5		6.8 b	140.0 b	36.3 b	14 ab	904 b
10		5.5 c	97.2 bc	28.8 bc	12 bc	323 c
15		4.3 d	56.8 c	18.0 c	10 c	208 c
	Untreated	5.6 b	122.6 b	36.2 b	13 a	710 b
	Magnetically-treated	6.9 a	156.3 a	42.1 a	14 a	989 a

[z] Means followed by same letters are not significantly different ($p \leq 0.05$) according to Student's *t*-test.

Plant fresh and dry weights were significantly increased ($p \leq 0.05$) when plants were irrigated with magnetically-treated water (156.3 g and 42.1 g) compared to plants irrigated with untreated water (122.6 g and 36.2 g), respectively (Table 3). The increase in the salinity level of the irrigation water significantly decreased ($p \leq 0.05$) plant fresh and dry weight from 263.8 g and 73.4 g at 0 dS/m to 56.8 g and 18 g at 15 dS/m (Table 3).

For the fruit number per plant, there was no significant difference ($p \leq 0.05$) in fruit number per plant for the plants irrigated with magnetically-treated water compared to those irrigated with untreated water. Both treatments had an average of 14 fruits/plant. The increase in the salinity level of the irrigation water significantly decreased ($p \leq 0.05$) the fruit number per plant from the 17 fruits/plant at 0 dS/m to 10 fruits/plant at 15 dS/m (Table 3).

Plants irrigated with magnetically-treated water had significantly higher ($p \leq 0.05$) fruit yield (989 g/plant) than those irrigated with untreated water (710 g/plant). The increase in salinity level of irrigation water significantly decreased ($p \leq 0.05$) fruit yield from 1964 g/plant at 0 dS/m to 208 g/plant at 15 dS/m (Table 3).

3.5. Electrical Conductivity and pH of Growing Medium

Applying magnetically-treated water to the growing medium significantly reduced ($p \leq 0.05$) the electrical conductivity (EC) in the medium compared to untreated water (Table 4). The EC was 10.6 dS/m in medium irrigated with magnetically-treated water compared to 12.6 dS/m in medium irrigated with untreated water. The EC was significantly increased ($p \leq 0.05$) from 3.9 dS/m at a salinity level of 0 dS/m to 19.2 dS/m at a salinity level of 15 dS/m.

Table 4. The electrical conductivity and pH of the growing medium in the greenhouse experiment.

Salinity Level	Magnetic Treatment	EC [z]	pH
dS/m		dS/m	
0	Untreated	4.3 g [y]	5.6 b
	Magnetically-treated	3.3 h	5.7 ab
5	Untreated	10.6 e	5.8 ab
	Magnetically-treated	7.7 f	5.8 ab
10	Untreated	15.4 c	5.9 ab
	Magnetically-treated	13.1 d	5.7 ab
15	Untreated	20.4 a	5.9 a
	Magnetically-treated	18.0 b	5.8 ab
Main Effect			
0		3.8 d	5.7 a
5		9.0 c	5.6 a
10		14.2 b	5.7 a
15		19.1 a	5.9 a
	Untreated	12.6 a	5.8 a
	Magnetically-treated	10.6 b	5.8 a

[z] EC: Electrical conductivity of the growing medium. [y] Means followed by same letters are not significantly different ($p \leq 0.05$) according to Student's *t*-test.

For the pH of the growing medium, there was no significance when plants were irrigated with magnetically-treated water compared to untreated water (Table 4). Similarly, the pH of the growing medium was not significantly different among salinity levels.

4. Discussion

Many researchers have reported that salinity reduced seed germination performance, plant growth, and yield of many crop species [17,18]. In the present study, the increase in salinity level decreased seed germination percentage, speed of germination (higher MTG), seedling fresh and dry weight, and seedling length in two laboratory experiments and decreased plant height, fresh and dry weight, stem diameter, and fruit number and yield in a greenhouse experiment. The reduction in fruit yield under salinity (89%) was the highest, while the reduction in seed germination percentage (21–28%) was the lowest. The reduction in plant growth and yield under salinity could be due to osmotic stress (causing water deficit), ion toxicity, and/or inhibition of cell division [18]. Salinity resulted in greatly delayed seed germination by increasing MTG by 60–63% and significantly reduced seedling and plant growth by 48–78%. There was a significant reduction in tomato shoot fresh and dry weight [19] and stem and leaf dry weights [17] in response to salinity stress. The reduction in germination percentage and the delay in the speed of germination under salinity may be due to the osmotic stress of the high salt solutions, hindering water uptake by seeds [18]. Late-germinated imbibed seeds are likely susceptible to fungal infection and consequently may lose germination ability [20,21].

A technology of magnetization applied to either water or seeds has been shown to significantly improve seed germination, emergence, and plant growth of many species [2,3,7,22,23]. In the present study, a magnetic field was applied to water or seeds to study its effectiveness on seed germination and seedling growth under a range of salinity stress (0, 5, 10, and 15 dS/m) in two laboratory experiments and on plant growth and yield in a greenhouse experiment.

In the two laboratory experiments, application of a magnetic field to either water or seeds significantly improved germination percentage by 10–17% only under salinity stress, but was not significant under no salinity stress (0 dS/m). Regarding the speed of germination, magnetically-treated water or seeds reduced MTG by 9–30% (higher speed of germination) under salinity conditions of 0, 5, and 10 dS/m. Magnetizing water or seeds had little impact on MTG under severe salinity stress (15 dS/m). Magnetic treatment of water has increased seed germination percentage, seedling vigor index, speed of germination, and emergence rate index in many crop species [24–26]. Other researchers have also shown that magnetic treatment of seeds, rather than water, improved the seed germination and speed of germination of several crops [3,22,23,27,28]. The applied magnetic field to seeds may interact with ions in the cell membrane of the seed embryo, inducing osmotic pressure and ionic concentration on both sides of the membrane [29] or increase water uptake by seeds [30]. In the present study, the improvement in seed germination and speed of germination by magnetic treatment of water or seeds was more pronounced under salinity stress.

Magnetic treatment of water or seeds had an inconsistent effect on seedling fresh weight but significantly improved seedling dry weight under salinity levels of 5 and 10 dS/m. Neither treatment had an effect at the highest salinity level (15 dS/m). Similarly, magnetic field application to water or seeds had a positive effect on the seedling length and shoot length only under salinity levels of 10 or 15 dS/m. Other researchers found that magnetically-treated water increased seedling length compared with untreated water [12,13]. Magnetic treatment of seeds also increased seedling fresh and dry weight [31], stimulated dry matter production and improved its partitioning [32], and increased seedling length and dry weight of chickpea [33]. The results of the present study indicated that magnetization of water or seeds had a greater impact under salinity stress.

In the greenhouse experiment, irrigating tomato plants with magnetically-treated water improved plant growth and yield. Plants irrigated with magnetically-treated water grew taller than those irrigated with untreated water when plants were sampled at 30, 37, 43, 50, 57, 63, and 72 d after transplanting, averaged over all levels of salinity. Similarly, the height of tomato plants irrigated with magnetically-treated water was significantly higher than plants irrigated with untreated water [34]. Using magnetized irrigation water also improved plant stem diameter and plant fresh and dry weight. These results were in agreement with previous studies on different crops such as lentil [2], snow pea and chickpea [25], and tomato [35], showing an increase in fresh and dry weight of plants irrigated with magnetized water. Treating irrigation water with a magnetic field improved the vegetative growth [5] and resulted in taller and heavier plants and increased the yield and yield components of several crops [36]. Using magnetically-treated irrigation water did not significantly change fruit number. However, irrigating plants with magnetically-treated water improved fruit yield only under 0 and 5 dS/m salinity, but had no significant effect under high salinity stress (10 and 15 dS/m). These results indicated that the magnetization of water can be an effective technique to improve the yield of crops irrigated with zero or moderately saline water and can be an effective method to alleviate the negative impact of saline irrigation water on crop productivity. The irrigation water and extensive use of fertilizers are major causes of land salinization and degradation in the arid and semiarid region of Jordan, where vegetable crops are grown under irrigation [37,38].

5. Conclusions

Salinity stress reduced seed germination, speed of germination, and all parameters of plant growth and fruit yield of tomatoes. The speed of germination, seedling and plant growth, and fruit yield had the highest reduction under salinity, while seed germination percentage had the lowest reduction. Magnetic treatment of water or seeds improved seed germination percentage, speed of germination, and seedling growth in two laboratory experiments, especially under salinity stress of 5 and 10 dS/m. Magnetic treatment of water or seeds were effective methods to enhance the seed germination of tomatoes. In the greenhouse experiment, magnetic treatment of water was effective in improving fruit yield only under zero or moderate salinity stress.

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