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ORIGINAL ARTICLE

Enhanced nutrient uptake in salt-stressed *Mentha piperita* using magnetically treated water

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Abstract

The improvement of the growth and quality of medicinal plants under stress is of significance, worldwide. The hypothesis was to alleviate salinity stress in *Mentha piperita* by enhancing nutrient uptake using magnetically treated water, which to our knowledge has not been previously investigated. The objective was to test the effects of magnetized water (using alternating magnetic fields) (main plots, M1-M4 representing control, 100, 200, and 300 mT, respectively), salinity (subplots, S1-S4 representing control, 40, 80, and 120 mM NaCl, respectively), and growth medium (sub-subplots, X1-X4 representing coco peat, palm, coco peat + perlite, and palm + perlite, respectively) on *M. piperita* nutrient uptake in the greenhouse. The M treatments, especially the 100 and 200 mT levels, significantly increased plant N (1.08%, S3M4X1), P (0.89%, S3M3X1), K (3.23%, S3M3X1), Ca (53.6 mg/kg, S4M4X4), and Mg (39.63 mg/kg, S3M3X2) concentrations (compared with control at 0.71, 0.49, 2.4, 26.63, 1.63) even at the highest level of salinity. Magnetically treated water also significantly enhanced plant Fe and Zn concentration to a maximum of 750 μg/kg (M4S3X1) and 94.67 μg/kg (S4M4X3), under salinity stress, respectively. The single and the combined use of organic and mineral media significantly affected plant nutrient uptake, especially when used with the proper rate of M treatment. If combined with the proper growth medium, the magnetized water may be more effective on the alleviation of salt stress in *Mentha piperita* by enhancing nutrient uptake.

Keywords Calcium · Coco peat · Iron · Magnesium · Magnetism, medicinal plants

Introduction

Salinity is one of the most important stresses, worldwide, negatively affecting plant growth and yield production. Salinity decreases plant growth and nutrient uptake due to increased osmotic potential and the toxicity of sodium (Na^+) and chloride (Cl^-) ions (Miransari and Smith 2007). A large part of agricultural lands is saline or subjected to some kind of salinity, especially under arid and semi-arid areas of the world indicating the significance of research on the alleviation of salt stress (Jamshidi and Javanmard 2018).

Due to the health and economic significance of medicinal plants, they are planted, globally. Depending on the morphological and physiological properties of medicinal plants, their growth and nutrient uptake decrease under salt stress (Nakabayashi and Saito 2015). The medicinal plant *Mentha piperita* is widely used for medical purposes including the production of essential oil. However, it is not a tolerant plant under salinity stress and its growth decreases under such a stress (Saharkhiz and Goudarzi 2014).

Different methods including the physical, chemical, and biological ones have been used to alleviate the negative effects of salinity on plant growth and nutrients uptake. Among the physical methods, the use of magnetic fields (Xi et al. 1994) (in the present research, the use of magnetically treated water) is one of the newest (Abdani Nasiri et al. 2018). Magnetic fields affect the following: (1) the energy of structural elements, (2) rearrangement of molecules, (3) the size of

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molecules including water, and (4) the temperature of the molecules. Magnetic fields can affect plant growth by affecting cell division, growth, and development. Magnetic fields also affect cellular activities by altering ionic concentrations in different parts of the cell, especially across the cellular membrane affecting cellular osmotic potential, and the subsequent water and nutrient uptake (Selim and El-Nady 2011; Hachicha et al. 2018). Teixeira Da Silva and Dobránszki (2016) indicated magnetic field may influence plant growth by affecting the following: (1) the morphogenesis of different plant species, (2) seed germination and seedling growth, (3) plant responses under stress, (4) plant physiology and biochemistry including the movement of different substances, and (5) cellular and molecular alteration.

In another review by Teixeira da Silva and Dobránszki (2014), it was indicated that magnetized water may quantitatively and qualitatively affect the growth and development of plants and alter the nutrient uptake of seeds and fruits. The authors accordingly indicated that the intensity of magnetized water on plant growth and quality is a function of water quality, the concentration of ions, method of magnetization, and plant genotype. The other important point raised by the authors is that a set of standard conditions must be defined to indicate if magnetized water can be used as a source of induction or inhibition (Teixeira da Silva and Dobránszki 2014). When water is treated by a magnetic field, it becomes more suitable for industrial purposes, and its physicochemical properties including pH (increases), electrical conductivity, viscosity, surface tension (decreases), and shear tension (increases) are affected (Esmaeilnezhad et al. 2017).

Different researches have indicated the positive effects of magnetic fields on plant growth under stress. Alikamanoglu and Sen (2011) investigated the effects of magnetic field on the growth and biochemical properties of wheat in the range of 2.9–4.8 mT, and found that magnetic field enhanced plant growth and improved plant biochemical properties including the protein contents and the activities of antioxidant enzymes. Eşitken and Turan (2004) indicated the enhancing effects of magnetic field on the nutrient uptake of strawberry. Hachicha et al. (2018) found that electromagnetic water can alleviate the negative effects of salinity on crop yield and nutrient uptake as well as on soil functioning. Alavi et al. (2020) just found that the use of magnetic field alleviated salinity stress on peppermint growth and biochemical properties by the following: (1) increasing plant growth, and (2) enhancing plant menthol, menthone, chlorophyll, and proline contents. The positive effects of alternating magnetic field were improved when combined with coco peat growth medium.

Growth medium is also another important factor significantly affecting plant growth under different conditions including stress (Bostani 2018). The physical, chemical, and biological properties of growth medium affect plant growth and nutrient uptake (Ghehsareh et al. 2011, 2012; Shahabifar et al. 2019; Doostikhah et al. 2020). The authors compared the effects of different growth medium including palm and perlite on the growth of tomato and cucumber. They found that the palm growth medium was a more suitable medium for tomato and cucumber growth as it had a less C/N ratio, higher CEC, and optimum pH and bulk density.

Although there is little data on the use of magnetic field for the alleviation of salinity stress on the growth and quality of medicinal plants (Azimian and Roshandel 2015), there is not any data, to our knowledge, on the combined use of alternating magnetic fields with growth medium on *M. piperita* nutrient uptake under salinity stress. Accordingly, the objective was to determine the combined effects of magnetic field (used for the treatment of irrigation water) and growth medium on the nutrient uptake of *Mentha piperita* under salinity stress in the greenhouse conditions.

Materials and methods

Experimental site

The experiment was conducted in the Research Greenhouse of Islamic Azad University, Isfahan Branch, Iran, which is located in the Eastern longitude of 51^o 77′ and the northern latitude of 32^o 63′.

Experimental design and treatments

The experiment was a split-split plot on the basis of a completely randomized block design using three replicates in which the effects of magnetic fields and growth medium (Table 1) on the growth of *M. piperita* were determined under different salinity levels (Fig. 1). The following experimental treatments were tested: (1) alternating magnetic fields (main plots) including control (M1), 100 (M2, ampere of current = 1.05), 200 (M3, ampere of current = 3.5), and 300 mT (M4, ampere of current = 4.4); (2), salinity levels (subplots) including control (S1), 40 (S2), 80 (S3), and 120 (S4) mM NaCl; and (3) growth media (sub-subplots) including coco peat (X1), palm (X2), coco peat + perlite (v/v = 50, X3), and palm + perlite (v/v = 50, X4) (Table 2). The irrigation water properties including salinity (0.356 dS/m), pH (7.5), Ca (60 mg/l), Mg (12 mg/l), HCO_3- (2.2 mg/l), and SO_4^{2}- (0.15 mg/l) were analyzed using the standard methods (Miransari et al. 2008; Swanhart et al. 2014). The greenhouse conditions were according to the following: light, 25000 lx; relative humidity, 25–30%; day temperature, 25 °C; night temperature, 18 °C; light duration in the

Table 1 Analyses of organic growth media

Organic growth medium	EC (dS/m)	pH	CEC (cmol/kg)	OC (%)	moisture holding capacity (%)
Coco peat	2.5	6.73	63.4	27.1	90
Perlite	1.5	7.5	0	0	69.3
Palm	3.1	6	53.12	18.43	49.16

EC electrical conductivity, *CEC* cation exchange capacity, *OC* organic carbon

beginning of the growth period, 13 h; and at the end of the growth period, 13 h.

Planting

The cuttings of *M. piperita* were grown in coco peat using trays and the grown seedlings were then planted in the 3-l plastic pots in the greenhouse. The commercial coco peat was treated with water to enhance its volume and usability. The growth medium of the pots was prepared using the experimental treatments including coco peat, palm, coco peat + perlite (v/v = 50), and palm + perlite (v/v = 50) (Ghehsareh et al. 2011, 2012). The pots were first irrigated with salty water twice per day and when the seedlings grew, it was increased to four times a day, according to the experimental treatments. The salty water was stored in 100-l tanks. The salty water was then magnetized using the experimental magnetic fields and the pots were then ferti-irrigated.

Magnetizing water

Using the following setup, the salty water was magnetized as follows: (1) AC (alternating current) to DC (direct current) convertor (2) oscillator (alternator of selector) to alternate the current rate, and (3) copper coils with an iron coil, which was required for the production of the magnetic field (Fig. 1) (Alavi et al. 2020). The alternating magnetic field was established around the metal water pipes (connected to plastic water tubes for the irrigation of the pots) by placing the iron coil cores. The direct current rate, with respect to the abovementioned details, determined the rate of magnetic field, and hence, using an oscillator (alternator), different rates of alternating magnetic fields, according to the experimental treatments, were established. The rate of magnetic field was adjusted using the selector; the maximum magnetic field of 300 mT was produced when all the keys were active; accordingly, the other rates of alternating magnetic were also established (Fig. 1). The water was magnetized inside the metal pipes for 5 min for the different intensities of 100 (ampere of current = 1.05), 200 (ampere of current = 3.5), and 300 mT (ampere of current = 4.4), stored in the big blue containers (Fig. 1), and was immediately used for the irrigation of the pots by hand.

Plant nutrition

The V2-V4 seedlings (planted at the pots) were fertilized at planting using N-P-K (20–20-20). Two weeks following the planting of seedlings in the greenhouse, Hoagland solution (Hoagland and Arnon 1950) was used to fertigate the pots. Accordingly, the pots were irrigated with water (containing Hoagland solution), control, or salty, which had been or had not been treated with alternating magnetic field. During the experiment, the pH (5.5–6.5) and the salinity (1.5–2 dS/m) of the solutions were kept constant, the daily and nightly temperature was equal to 35 and 17 °C, respectively, and the plants were thinned during the growth. At the 20-cm growth stage, the plants were placed on a big stool (Alavi et al. 2020). The pests

Table 7 The flowchart of the experiment. Main plots irrigated with magnetically treated water including control (M1, 100 (M2), 200 (M3), and 300 mT (M4); salinity levels (subplots) including control (S1), 40 (S2), 80 (S3), and 120 (S4) mM NaCl; and (3) growth media (sub-subplots) including coco peat (X1), palm (X2), coco peat + perlite (v/v = 50, X3), and palm + perlite (v/v = 50, X4)

M1				M2				M3				M4			
S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1	X1
X2	X2	X2	X2	X2	X2	X2	X2	X2	X2	X2	X2	X2	X2	X2	X2
X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3	X3
X4	X4	X4	X4	X4	X4	X4	X4	X4	X4	X4	X4	X4	X4	X4	X4

Fig. 1 Different stages of the experiment including the following: (1) the preparation of the growth media, (2) magnetizing and irrigating the pots using the following setup, the salty water was magnetized: (1) AC (alternating current) to DC (direct current) convertor (2) oscillator to alternate the current rate, and (3) copper coils with an iron coil, which was required for the production of the magnetic field (Alavi et al. 2020)

including Aleyrodidae (Hemiptera) and *Tuta absoluta* (Lepidoptera: Gelechiidae) were controlled four times during the growth period using Evisect (thiocyclam hydrogen oxalate) and Avaunt (Indoxacarb) pesticides.

Nutrient concentration

The samples were collected at harvest and their wet weight determined. The samples dry weight was determined by

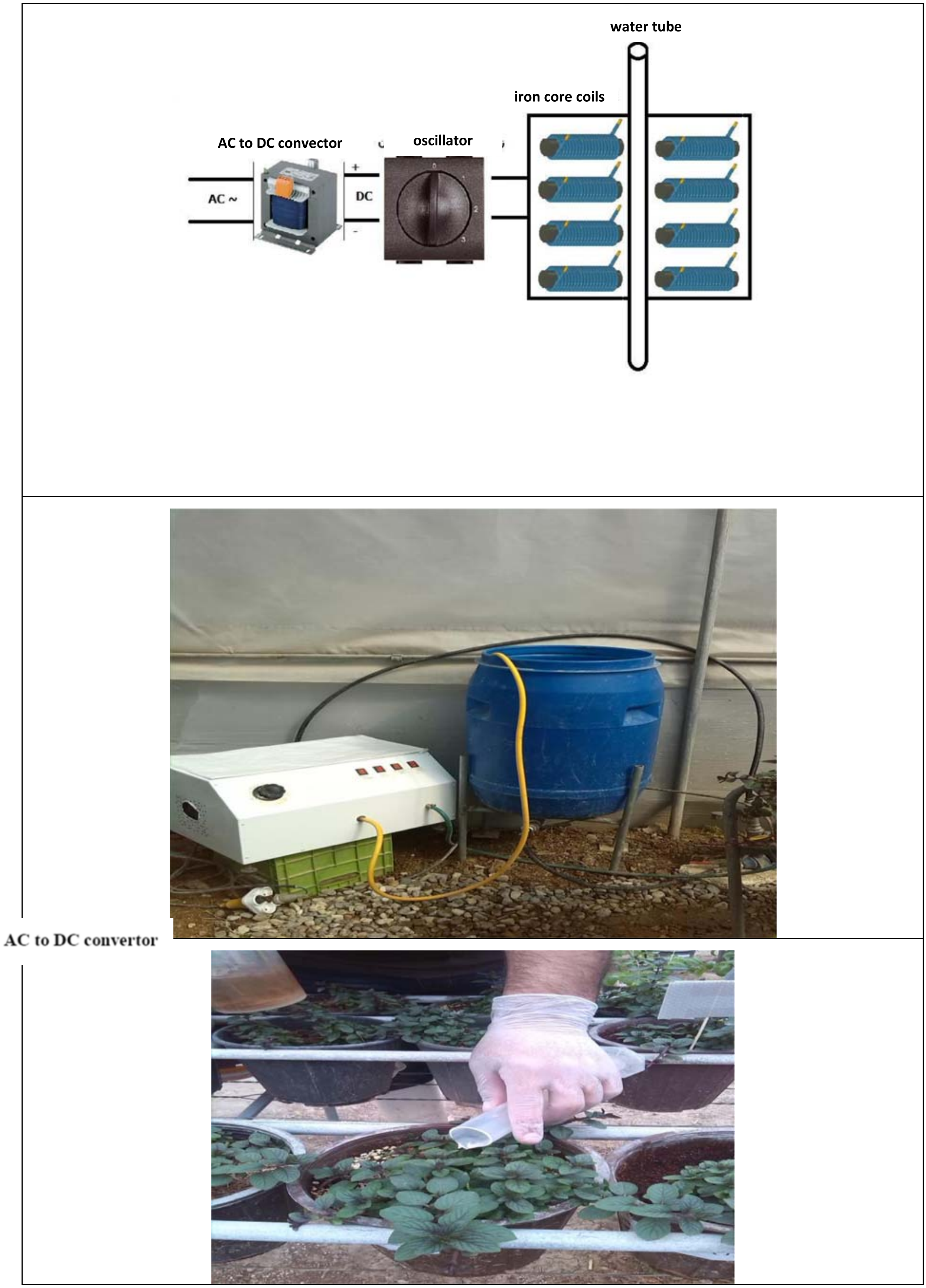

Fig. 1 (continued)

washing the samples with distilled water, air drying for 48 h, and using oven at 70 °C. The dried samples were finally milled using electric mills. Nitrogen (N) was measured by the Micro-Kjeldahl method as 0.3 g of the sample was digested using sulfuric acid, and N concentration was determined using the Kejeldahl apparatus (Kejletek Analyzer unit 2300). The concentrations of phosphorus (P), potassium (K), iron (Fe), and zinc (Zn) were determined according to the following details. The samples were first extracted using the dry ash method as 1 g of the sample was extracted using hydrochloric acid 1 M for 18–24 h at 550 °C. Phosphorous was determined by treating 5 ml of the extract with the indicator of ammonium-molybdate-vandate in a 25-ml volumetric flask, which was brought up to volume. The spectrophotometer was calibrated using the concentrations of 0, 5, 10, and 15 mg/l, and then, the P concentration was determined in the samples.

Potassium was determined using a flame photometer, which was first calibrated using the standard solutions of potassium and then was used to measure the concentration of potassium in the samples. Calcium and magnesium were measured using 1 ml of the extract, which was mixed with 9 ml of lanthanum and was measured by atomic absorption spectrometer (Varian Spectra-10AA). The concentrations of micronutrients including iron, zinc, copper, and manganese were also determined using atomic absorption spectrometer.

Statistical analyses

Data were subjected to the analysis of variance using Minitab. The null hypothesis was to test the assumption that the use of magnetized irrigation water can enhance the uptake of different nutrients by *Mentha piperita* under salinity stress. Data were not subjected to any kind of transformation. Means were compared using Duncan multiple range test at $P = 0.05$.

Results

Analysis of variance indicated the significant effects of different experimental treatments and their interactions on the uptake of different nutrients including N, P, K, Ca, Mg, Fe, and Zn by *M. piperita* (Table 3).

Plant N concentration

With increasing the level of salinity, plant N concentration significantly decreased to 0.22 (S4M1X3), and S1 and S2 resulted in the highest N concentration ranging from 0.47 (S2M1X2) to 1.71% (S2M3X4). Interestingly, although salinity significantly decreased N concentration, the M treatments could significantly increase plant N concentrations (compared with control), even at the highest level of salinity, to a maximum of 1.08% (S3M4X1). The two organic media including coco peat and palm, as well as their combination with the mineral medium (especially the palm/perlite combination), could efficiently improve plant N concentration under salinity stress (Table 4).

Plant P concentration

Although salinity significantly decreased plant P concentration to a minimum of 0.12% (S4M1X4), the use of magnetic fields, especially 100 and 200 mT, significantly increased plant P concentration at the higher levels of salinity (S3 and S4) to a maximum of 0.89% (S3M3X1). The single effects of organic media and their combination with the mineral medium (especially the palm/perlite combination) significantly improved plant P concentration even at the highest level of salinity (Table 4).

Table 2 Analysis of variance indicating the effects of salinity, magnetic field, and growth medium on the nutrient uptake of *Mentha piperita*

S.V.	d.f.	N	P	K	Ca	Mg	Fe	Zn
Rep	1	100.110**	40.526**	125.653**	170,983/79**	64217**	5,817,516.88**	496,235.005**
S	3	0.815**	0.1**	25**	925.959**	223.78**	256,414.14**	2987.255**
M	3	0.271**	0.263**	2.41**	2340.118**	344/511**	167,746.686**	287.227**
X	3	0.446**	0.085**	0.401**	71.193**	207.5**	1677.46.547**	424.255**
S × M	9	0.054**	0.115**	2.854**	579.024**	491.6**	225,115.95**	453.681**
S × X	9	0.295**	0.051**	0.911**	132.390**	201.05**	42590607**	582.246**
M × X	9	0.082**	0.213**	2.764**	535.992**	231.8**	77,117.427**	803.663**
S × M × X	27	0.240**	0.043**	1.806**	370.864**	362.43**	95,758.721**	655.993**
Error	128	0.001	0.00	0.070	0.113	0.07	20.411	6.536
C.V. (%)		38.88	38.50	39.98	42.87	56.57	31.01	40.32

S.V. source of variation, *d.f.* degree of freedom, *S* salinity, *M* magnetic field, *X* organic growth medium

*, and ** represent significant level at $P = 0.05$, and 0.01, respectively

Table 3 Plant N and P concentration (%) as affected by different experimental treatments

M (millitesla)	X	S (dS/m) 2	4	8	12
N					
0	Coco peat	0.7 ± 0.025	0.53 ± 0.2	0.82 ± 0.023	0.57 ± 0.026
	Coco peat/perlite	0.53 ± 0.025	0.47 ± 0.02	0.39 ± 0.01	0.57 ± 0.025
	Palm	0.927 ± 0.025	1.04 ± 0.045	0.32 ± 0.025	0.22 ± 0.025
	Palm/perlite	0.8 ± 0.026	1.04 ± 0.04	0.72 ± 0.025	0.627 ± 0.025
100	Coco peat	0.58 ± 0.025	0.63 ± 0.025	0.92 ± 0.025	0.73 ± 0.03
	Coco peat/perlite	0.63 ± 0.015	0.91 ± 0.025	0.72 ± 0.025	0.657 ± 0.02
	Palm	0.23 ± 0.025	1.16 ± 0.015	0.83 ± 0.02	0.38 ± 0.026
	Palm/perlite	0.98 ± 0.02	1.4 ± 0.05	0.367 ± 0.02	0.58 ± 0.025
200	Coco peat	0.727 ± 0.025	1.2 ± 0.025	0.463 ± 0.015	0.463 ± 0.015
	Coco peat/perlite	0.657 ± 0.02	0.72 ± 0.025	0.96 ± 0.03	0.096 ± 0.03
	Palm	0.63 ± 0.025	0.75 ± 0.026	0.71 ± 0.01	0.63 ± 0.02
	Palm/perlite	1.04 ± 0.04	1.71 ± 0.085	0.72 ± 0.025	0.58 ± 0.025
300	Coco peat	0.71 ± 0.017	0.56 ± 0.015	1.08 ± 0.026	0.577 ± 0.025
	Coco peat/perlite	0.65 ± 0.025	0.57 ± 0.025	0.72 ± 025	0.72 ± 0.025
	Palm	0.35 ± 0.03	0.82 ± 0.026	0.36 ± 0.02	0.72 ± 0.025
	Palm/perlite	0.96 ± 0.036	0.82 ± 0.026	0.43 ± 0.015	0.23 ± 0.025
P					
0	Coco peat	0.307 ± 0.01	0.27 ± 0.02	0.52 ± 0.02	0.527 ± 0.02
	Coco peat/perlite	0.51 ± 0.01	0.27 ± 0.02	0.62 ± 0.02	0.43 ± 0.02
	Palm	0.29 ± 0.01	0.23 ± 0.01	0.32 ± 0.02	0.33 ± 0.02
	Palm/perlite	0.53 ± 0.02	0.19 ± 0.01	0.38 ± 0.02	0.12 ± 0.02
100	Coco peat	0.73 ± 0.01	0.62 ± 0.02	0.53 ± 0.01	0.38 ± 0.02
	Coco peat/perlite	0.56 ± 0.01	0.42 ± 0.02	0.37 ± 0.02	0.69 ± 0.01
	Palm	0.847 ± 0.03	0.43 ± 0.01	0.66 ± 0.01	0.62 ± 0.02
	Palm/perlite	0.67 ± 0.02	0.403 ± 0.01	0.33 ± 0.02	0.33 ± 0.02
200	Coco peat	0.49 ± 0.01	0.477 ± 0.15	0.89 ± 0.01	0.63 ± 0.02
	Coco peat/perlite	0.49 ± 0.01	0.403 ± 0.15	0.5 ± 0.01	0.48 ± 0.01
	Palm	0.24 ± 0.03	0.807 ± 0.005	0.5 ± 0.02	0.33 ± 0.02
	Palm/perlite	0.97 ± 0.02	0.43 ± 0.01	0.35 ± 0.02	0.53 ± 0.02
300	Coco peat	0.417 ± 0.02	0.33 ± 0.01	0.35 ± 0.01	0.33 ± 0.02
	Coco peat/perlite	0.29 ± 0.01	0.36 ± 0.01	0.35 ± 0.01	0.43 ± 0.02
	Palm	0.07 ± 0.02	0.5 ± 0.01	0.5 ± 0.01	0.49 ± 0.01
	Palm/perlite	0.49 ± 0.01	0.48 ± 0.02	0.72 ± 0.02	0.37 ± 0.02

M, X, and S stand for magnetic field, growth medium, and salinity, respectively. Data are presented with their corresponding standard deviations

Plant K concentration

Similar to plant N and P concentrations, increased levels of salinity significantly decreased plant K concentration to a minimum of 1.03% (S3M4X3). Although the highest K concentration (5.73%) was resulted at the least level of salinity by the magnetic level of 200 mT (M3S1X1), even at the higher levels of salinity, especially at S3, the use of magnetic field significantly increased plant K concentration to a maximum of 3.23% (S3M3X1). The organic growth medium of coco peat was one of the most efficient and most effective growth media for the increased uptake of plant K (Table 5).

Plant Ca concentration

Salinity significantly reduced plant Ca concentration to a minimum of 13.27 mg/kg. However, interestingly, the use of magnetic field significantly increased plant Ca concentration even at the highest level of salinity to a maximum of 53.6 mg/kg (S4M4X4). M4 was the most effective

Table 4 Plant K concentration (%) as affected by different experimental treatments

M	X	K			
				S	
		2	4	8	12
0	Coco peat	3.2 ± 0.25	1.77 ± 0.25	2.067 ± (0.11)	1.26 ± 0.25
	Coco peat/perlite	3.27 ± 0.25	1.33 ± 0.15	2.73 ± 0.25	1.73 ± 0.25
	Palm	3.2 ± 0.25	1.56 ± 0.25	2.2 ± 0.26	2.17 ± 0.28
	Palm/perlite	3.2 ± 0.26	2.2 ± 0.26	2.73 ± 0.26	1.8 ± 0.25
100	Coco peat	2.4 ± 0.4	2.23 ± 0.25	2.2 ± 0.26	2.2 ± 0.25
	Coco peat/perlite	2.23 ± 0.25	3.26 ± 0.25	2.7 ± 0.25	2.7 ± 0.25
	Palm	2.63 ± 0.4	2.26 ± 0.25	1.5 ± 0.2	1.76 ± 0.25
	Palm/perlite	4.2 ± 0.26	2.16 ± 0.28	1.9 ± 0.21	1.4 ± 0.2
200	Coco peat	5.73 ± 0.25	3.23 ± 0.25	3.23 ± 0.25	2.17 ± 0.28
	Coco peat/perlite	4.767 ± 0.25	2.26 ± 0.25	1.76 ± 0.25	1.7 ± 0.26
	Palm	3.27 ± 0.25	1.76 ± 0.25	2.16 ± 0.28	1.17 ± 0.28
	Palm/perlite	4.4 ± 0.4	1.76 ± 0.25	2.16 ± 0.25	1.7 ± 0.26
300	Coco peat	3.17 ± 0.21	1.73 ± 0.25	3..02 ± 0.26	1.77 ± 0.25
	Coco peat/perlite	3.27 ± 0.25	2.23 ± 0.25	1.7 ± 0.26	1.67 ± 0.28
	Palm	3.27 ± 0.25	3.2 ± 0.26	1.03 ± 0.15	1.73 ± 0.25
	Palm/perlite	2.73 ± 0.25	2.46 ± 0.31	2.06 ± 0.25	1.73 ± 0.25

M, X, and S stand for magnetic field, growth medium, and salinity, respectively. Data are presented with their corresponding standard deviations

level of magnetic field as it significantly increased plant Ca concentration compared with the control treatment. The combination of palm and perlite was the most efficient growth medium significantly increasing plant Ca concentration (Table 6).

Plant Mg concentration

At the second level of salinity, plant Mg concentration increased to a maximum of 37.27 mg/kg; however, at the higher levels of salinity, plant Mg concentration significantly decreased to a minimum of 3.2 mg/kg. The use of magnetic field alleviated the stress by significantly increasing plant Mg concentration to a maximum of 39.63 mg/kg (S3M3X2). The combination of palm and perlite was the most efficient growth medium significantly affecting plant Mg concentration (Table 6).

Plant Fe concentration

Salinity stress significantly affected plant Fe concentration to a minimum of 92 μg/kg at M1S4X1. However, the use of magnetic field significantly increased plant Fe concentration to a maximum of 750 μg/kg at M4S3X1. Coco peat was the most efficient growth medium compared with the other growth media (Table 7).

Plant Zn concentration

Salinity significantly reduced plant Zn concentration to a minimum of 28 μg/kg. However, the use of magnetic field significantly increased plant Zn concentration, as it, for example, was the highest at S4M4X3 (94.67 μg/kg). The organic and mineral growth media efficiently increased plant Zn concentration (Table 7).

Discussion

The effects of treating salty irrigation water with alternating magnetic field on the uptake of different nutrients by *M. piperita* were investigated. There has been previously little data on the use of magnetic field affecting the growth and quality of medicinal plants under salinity stress (Azimian and Roshandel 2015). However, there is not any data, to our knowledge, on the use of magnetic field and growth medium affecting the nutrient uptake of *M. piperita* under salinity stress.

The results indicated that it is possible to alleviate salinity stress on *M. piperita* nutrient uptake by using magnetically treated water for irrigation of salt-stressed plants. Alavi et al. (2020) also just found it is possible to enhance the growth and biochemical properties of *M. piperita* using water that had been exposed to alternating magnetic fields (magnetically treated water). Research has indicated a static magnetic field

Table 5 Plant Ca and Mg concentration (mg/kg) as affected by different experimental treatments

		Ca			
M	X	S			
		2	4	8	12
0	Coco peat	13.3 ± 0.3	34.6 ± 0.4	26.7 ± 0.26	13.27 ± 0.25
	Coco peat/perlite	13.6 ± 0.36	21.36 ± 0.4	26.63 ± 0.35	13.27 ± 0.25
	Palm	29.6 ± 0.36	13 ± 0.13	26.6 ± 0.4	26.71 ± 0.24
	Palm/perlite	26.67 ± 0.2	21.07 ± 0.4	39.8 ± 0.2	13.27 ± 0.25
100	Coco peat	26.67 ± 0.2	25.43 ± 0.4	13.33 ± 0.13	13.27 ± 0.25
	Coco peat/perlite	26.67 ± 0.2	31.8 ± 0.26	26.5 ± 0.45	13.27 ± 0.25
	Palm	39.8 ± 0.26	26.53 ± 0.5	26.83 ± 0.2	18.57 ± 0.35
	Palm/perlite	34.56 ± 0.35	26.53 ± 0.5	39.63 ± 0.55	13.27 ± 0.25
200	Coco peat	39.87 ± 0.15	26.66 ± 0.2	26.7 ± 0.26	26.57 ± 0.35
	Coco peat/perlite	53.27 ± 0.25	18.7 ± 0.26	39.8 ± 0.26	26.5 ± 0.45
	Palm	21.27 ± 0.25	13.3 ± 0.25	18.6 ± 0.4	13.27 ± 0.25
	Palm/perlite	26.67 ± 0.2	13.3 ± 0.25	26.5 ± 0.45	26.57 ± 0.35
300	Coco peat	53.43 ± 0.51	45.43 ± 0.51	39.8 ± 0.26	53.27 ± 0.27
	Coco peat/perlite	31.8 ± 0.5	53.26 ± 0.25	26.6 ± 0.4	13.3 ± 0.25
	Palm	26.53 ± 0.2	53.26 ± 0.25	45.43 ± 0.51	23.8 ± 0.25
	Palm/perlite	66.7 ± 0.26	39.8 ± 0.26	39.8 ± 0.26	53.6 ± 0.36
Mg					
0	Coco peat	22.36 ± 0.4	37.27 ± 0.25	7.8 ± 0.26	15 ± 0.26
	Coco peat/perlite	22.36 ± 0.4	4.73 ± 0.25	7.8 ± 0.26	15.8 ± 0.26
	Palm	1.5 ± 0.25	7.8 ± 0.26	7.8 ± 0.26	12.73 ± 0.25
	Palm/perlite	23.8 ± 0.26	7.8 ± 0.26	15.8 ± 0.26	23.8 ± 0.26
100	Coco peat	31.87 ± 0.15	27.23 ± 0.25	7.8 ± 0.26	23.8 ± 0.26
	Coco peat/perlite	23 ± 0.15	20.73 ± 0.25	31.8 ± 0.26	15.8 ± 0.26
	Palm	1.53 ± 0.25	23.8 ± 0.26	23.8 ± 0.26	15.8 ± 0.26
	Palm/perlite	43.6 ± 0.45	27.23 ± 0.25	15.76 ± 0.32	23.8 ± 0.26
200	Coco peat	23.8 ± 0.26	35.2 ± 0.26	3.2 ± 0.26	3.2 ± 0.26
	Coco peat/perlite	1.63 ± 0.23	31.8 ± 0.26	39.63 ± 0.55	3.2 ± 0.26
	Palm	20.73 ± 0.25	30.27 ± 0.25	15.8 ± 0.26	7.8 ± 0.26
	Palm/perlite	30.27 ± 0.25	23.8 ± 0.26	23.8 ± 0.26	7.8 ± 0.26
300	Coco peat	7.8 ± 0.26	19.2 ± 0.26	11.8 ± 0.26	23.8 ± 0.26
	Coco peat/perlite	28.7 ± 0.25	11.2 ± 0.26	23.8 ± 0.26	7.8 ± 0.26
	Palm	7.8 ± 0.26	28.73 ± 0.25	7.8 ± 0.26	9.5 ± 0.3
	Palm/perlite	15.8 ± 0.26	28.73 ± 0.25	31.8 ± 0.26	7.8 ± 0.26

M, X, and S stand for magnetic field, growth medium, and salinity, respectively. Data are presented with their corresponding standard deviations

decreased the ratio of Na+/K+ in plant under salinity stress (Rathod and Anand 2016). This may be due to the exclusion of Na + from the plant or due to the increased uptake of K + (Miransari and Smith 2019). According to their results (Rathod and Anand 2016), wheat (*Triticum aestivum* L.) seeds subjected to static magneto-priming at 50 mT (2 h), under salinity stress (150 mM NaCl), increased plant growth and photosynthesis rate both in sensitive and salt tolerant wheat genotypes. They accordingly suggested that it is possible to alleviate salinity stress on wheat growth using magnetic field (Rathod and Anand 2016). In a review by Dobránszki (2014), it was indicated that magnetic field can improve the quality and quantity of plant and alter the nutrient uptake of seeds and fruits. The mechanisms affecting the growth and quality of plant by magnetic field under different conditions including stress have been indicated by Teixeira da Silva and Dobránszki (2016).

In another research by Hozayn et al. (2016), magnetizing irrigation water increased plant yield and yield components including oil percentage and composition, plant nutrient

Table 6 Plant Fe concentration (μg/kg) as affected by different experimental treatments

		Fe			
M	X			S	
		2	4	8	12
0	Coco peat	101 ± 1	162 ± 2.64	124.67 ± 5.03	92 ± 2.64
	Coco peat/perlite	97.67 ± 2.52	157.67 ± 2.51	92.67 ± 2.51	102.67 ± 2.51
	Palm	129 ± 3.6	152.67 ± 2.51	85.67 ± 2.08	164.67 ± 5
	Palm/perlite	150 ± 5	164.67 ± 5	110 ± 2	161.3 ± 3.21
100	Coco peat	133.67 ± 3.51	152.67 ± 2.51	119.67 ± 5.03	86 ± 1.7
	Coco peat/perlite	129 ± 1	122.3 ± 2.51	81.3 ± 3.21	104.33 ± 4.04
	Palm	107.67 ± 2.51	98 ± 2.64	164.67 ± 5	72 ± 2.64
	Palm/perlite	107.3 ± 2.51	139 ± 1	97.67 ± 2.5	97.67 ± 2.5
200	Coco peat	137.667 ± 2.51	90 ± 2	470.67 ± 15.56	127 ± 2.64
	Coco peat/perlite	110 ± 2	92.67 ± 2.51	703.3 ± 4.16	107.67 ± 2.51
	Palm	106 ± 4	125 ± 5	162 ± 2.64	61.67 ± 2.88
	Palm/perlite	77.67 ± 2.51	505.67 ± 6.02	112.3 ± 2.51	27.3 ± 2.51
300	Coco peat	1540.67 ± 5.29	122.67 ± 2.5	750.3 ± 8.74	146.4 ± 3.21
	Coco peat/perlite	92.3 ± 2.5	113 ± 2.64	147.67 ± 2.51	101 ± 1.73
	Palm	72.3 ± 2.51	327 ± 2.64	200.67 ± 1.15	376 ± 4
	Palm/perlite	119 ± 1	730.67 ± 18.77	87.66 ± 2.51	178 ± 2.64
Zn					
0	Coco peat	42.67 ± 2.51	49 ± 1	50 ± 2	30 ± 2
	Coco peat/perlite	62.3 ± 2.51	47.33 ± 1	35 ± 3	35 ± 2
	Palm	82 ± 2.65	39.3 ± 0.58	56 ± 4	56 ± 3
	Palm/perlite	47.3 ± 2.51	42.67 ± 2.51	43.67 ± 1	28 ± 2
100	Coco peat	77.33 ± 2.51	57 ± 2.64	37.3 ± 2.51	42 ± 2.64
	Coco peat/perlite	63.67 ± 2.51	41.67 ± 2.08	47.3 ± 2.51	38 ± 2
	Palm	58.33 ± 2.08	33.3 ± 3.05	42 ± 2.64	37 ± 2
	Palm/perlite	62.67 ± 3.05	67.3 ± 2.51	51.67 ± 2.88	50.3 ± 1.52
200	Coco peat	72 ± 2.64	37 ± 2	44.67 ± 3.05	37.67 ± 2.51
	Coco peat/perlite	52.33 ± 2.51	54.67 ± 5.03	47.67 ± 2.51	44 ± 2
	Palm	72.3 ± 2.51	37.67 ± 2.51	52 ± 2.64	57.3 ± 2.5
	Palm/perlite	39 ± 1	42.3 ± 2.51	42 ± 2.64	28 ± 2
300	Coco peat	171.67 ± 3.6	37.3 ± 2.51	47 ± 4.52	42.3 ± 2.51
	Coco peat/perlite	89.67 ± 2.08	42.67 ± 2.51	62.67 ± 2.64	60.67 ± 1.15
	Palm	42.3 ± 2.51	45 ± 3	45 ± 3	94.67 ± 3.05
	Palm/perlite	84.67 ± 3.05	57.67 ± 2.51	52 ± 2.64	42 ± 2.64

M, X, and S stand for magnetic field, growth medium, and salinity, respectively. Data are presented with their corresponding standard deviations

uptake (K, Mg, Ca, and Mn), and water use efficiency. They accordingly made the conclusion that the use of magnetized irrigation water is a useful modern technique for treating canola under field conditions resulting in the improved crop yield and quality and reduced use of irrigation water. They indicated that the stimulating effects of magnetically treated water on plant pigment contents and hence the photosynthesis process are by the following: (1) the increased rate of proline, (2) the subsequent increased uptake of Mg (required for chlorophyll production), and (3) the enhanced uptake of K, which increases the photosynthesis efficiency possibly due to the increased number of chloroplasts per cell. Such enhancing effects of magnetically treated water on plant growth, photosynthesis rate, and nutrient uptake can also be due to the increased production of plant growth promoters (gibberellins and auxin).

Similar to our results, in a research by Eşitken and Turan (2004), the stimulating effects of magnetic water in the range of 96–192 mT were indicated on the growth and nutrient uptake of strawberry. However, at the higher rates of magnetism, the magnetic field caused some negative effects on plant growth and nutrient uptake. In another research, Hachicha et al. (2018) found that magnetizing salty water increased plant nutrient uptake of N, P, and K. The authors also found that the use of magnetized saline water decreased soil salinity (ECe) and the Na + and Cl− contents.

Karimi et al. (2017) investigated the effects of magnetic field (15 and 150 mT) at different levels of salinity (0, 50, and 100 mM) and found magnetic field improved seed germination and plant growth under different levels of salinity. The stress increased plant proline content and decreased plant water content; however, the magnetic field reduced the accumulation of plant proline by increasing water uptake. The increased accumulation of H_2O_2 and membrane thermostability by the magnetic treatments indicated the alleviating effects of magnetic field at proper rate on plant growth can be by the H_2O_2 signaling under salinity stress.

Kataria et al. (2020) found that the use of magnetic field can improve the growth and quality of soybean plants subjected to the stress of ultraviolet B by affecting the activity of nitric oxide and reactive oxygen species. The stress decreased plant growth and yield, the activity of different enzymes, and nitric oxide. However, pretreatment of the seeds with magnetic field enhanced plant growth and quality by significantly decreasing the activity of antioxidants and proline content and considerably increasing plant genetic contents, protein, nitric oxide, photosynthetic characteristics of the plant, and plant N fixation.

Growth medium is also an important parameter affecting plant growth and nutrient uptake. The comparison of the organic media (coco peat and palm) with the mineral medium (perlite) indicated that although the organic media were more effective on the enhanced nutrient uptake of *M. piperita* under salinity stress, the combined media of organic and mineral was the most effective treatment. The effects of growth medium on plant growth and nutrient uptake are by affecting physical properties including water moisture, bulk density, and physical structure; chemical properties including C/N ratio, pH, and CEC; and biological properties including the microbial activities (Ghehsareh et al. 2011, 2012; Sabet and Mortazaeinezhad 2018; Taherian et al. 2019).

Conclusion

Different methods have been used for the alleviation of salt stress on plant growth, among which the use of magnetic field is one of the newest. Salinity stress decreases plant growth by different mechanisms including the reduction of nutrient uptake. Accordingly, in this research, it was hypothesized, it is possible to increase *M. piperita* nutrient uptake under salinity stress using magnetically treated water and the proper growth medium. Magnetic field can affect the properties of water and dissolved ions, and hence alternate their uptake by plant. According to the results although salinity significantly decreased plant nutrient uptake (N, P, K, Ca, Mg, Fe, and Mn), the magnetic treatment, especially in the range of 96–192 mT, significantly enhanced the nutrient uptake of salt-stressed *M. piperita*. It is possible to plant *M. piperita* under salt stress conditions by magnetizing irrigation water and using the proper growth medium. Such results are of practical use in the saline soils, especially for recycling salty water in the controlled conditions such as the greenhouses, which are now widely used for the production of different products including the vegetables. However, more research is required to determine the alleviating effects of magnetic field and growth medium on the growth of medicinal plants including *M. piperita* under different stresses including salt stress.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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