Article

Not peer-reviewed version

Improvement of Salt Leaching and Water Content in Soil Irrigated with Electromagnetically Treated Saline Water

Mohamed Bouhlel * , Khawla Khaskhoussy , Mohamed Hachicha

Posted Date: 23 August 2024

doi: 10.20944/preprints202408.1660.v1

Keywords: saline water; electromagnetic treatment; salt leaching; soil; irrigation; Tunisia

Article

Improvement of Salt Leaching and Water Content in Soil Irrigated with Electromagnetically Treated Saline Water

Bouhlel M *, Khaskhoussy Kh and Hachicha M

University of Carthage, National Research Institute of Rural Engineering, 17 rue HédiKarray, B.P n°10, Ariana 2080, Tunisia, Water and Forests LR16INRGREF02. Non-Conventional Water Valorization, inrgref@iresa.tn.

* Correspondence: bouhlelmohamed13@gmail.com

Abstract: While the beneficial effects of using magnetic and electromagnetic treatment (ET) of brackish and saline waters on soil salinity reduction in the root zone were widely reported more studies are needed to answer questions about the soil salt leaching efficiency and the effect of the duration of the exposure to ET. For this aim, pot experiments were conducted using an Aqua-4D^R physical water treatment device. The first experiment included two trials. The first considered 5 concentrations: C0:1.0; C1:4.5; C2:9; C3:13.5; and C4:18 dSm^{-1}. The results revealed that the volume and the salt concentrations of the drained waters were significantly higher under irrigation with ET saline waters than those provided by untreated waters. The drained fraction of water varied from 20 to 26% under irrigation with untreated water and increased from 33 to 56% under irrigation with electromagnetized water indicating an improvement of salt leaching. The second trial was carried out with different irrigation doses. The result showed that the higher the dose, the more obvious and significant ET effect. The different treatment durations of water exposure revealed that the volume and salinity of drained water significantly increase as the ET duration increases. An increase in ET duration induces also an increase in soil water content of around 2.5%. Based on the experimental findings, we may conclude that the ET of saline water can reduce the adverse effect of salinity on the top soil, but these leached salts are carried away in depth and there is no concentration limit of water to the effect of the ET.

Keywords: saline water; electromagnetic treatment; salt leaching; soil; irrigation; Tunisia

---

1. Introduction

In the Mediterranean region, water scarcity is one of the huge challenges for socio-economic development. Furthermore, the increase in water demand for agricultural production reduces the amount of water allocated to grow a crop and, in turn, limits the development of agriculture. It is noteworthy that the agriculture sector in Tunisia consumes a large share of water, reaching about 80% of the total water demand. Hence, the growing demand for water has raised the necessity for a better management of the limited natural freshwater resources and the excessive use of saline water. However, the mismanagement and the over-use of saline water for irrigation have caused the salinization of soil and water and resulted in environmental problems exacerbated by climatic change, excessive exploitation of groundwater, and an inappropriate crop pattern [1,2]. Therefore, the search and application of novel strategies and modern techniques for the conservation and maintenance of the quantity and good quality of freshwater resources that canprevent the build-up of salts in the root zone to levels that limit the root water uptake and minimize the damaging effects of salinity on crop transpiration and soil evaporation for optimal crop growth become crucial [3–5]. In this context, many methods, such as hydraulic techniques (e.g., irrigation and drainage), physical techniques (e.g., soil leveling), farming techniques (e.g., using organic matter) and biological techniques, have been used to alleviate the adverse effects of saline water irrigation. Moreover, several technologies were applied to treat saline water. Among these technologies, it is important to cite the magnetic / electromagnetic water treatment which is based on a physical treatment approach and increasingly an attractive field for users and scientists [6,7] that has been widely used for reducing the effects of salts on irrigation water.

Magnetization technology is inexpensive, environmentally friendly and easy-to-use [8–15].

It offers numerous benefits, including water and soil desalinization as well as plant growth enhancement [16,17]. Due to their benefits, the magnetic / electromagnetic water treatment has been widely used in agriculture and its effects on water, soil properties and crops have been studied.

Magnetized water is obtained by exposing a magnetic / electromagnetic field. Magnetization undergoes several changes in the atomic, molecular and electronic structure of the water including thermodynamics, dielectric constant, mechanics, freezing and boiling points, surface tension, electrical conductivity (EC), and viscosity [17,18].

Given by the literature, the mechanism of magnetic water treatment is related to the polarizing effect on water molecules and solutes. Since water molecules are linked via hydrogen bonds to form multiple clusters, some theories have explained the effect of a magnetic field by the mechanism of cluster transformation [19], in which the magnetic field weakens the hydrogen bonds within clusters, reducing the stability of individuals breaking larger clusters, forming smaller clusters with stronger hydrogen bonds due to Lorentz force [20,21]. The influence of the magnetic fields on the physicochemical properties of water has been widely reported [22–29].

It has been observed that the hydrogen bonding is improved and the structure of liquid water becomes more stable when exposed to a magnetic field due to molecular dynamics simulation [23,30]. The physical treatment of water by a magnetic device with very low frequency and intensities, permits creating a structure of natural and optimized water that dissolves and transports minerals. Several researchers have reported a reduction in pH and surface tension, and, an increase in viscosity, hydration rate, and evaporation [22,28–31].

Based on previous investigations, the magnetic field can affect the electrical conductivity (EC) of water, whereas the physical changes of magnetized water remain controversial. Thus, while some researchers have reported an increase in water EC [34–36], others have shown the opposite results [37–39].

These controversial results could be related to the operating conditions, the water type, the field intensity level, the exposure time, polarity, and orientation [7]. Nevertheless, such changes in the structure of water cannot be permanent following the exposure to magnetic/ electromagnetic fields when the demagnetization of the MW occurs after a period of time. Thus, it has to keep in mind some features that derive from the mechanism of water magnetization which determine its effective usability [40]. Three main features can be noted as saturation, temperature dependence, and water memory effect.

Since the application of a magnetic field is given as an effective method for salt filtration enhancement, magnetic water treatment has been developed in different fields and in various industries such as medicine [41–43], safety health [44], anti-scaling in water systems [26,45–48], corrosion prevention [49] and food industry [50,51].

This magnetic treatment limits the amount of sessile microorganisms in the biofilm [26,52], inhibits bacterial growth [53–55] and water purification [56].

Several beneficial effects of irrigation with electro/magnetized on plant growth and development have been reported. It has been found that irrigation with magnetized water can enhance seed germination and seedling growth, leading to uniform germination, improve growth characteristics, and even increase yield and improve fruit quality [32,42,57,58]

Several studies revealed that magnetic treatment could improve water and mineral metabolism of plants by reducing the adverse effect of water stress, enhancing water and nutrient uptake, increasing chlorophyll, promoting Nitrate reductase activity, and reducing the ROS production [36,40,59–61] for better growth and development. However, in some cases, negative effects due to the operating conditions, plant species and flow rate, as well as magnetic and electromagnetic device properties such as intensity, exposure time, and magnet type have been observed [36]. These positive effects could be due to direct or indirect influence of electro/magnetic treatment application. Either way, the improvement of plant growth and crop yield can be attributed to the effects of a magnetic field on the soil physico-chemical properties and micro-environmental conditions [62,63].

In respect of the above-mentioned, many beneficial effects of magnetized water irrigation on soil properties have been reported. It can be used as an effective method for soil desalinization and enhancing soil properties via washing salts from the soil rhizosphere [64].

In fact, the application of a magnetic field on water decreases the hydration of salt ions and colloids, and accelerates coagulation and salt crystallization [65].

Several studies have been conducted to evaluate the effect of magnetic treatment of irrigation water on soil. Most researchers [4,66] have reported that the use of this physical treatment (ET) of water affects the soil properties such as salinity, moisture content and the soluble salts [16,37,57,67].

Yadollahpour and Rashidi [68] and Hachicha et al. [57] have observed a more significant decrease of soil salinity (ECe, Na and Cl contents) in soils irrigated with electromagnetically treated saline water compared to the soils irrigated with normal saline water. According to Hilal and Hilal [65], three positive effects occur in the soil when it is irrigated with saline water; an increased leaching of excess soluble salts, ii) a decrease in alkalinity and iii) dissolution of soluble salts such as carbonates, phosphates and sulfates. Similarly, [69] have reported that the magnetic water dissolved slightly soluble salts such as carbonates, phosphates and sulfates. In the pioneering work of Zhou et al. [70], laboratory tests have shown that the desalination of a saline soil was 29% greater in the first leaching and 33% greater in the second leaching where magnetized water was used, compared to non-magnetized water. Soliman et al. [71] stated also that magnetized water can be used to desalinate the soil because of the enhanced dissolving capacity of the magnetized water. They added that magnetized water was removed from 50% to 80% of soil Cl-, while normal irrigation water removed only 30%.

The effects of magnetically treated irrigation water on the physico-chemical properties of water, such as a reduction in water electrical conductivity [24,25,72], surface tension [49,73], vaporization rate [20,33] and pH of water, have widely been investigated.

Han et al. [25] has reported an increase in the water viscosity and a rapid leaching of salts due to this treatment. Therefore, high water permeability minimizes the amount of water required for each irrigation cycle and improves the conditions of the root layers by leaching the salts away from the root zone [74].

Based on the literature review, the ET of water used for irrigation has enhanced water, soil properties, salt leaching and the growth parameters of various plant species. Moreover, it has been proven that the magnetic treatment influences the precipitation of soluble salts, viscosity, surface tension, pH as well as the electrical conductivity of both water and soil [21,67,75,76]. Nevertheless, the efficiency of this physical treatment on salt leaching depends to different factors, including the water quality, the soil type, the duration of treatment, and others which need more investigation. Therefore, this current study aims to evaluate the effect of electromagnetic water salinity treatment on the efficiency of salt leaching under different water qualities and doses on soil and drained water characteristics as a function of time exposure of water to the Aqua 4D system.

2. Material and Methods

2.1. Experimental Design

Two pot experiments were conducted under greenhouse at the experimentation site of the INRGREF of Tunis. Soils were taken from the surface layer (0-20 cm) and placed in plastic pots with a diameter of 16 cm and a height of 24 cm. Each pot was previously perforated on its side to allow the water drainage and filled with quartz gravel up to a thickness of 2 cm. A synthetic textile washer was placed above the gravel bed to stabilize the soil and filter the water. For each treatment, five pots were used and all pots were arranged in a randomized block design.

The irrigation dose was kept constant at 200 ml, i.e., around 6 mm. The quantity and quality of water supplied and drained were monitored.

Experiment 1: Salt leaching efficiency

This experiment was carried out to assess the effect of ET treatment on salt leaching, two trials were performed. The first trial concerned salt leaching as a function of irrigation water salinity, and the second assess the salt leaching under different irrigation water doses. The quantity and salinity of water applied and drained were monitored, and soil water content was measured before and after irrigation. The trial involved 27 irrigations with 10 pots per experiment.

To study the effect of ET treatment by quality, four solutions were used with a constant dose of 120 ml (i.e., 6 mm) as follow:

C0: drinking water with approx. 1 mS cm-1;

C1: drinking water + salt for approx. 4.5 mS cm-1;

C2: drinking water + salt for approx. 9.0 mS cm-1;

C3: drinking water + salt for approx. 13.5 mS cm-1;

C4: drinking water + salt for approx. 18.0 mS cm-1.

-For the effect of ET treatment per dose, four quantities (doses) of a constant water quality (C1: drinking water + cooking salt to obtain approx. 4.5 mS cm-1) were applied:

D0 :120 ml

D1 :132 ml (D0 + 10% leaching fraction)

D2 :144 ml (D0 + 20% Leaching Fraction)

D3 :156 ml (D0 + 30% Leaching Fraction)

D4:168 ml (D0 + 40% leaching fraction)

Based on water irrigation, two treatments were selected: magnetized and non-magnetized water.

Experiment 2: Duration of ET treatment

This experiment was carried out to assess the effect of ET on the characteristics of the soil and drained water, the water applied for irrigation was prepared from drinking water with an addition of cooking salt to get an EC of around 4.5 mS cm^{-1}, the same quality that had been retained in Experiment 1.

This experiment consisted in exposing water to electromagnetic fields during three durations: T1: water subjected to ET for one second.

T2: water subjected to ET for 15 min.

T3: water subjected to ET for 30 min.

2.2. The Soils Characterization

The soil used (Table 1), in this study, was silty clay loam soil, rich in limestone, poor in organic matter, basic with low electrical conductivity (ECe).

Table 1. Main physical and chemical characteristics of the soil.

Clay (%)	Silt (%)	Sand (%)	CaCO3 (%)	Organic matter (%)	Bulk density (g cm^{-3})	pH	ECe (dS m^{-1})
26	44	30	25	1.0	1.4	8.1	0.1

2.3. Water Treatment

The waters used in this study were treated with the electromagnetic (EM) device t Aqua-4D® 60E model from Aqua 4D - Water solutions, operated at low frequencies and intensities. This device consists of two basic modules: an electronic box pre-programmed to generate EM waves and treatment units designed to transmit the EM waves into the water. Each treatment unit contains two coils that diffuse the EM waves in the water. The magnitude of EM field was 3.5 mT inside the coils [52]. It consists of a tube transmitting signals into the water and an electronic box generating the treatment signals. Water is in contact with the most intense electromagnetic field when inside a tube. The electromagnetic wave activity circulates in the water as long as there is no pressure reduction or stoppage. The dipole of the water molecule is influenced by an electromagnetic field. Under these conditions, water undergoes physical changes (molecule orientation and cluster size) or changes in its behavior with other molecules or ions present in the water: hydrophobic and polar interactions, ionic interaction and dissolution capacity. In fact, this treatment does not alter the mineral composition of the water. The more limescale in the water, the more effective the device will be, as the water will have better conductivity.

2.3. Water and Soil Physicochemical Analysis

2.3.1. Soil Water Content Measurement

The soil water content was assessed by a TDR (Time Domain Reflectrometry) from the Soil moisture Corp., model Trace. This device measures soil water content using time-domain reflectometry. The probes used are sheathed mini-probes Model 6005 LC. The soil moisture content measurements were taken before and after one hour of irrigation. The soil water tension was measured using Watermark tensiometers manufactured by Irrometer Corp. These tensiometers measure the water status of the soil in terms of tension in a range from 0 to 200 centibars (Cbar). The probes were placed in each pot. Different measurements were taken daily. Beforehand, a calibration of the tension and soil moisture masses was carried out. The data acquired enabled curves to be drawn of the variation in water tension as a function of water content: h(Θ).

2.3.2. Bulk Density

In addition to monitoring soil water content in situ, soil moisture was determined by taking soil samples from each pot at the end of the experiment. For this purpose, and to convert weight moisture into volume moisture, the dry bulk density of the soil per pot was measured using the cylinder method. This density was also used to estimate the variation in total soil porosity.

2.3.3. Soil Electrical Conductivity

Soil salinity was determined before the first irrigation and at the end of the irrigation cycle. Soil was taken from each pot, air-dried and sieved to 2 mm. An aqueous solution was extracted from the saturated paste to determine electrical conductivity (ECe) by the electrical conductivity meter, VWR pHenomenal® CO 3100L.

2.3.4. Drainage Water pH

The pH was determined on the drainage water collected after each irrigation and at each pot using a pH meter, VWR pHenomenal® pH 1100L.

2.3.5. Salt Analyses

Sodium (Na+), potassium (K+), calcium (Ca2+), magnesium (Mg2+), chloride (Cl-), bicarbonate (HCO3), and sulfates (SO42-) were analyzed directly for water and on saturated paste for soil. Na+ and K+ were analyzed by flame photometry (NF A20–603, 1989). Ca2+ and Mg2+ concentrations were determined by EDTA titration method. Cl- was quantified based on silver nitrate titration method (Karaivazoglou et al. 2005). HCO3- was analyzed by titration with sulfuric acid (H2SO4 0.01 N) and SO42- content was determined according to the nephelo metric method (NFT 90–040).

2.3.6. Data Analyses

Statistical processing was performed via the software SPSS (Statistical Package for the Social Sciences, 10.2.95.0). All values are the means of comparing 27 replications (n = 27). Statistical analyses were carried out by the LSD test at the significance level of 0.05.

3. Results and Discussion

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 August 2024 doi:10.20944/preprints202408.1660.v1

In this study, the effect of ET of saline water on the leaching efficiency of soil salinity along with the effect of ET duration on drainage water and soil salinity were reported.

3.1. Effect of Saline Water TE on Soil Salt Leaching Efficiency

3.1.1. Effect of ET on Salt Leaching in Response to Irrigation Water Salinity

3.1.1.1. Effect of ET on Drained Water

The drained fraction was evaluated for the volume of each irrigation (Figure 1) and for the cumulative volume of each treatment (Figure 2). The findings revealed that the ET of saline water significantly affected the volume of drainage water. Indeed, the volume of ET irrigation water was significantly higher than that of the untreated irrigation water for all five concentrations: C0, C1, C2, C3 and C4. The fraction of the drained water after electro magnetization increased from about 33 to 56% in comparison with non-treated saline water, which showed an increase from 20 to 26%. These results show that the increase in the volume of drainage water was observed over time with the rise in the irrigation frequency. Similar findings were reported in the study conducted by Zlotopolski [16] who proved that the total volume of water collected in reservoirs under the columns (leachate) was different between the Magnetically-treated water (MTW) and untreated columns. Hamza [78] also reported an increase of the volume of drainage water by 20%, compared to non-magnetized water (NMW) due to the augmentation in magnetic field in the drainage water. Besides, the magnetization effect was reported to increase at a longer exposure time of water to magnetic field [79,80].

In similar way, Zúñiga et al.[80] stated that the increase of the time of water exposure to magnetism could modify the polarity and intensity of water molecules and raise their excitation, which allowed the efficient reorganization of their clusters.

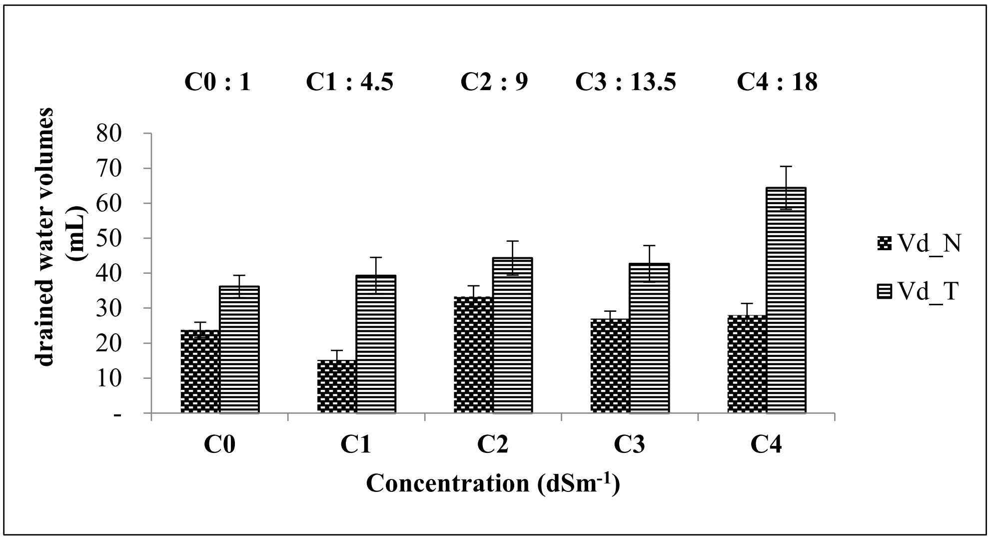

Figure 1. Variation in the average volume of drained water with salinity level of irrigation water (Vd_N: Volume of untreated drained water; Vd_T: Volume of treated drained water).

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 August 2024 doi:10.20944/preprints202408.1660.v1

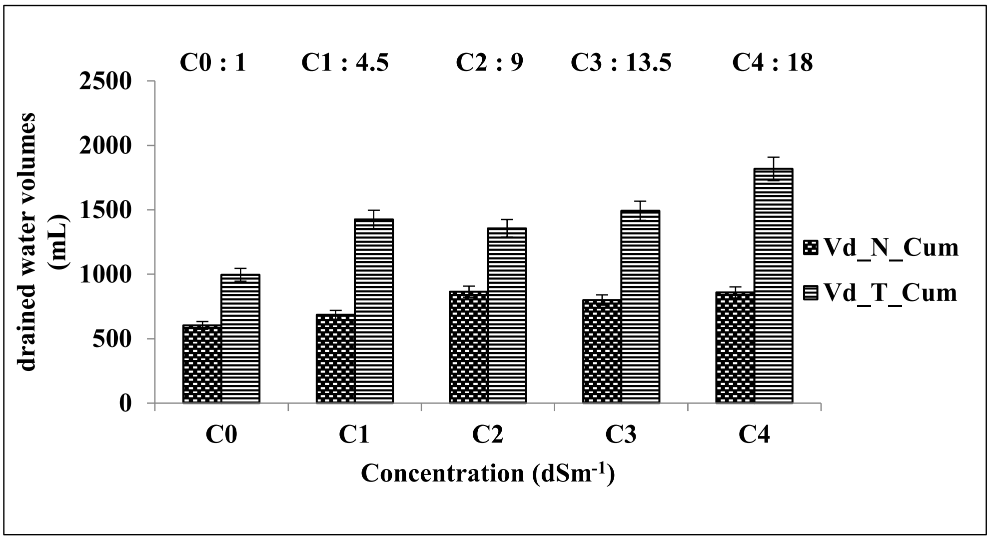

Figure 2. Variation of the drained water fraction of the cumulative volume with treatment (Vd_N_Cum: Cumulative untreated drained water volume; Vd_T_Cum: cumulative treated drained water volume).

The results in Figure 3 revealed that the EC values in drained water from soil irrigated with electro-magnetized water were higher than those in untreated water. Hence, an increase in EC of drained water of 2.72, 3.48, 10.79, 11.18 and 19.15 $dS.m^{-1}$ for C0, C1, C2, C3 and C4 respectively, was observed. Based on these results, the irrigation with electro-magnetic saline water allowed to remove more soluble salts from the soil receiving high saline irrigation water.

Gudigar and Hebbara [74] stated that the use of magnetically-treated water increased the salt content in drainage water, which was not the case when applying non-magnetized water. This aligns with the findings of Mohamed and Bassem [81] who observed that the values of EC in drainage water irrigated with magnetized water were higher than in non-magnetized water. Additionally, Raheem [82] noticed that, by increasing the magnetic intensity, magnetized water can positively affect salt leaching with an augmentation of EC values of the drained water. According to Zlotopolski [16], the salt content, at a lower depth in a column of soil irrigated with MTW, was higher than that in control. Therefore, the finding in this study aligned with the previous studies in term of the salt accumulation in lower depths of the soil EC contents augmentation in the drainage water.

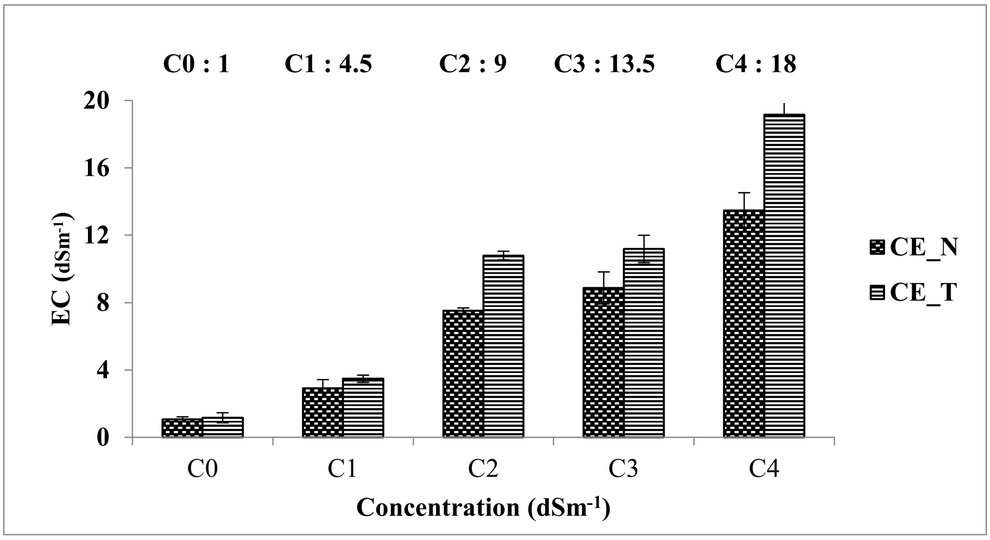

Figure 3. Variation of the average EC value of the drained water (EC_N: Untreated electrical conductivity; EC_T: Treated electrical conductivity).

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 August 2024 doi:10.20944/preprints202408.1660.v1

Besides, the leaching solutions of electro-magnetized water had a higher concentration of soluble cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) compared to those of untreated water (Table 2). According to these findings, we may conclude that the EMT irrigation water increased the leaching of soluble salts. Similar effect was also reported by Hilal and Anwar [83] who found that the solubility and uptake of Ca^{2+}, Mg^{2+} and Na^{+} were accelerated by magnetized water. Data obtained from HCO_3^-, SO_4^{2-} and Cl^- analysis in drainage water affected by using untreated water and EMT irrigation water are presented in Table 2.

Table 2. Effects of ET of saline water on the drainage water chemical components (me L^{-1}).

Treatment	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	SO_4^{2-}
EMT							
C0	4.50	5.50	247.10	2.88	233.15	3.50	14.36
C1	19.50	7.50	296.79	4.70	299.50	4.50	24.00
C2	15.30	6.60	170.30	2.50	169.78	7.40	14.60
C3	18.00	6.50	268.44	2.25	259.44	5.50	25.73
C4	35.41	13.50	459.60	6.80	463.12	7.60	43.80
NT							
C0	10.50	3.50	150.23	1.78	145.12	4.50	18.20
C1	17.00	12.00	154.78	1.90	160.20	5.50	17.80
C2	15.00	6.50	160.70	1.87	153.69	6.50	22.63
C3	17.80	9.50	212.89	2.74	220.23	8.00	21.34
C4	32.50	12.00	451.14	4.25	445.56	7.00	45.59

*Electromagnetic treated water, **Untreated water.

It was found that the use of EMT irrigation water resulted in significant increase of HCO_3^- and Cl^- concentrations, compared with untreated water. Therefore, these results highlight that EMT water played an important role in removing the soluble salts from the soil. In addition, ETW was more efficient in removing salts through drainage water, compared to untreated water, and allowed leaching under the root zone. This ET efficiency was clearly observed at the end of the irrigation cycle. Moreover, Gudigar and Hebbara [74] reported that dissolved salts, such as carbonates, phosphates, chlorides and sulfates, are slightly soluble in soil under magnetic treatment. Other previous researchers stated that irrigation with MTW boosted the leaching of the excessive amount of soluble salts such as calcium, sodium and bicarbonate [69].

Compared to the salts provided by saline irrigation water, the quantities of exported salts are significantly higher when the irrigation water was treated electromagnetically (Figure 4). The salt balance of the water shows that the quantities of exported salts vary from 21 to 31% with non-magnetized water and from 39 to 88% with magnetized water. These values are 88.04, 51.79, 38.73, 50.48 and 58.90% for C0, C1, C2, C3 and C4, respectively, in the case of electro magnetized saline water, while the values recorded under untreated irrigation water are 31.55, 21.77, 20.49, 22.79 and 25.70% for C0, C1, C2, C3 and C4, respectively.

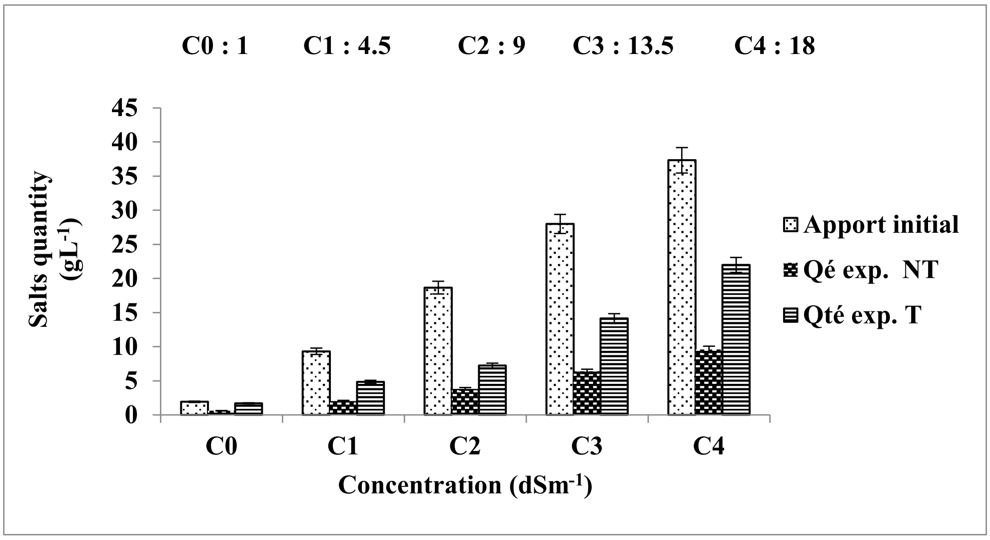

Figure 4. Variation of exported salt quantities with treatment (Q exp. NT: quantity of untreated exported salts; Q exp. T: quantity of treated exported salts).

3.1.1.2. Effect of ET on Soil Water and Salt Contents

The soil moisture contents showed a significant difference ($P<0.05$) between the ET irrigation water and the untreated irrigation water for five concentrations (Figure 5). The results demonstrated that irrigation with ETM water, compared to untreated water, increased significantly the soil moisture up to 9.9 % for C0 (1.0 $dS.m^{-1}$). However, these findings did not show a remarkable rise for C1 and C2. Accordingly, the use in certain conditions of electro-magnetized water for irrigation is recommended to save irrigation water. The results dealing with the effect of electromagnetic on soil salinity are consistent with those obtained by [76] where a small reduction in the rate of soil evaporation was observed when electromagnetized water was applied. Zlotopolski [16] showed that soil irrigated with MTW is wetter than control soil irrigated with the same amount of non-magnetized water. Moreoever, Gabrielli et al. [84] found also that the formation of aragonite, after the magnetization of water, increases the osmotic pressure of the soil with the decrease in evaporation. It was also concluded that the exposure of water to an electromagnetic field minimizes its surface tension, raises its solubility and, subsequently, increases the wettability of the soil [68]. Furthermore, Moosa et al. [34] found that the maximization of the soil moisture may be due to the degradation in the surface tension and water viscosity after exposure to the electromagnetic fields. The high soil moisture obtained under electro-magnetized irrigation water was due to the fact that the water molecules were influenced by hydrogenic bonds and Van der Waals forces and in reaction with the released ions which made water more cohesive [86]. Thus, the water molecules could be easily attached to the soil particles and water molecules might easily penetrate into the micro-spaces of the soil particles [86]. Moreover, when water passed through the electro-magnetized field, its structure and some of its physical characteristics changed [69]. The increase in soil moisture could be attributed to the decomposition of macromolecules of magnetized water into smaller molecules, increasing the mobility of water and then allowing it to enter smaller soil pores, which consequently, improved the retention of water soil macro-porosity [6,87].

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 August 2024 doi:10.20944/preprints202408.1660.v1

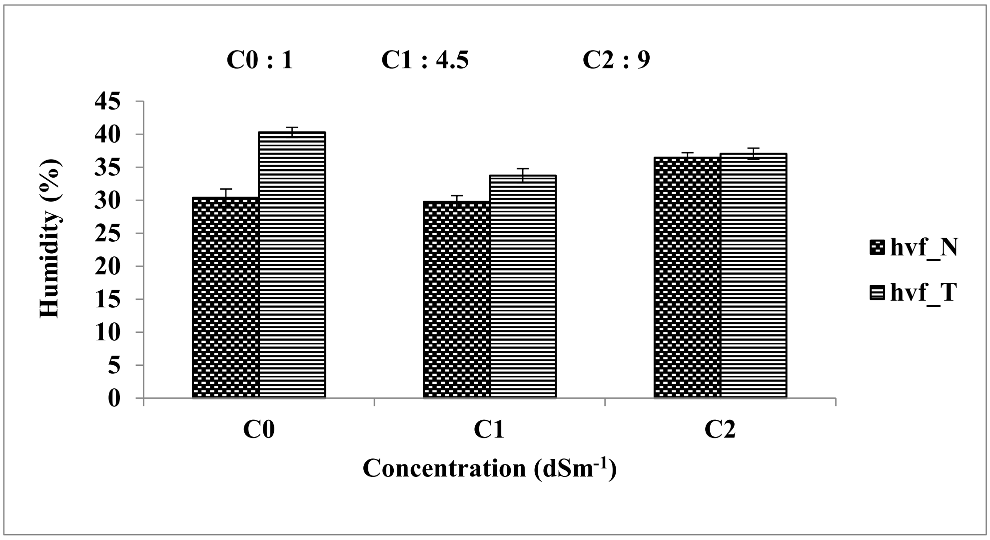

Figure 5. Variation in the water content of soils by salinity of irrigation water (hvf_N: Final untreated moisture; hvf_T: Final treated moisture).

The variation of average ECe of soil according to the irrigation water treatment is presented in Figure 6. The results revealed a significant increase in ECe with the increase in EC of irrigation water. For different treatments, the lowest mean values of soil EC were recorded under irrigation with electromagnetized water, compared with initial conditions. These results are consistent with those reported by Hamza [77] who revealed that soil leached with magnetically-treated water had lower salinity than soil leached with untreated water due to the significant salt removal using TM, compared to control. Amer [89] have also affirmed that soil irrigated with magnetically-treated fresh, saline, and highly saline water decreases the soil EC, compared to soil irrigated with non-magnetically treated water. Likewise, Mohamed and Ebead [90] concluded that magnetic treatment of irrigation water reduces the risk of sandy soil salinization. Such removal plays an important role in improving the regeneration of salt-affected soils [90–92].

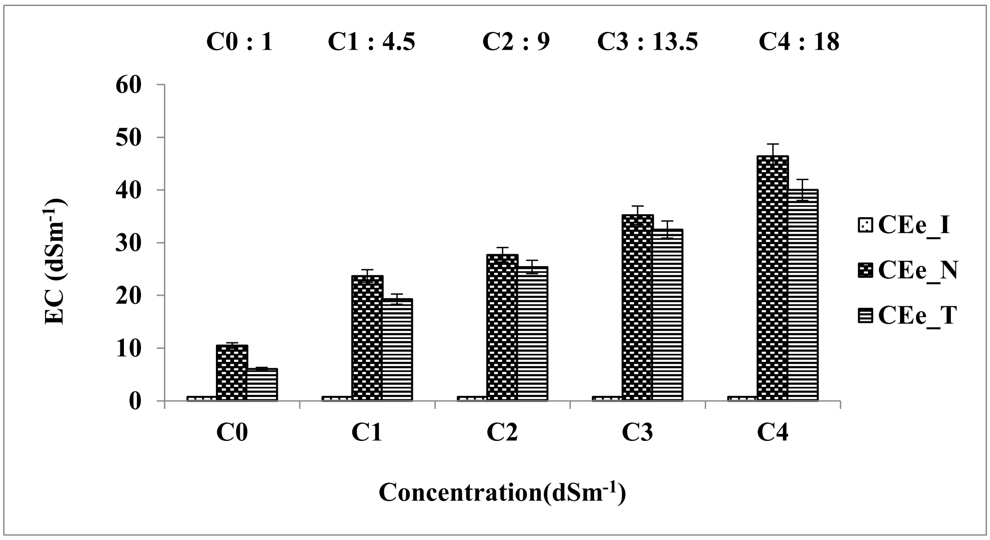

Figure 6. Variation of the average EC value of the soil (ECe_I: Initial electrical conductivity; ECe_N: Untreated electrical conductivity; ECe_T: Treated electrical conductivity).

Data showing the effect of leaching using untreated and electro-magnetized water on the soluble soil cation concentrations are presented in Table 3.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 August 2024 doi:10.20944/preprints202408.1660.v1

Table 3. Effects of ET of saline water on on soil the chemical components (me L^{-1}).

Treatment	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	SO_4^{2-}
EMT*							
C0	15.00	6.50	79.22	1.73	76.28	5.50	19.62
C1	35.30	12.50	202.91	2.82	208.98	6.00	41.58
C2	37.50	12.00	222.92	2.50	225.60	5.00	44.70
C3	39.00	11.00	356.08	2.96	358.56	5.50	45.25
C4	47.00	9.00	575.83	4.01	580.99	6.50	20.85
NT**							
C0	25.00	8.50	44.22	2.20	45.12	5.50	32.12
C1	38.00	16.50	186.78	2.80	194.4	7.20	45.20
C2	41.00	15.30	205.42	3.00	204.56	5.30	52.50
C3	41.50	17.82	298.78	3.11	296.21	6.70	57.19
C4	52.50	11.50	481.22	3.93	487.97	7.00	55.11

*Electromagnetic treated water, **Untreated water.

The latter revealed that salinity in the ET soil significantly decreased, compared with that in the untreated soil. This finding indicated that the soluble soil salts and the electro-magnetized irrigation water improves the solubility of Na+ salts in soil because Na is a paramagnetic element that has a small positive susceptibility to the magnetic fields, while other elements are diamagnetic and slightly repelled by a magnetic field [35]. It was also observed that the soil irrigated with EMT water significantly increased the available soil Mg and Ca content, compared with the soil irrigated with untreated water [93,94].

However, no clear trend for using ETM irrigation water in soluble K concentration was observed, compared with untreated water. This result is in contrast with that obtained by Abd-Elrahman [35] and Maheshwari and Grewal [94] who found that the potassium increased using the magnetically treated water. The concentrations of HCO_3^-, Cl^-, and SO_4^{2-} in soil decreased significantly with soil irrigated by EMT water. These results are in accordance with those of Mostafazadeh-Fard et al. [69] who indicated that the concentration of sulfate decreases in soil extraction by magnetized irrigation water. Hilal and Hilal [65] reported that magnetized water dissolves slightly soluble salts such as carbonates and sulfates. Hachicha et al. [57] have reported that the concentrations of SO4, Mg, Ca and HCO3 decreased when the saline water irrigation is exposed to ET in the soil, which is not the case when untreated water was used. The results of this study are in agreement with those provided by Mohamed and Ebead [90], who confirmed that irrigation with MTW declined remarkably Cl^-, Na^+ and $SO4^-$ content in the soil, compared to the control. Moreover, Kronenber [96] confirmed that, in untreated water, a quantity of carbonate is deposited in soil pores and on the plant roots. However, by using magnetic water, the carbonate salts cannot precipitate. Moreover, this water can break down the precipitated salts on the internal surface of irrigation pipes and laterals. Thus, its movement will occur easily than that of untreated water. In addition, the chloride content becomes lower in soils subjected to electromagnetic treatment due to the increase of salt leaching by electro-magnetized water. A similar result was reported by Maheshwari and Grewal [93] and Hilal et al. [94].

The variation of the ionic composition was analyzed at the level of the ratio between the cations through the SAR (Sodium Adsorption Ratio). The decrease in the SAR was highly significant for the C0, C3, and C4 concentrations, reflecting a more balanced cationic composition between Na^+ and Ca^{2+} Mg^{2+} produced from a higher Na^+ drain. These results are in agreement with those obtained by AL-Mosawi [97] who showed that the high values of the SAR can be provided by adding NaCl salts to drinking water, causing an excessive increase in Na^+. Besides, Papadopoulos et al. [98] reported a decrease in SAR with the increase of magnetic field (MF) levels.

Soil salt balance can be deduced from the ECe applying the parameters necessary for its mass conversion per pot using the following relationship:

$$S = ECe * 0.64 * SP * Bd \quad (1)$$

 doi:10.20944/preprints202408.1660.v1

where:

S: Salt stock (g pot^{-1}).

0.64: Conversion factor from ECe (g).

PS: Saturation percent equal to 0.4.

Bd: Bulk Density equal to 1.3 (g cm^{-3}).

The in Figure 7 confirm that the quantity of residual salts in the soil is less when the saline irrigation water is treated electromagnetically for the five concentrations. The quantities are 2.03, 6.42, 8.45, 10.81 and 13.31 g pot^{-1} for C0, C1, C2, C3, and C4, respectively, when the soil is subjected to EMT treatment and 3.49, 7.89, 9.22, 11.71, and 15.44 g pot^{-1} for C0, C1, C2, C3 and C4, respectively when the soil is subjected to untreated water.

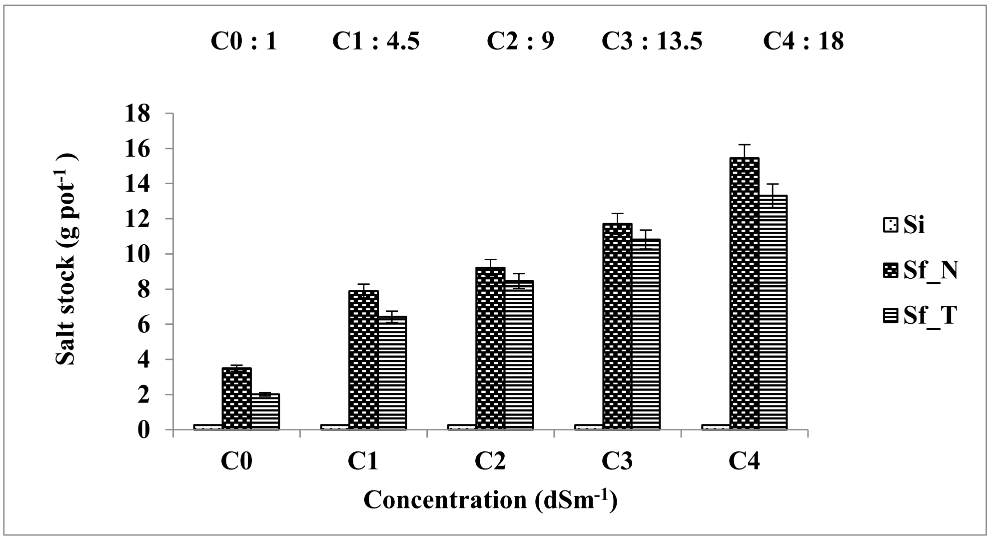

Figure 7. Variation of salt stocks according to treatments**.** (Si: Initial stock, Sf_N: Final untreated stock, Sf_T: Final treated stock).

For the same electrical conductivity of irrigation water (treated water and untreated water), the comparison between the quantities of salts in the soils deduced from the final salinity (ECe) and those estimated from the difference between the salts brought back by the irrigation water and those evacuated by the drainage water shows that these quantities are higher in soils for water of concentration C0 and C1, and lower for the other three concentrations (C2, C3 and C4).

3.1.2. Effect of the ET on Soil Salt Leaching in Response to Irrigation Dose

3.1.2.1. Effect on Drainage Water

As illustrated in Figure 8, the volume of drainage water is significantly affected by water treatment, especially, for high doses (D3 and D4). Indeed, the volume recorded under irrigation with treated saline water was significantly ($P<0.05$) higher than those recorded with untreated saline water and the difference ranged from 1.1% to 41.4%. Results for D3 and D4 showed that the fraction of drained water varies from 26 to 32% under irrigation with untreated water, and rises to 30 to 51% when using treated water. Figure 9 shows the average salinity values of drained water per irrigation dose. The mean EC values for treated and untreated water are significantly different for only the D0 dose. For the other doses, the EC of treated saline water is higher than that of untreated water, but this difference remains non-significant.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 August 2024 doi:10.20944/preprints202408.1660.v1

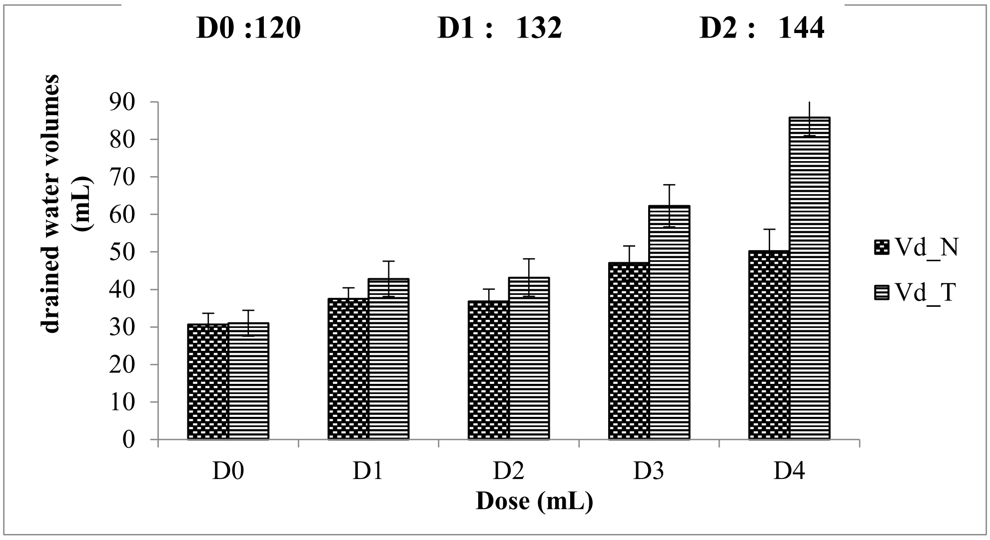

Figure 8. Variation in average drained volume values per irrigation dose.(Vd_N: volume of untreated drained water; Vd_T: volume of treated water).

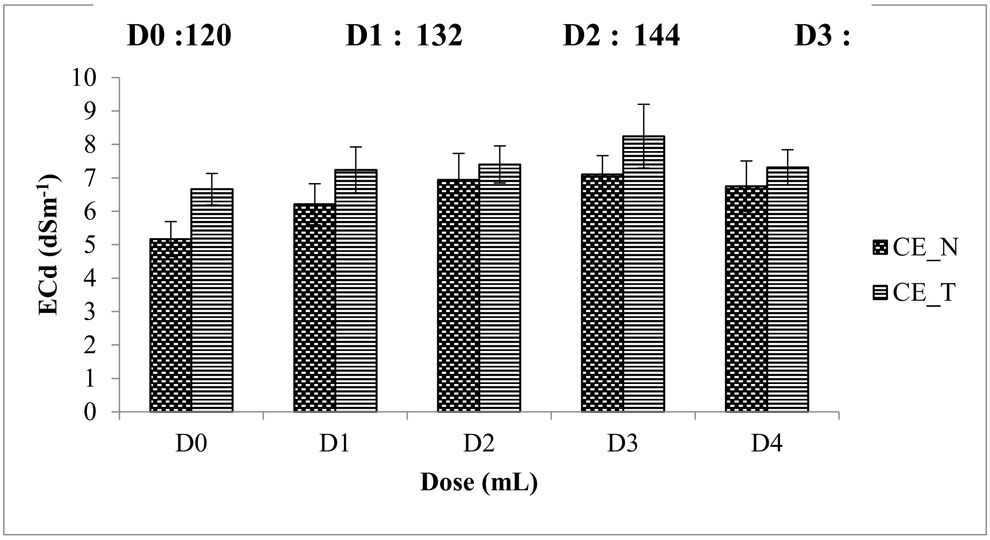

Figure 9. Variation in average EC value of drained water per irrigation dose. (EC_N: untreated EC; EC_T: treated EC).

According to Figure 10, a significant difference between the water content of the soil irrigated with treated and untreated water for doses D1 and D2 is shown. Nevertheless, the difference is not significant with D0. Generally, the soil moisture ranged between 0.8% and 10.5%.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 August 2024 doi:10.20944/preprints202408.1660.v1

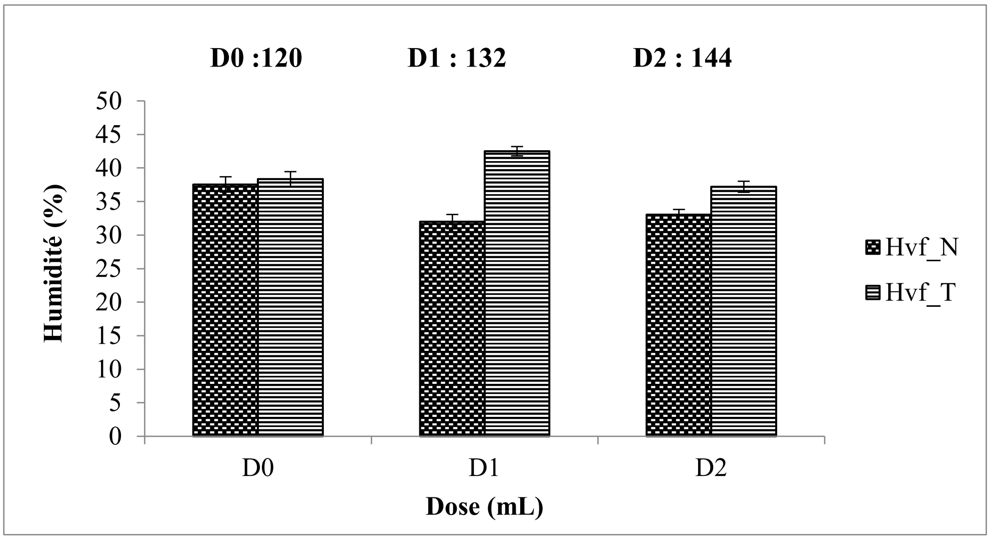

Figure 10. Average soil moisture content as a function of irrigation rate. (Hvf_N: untreated final moisture; Hvf_T: treated final moisture).

The soil salinity variation under different treatments was also investigated depending on the dose and the results are presented in Figure 11. The result showed a significant decrease in soil salinity when saline irrigation water is treated with electromagnetic fields compared to the same untreated water.

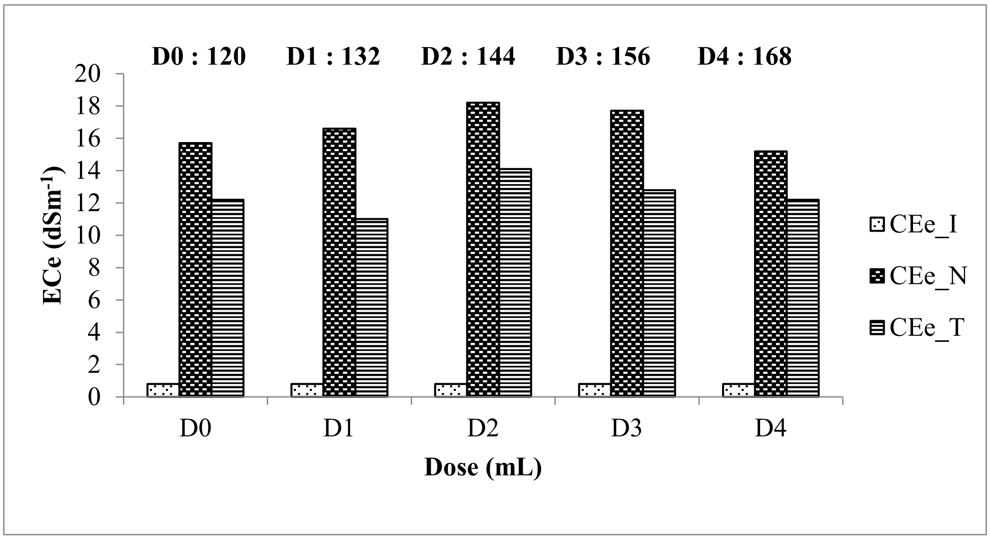

Figure 11. Variation in soil salinity (ECe) as a function of dose and treatment. (ECe_I: initial irrigation ECe, ECe_N: untreated ECe, ECe_T: treated ECe).

In addition, the determination of the salt balance in the soil confirms that the quantity of residual salts is significantly lower when saline irrigation water is treated. For the same treatment (treated and untreated water), the comparison between the quantities of salts in the soil deduced from the determination of final salinity (ECe) and those estimated from the difference between the salts brought back by irrigation water, and those discharged by drainage water shows that these quantities are fairly close, except for D4 concerning the water balance.

3.2. Effect of TE Duration on Drainage Water and Soil

3.2.1. Effect on Drainage Water

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 August 2024 doi:10.20944/preprints202408.1660.v1

The exposure time to any magnetic field is among crucial factors that can influence and explain the different observed effects. In the current study, the volumes of water drained are determined for three different durations of exposure to electromagnetic field (T1=1s, T2=15mn, and T3=30mn). The finding showed a highly significantly difference between treatments. For the duration of T1, the volume of drainage was about 31% of the total volume of irrigation water and increased with the increase of the duration of exposure to electromagnetic field, reaching 36% and 46% for T2 and T3, respectively (Figure 12).

The drained water ECs showed also significant differences ($p<0.05$) between treatments. For T1, T2 and T3 durations, ECe values vary between 9.8, 11.3 and 13.3 dS m^{-1} (Figure13).

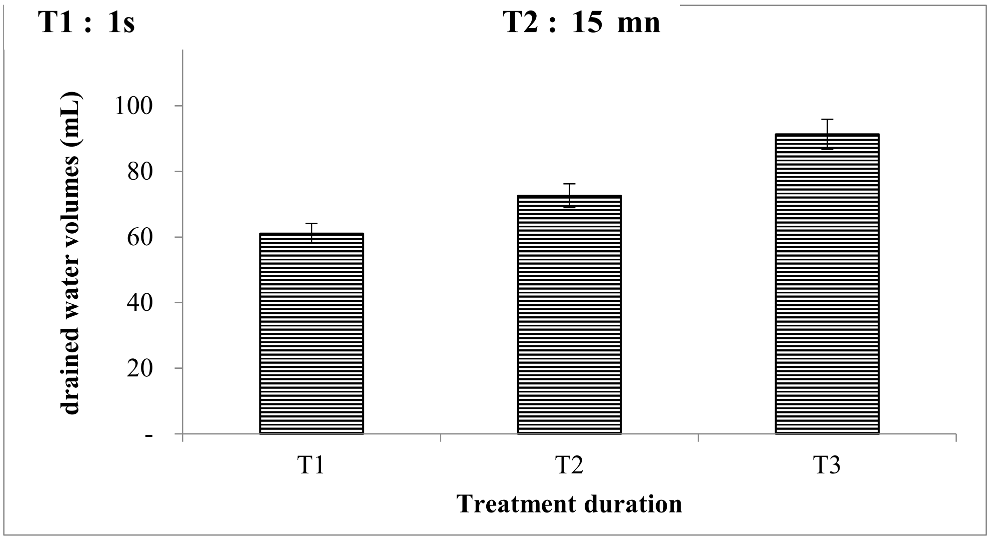

Figure 12. Variation in drained water volumes for different ET durations.

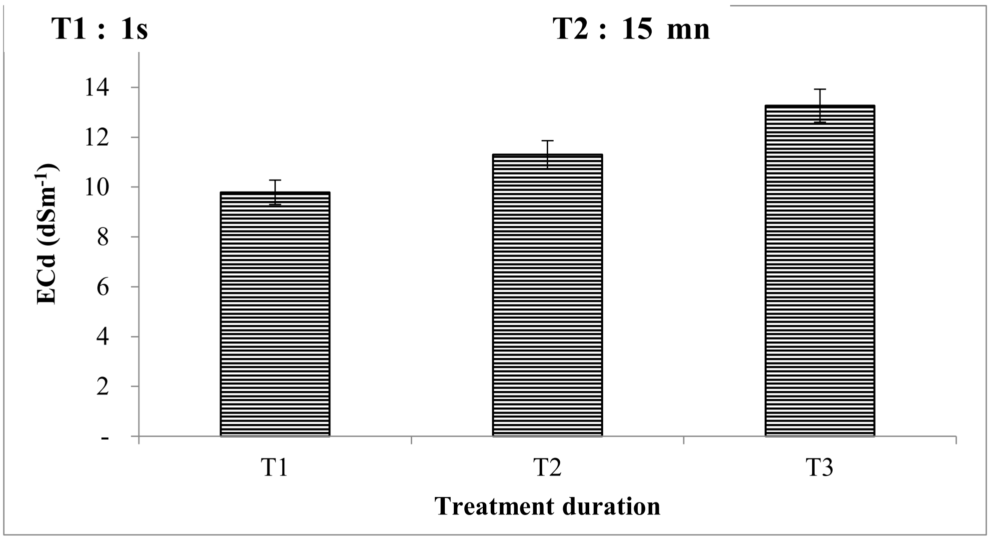

Figure 13. Variation in ECd of drained water for different ET durations.

3.2.2. Effect on Soil Water and Salt Contents

The effect of exposure time on soil moisture and salinity was also investigated. The results demonstrated that there is highly significant difference in water content between T1, T2 and T3 durations, varying between 2.44, 2.58 and 2.64% (Figure14). Overall, the soil moisture content at the end of the experiment is higher when the duration of ET of irrigation water is longer, suggesting that ET exposure duration is a significant criterion of effectiveness.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 August 2024 doi:10.20944/preprints202408.1660.v1

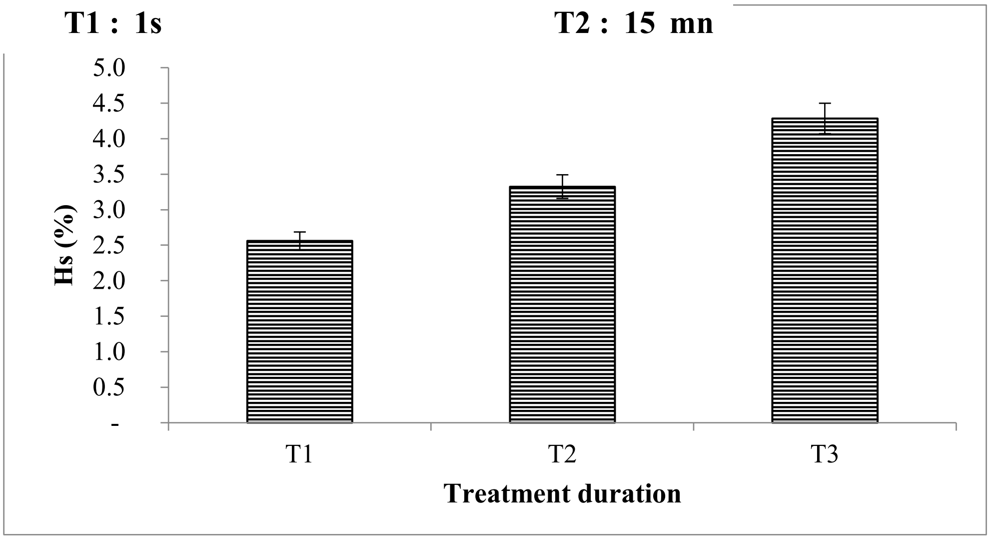

Figure 14. Variation in mean soil moisture values as a function of ET duration (Hs: Final moisture - Initial moisture).

The effect of ET duration on soil salinity was highlighted (Figure 15). In comparison with the beginning of the trial, ECe values at end of the trial showed a highly significant increase, reaching 9.01 dS m^{-1} with T1, 5.98 dS m^{-1} with T2 and 1.74 dS m^{-1} with T3.

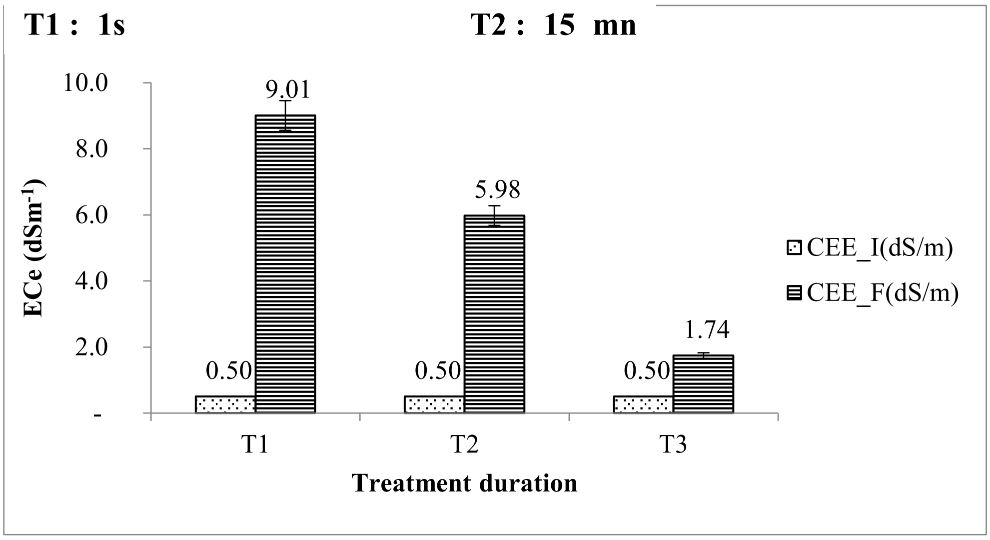

Figure 15. Variation in soil salinity (ECe) as a function of ET duration. (ECe_I: initial ECe; ECe_F: final ECe).

The findings of the current study are consistent with those reported by Abdul-Raheem and Azzubaidi [99] who showed that the efficiency of magnetized water in removing salts from the soil is more than the untreated water. They reported that as the magnetic intensity and exposure time are increased, more salts were leached out of the soil. The increase in salt leaching is manifested by an increase in EC values of the drained water.

Conclusion

The current study showed the benefits offered by the use of an electromagnetic device for saline water treatment on drained water and soil. Five salt concentrations were selected: a control, low-salt drinking water (C0=1dS m^{-1}) and four other concentrations (C1, C2, C3, C4), 4.5 dS. m^{-1}, 9 dS m^{-1}, 13.5

dS m^{-1} and 18 dS m^{-1}. The results demonstrated that electromagnetic treatment of saline water plays an important role in reducing soil salinity and increasing the volume of drainage water. The fraction of drained water increased from 20 to 26% when the irrigation water was untreated to about 33 to 56% when the same water was passed through the electromagnetic field. This finding reflected better salts leaching with the electromagnetic treatment and a better export of these salts outside the root zone. With regard to ionic composition, the evacuated salts under the electromagnetic treatment were rich in chloride and sodium. The salt balance of the water showed that the quantities of exported salts varied from 21 to 31%, with untreated water, and from 39 to 88% with electromagnetic treated water. The water content of soils irrigated with electro-magnetic treated water was slightly higher than in soils irrigated with untreated water. These results imply that the increase in the volume of drained water does not affect the volume of water retained by the soil, which leads to better water efficiency, which can be expressed in water saving.

Besides, the soil salinity (ECe) increased proportionally with the salinity level of the irrigation water, but remained low when the irrigation water was treated. The chloride and sodium contents were slightly lower, while those of sulfates, calcium and magnesium were slightly higher in soils irrigated with treated water. This kind of salt has a positive impact on the preservation of the soil structure against degradation and on better behavior of plants. The soil balance showed that the residual quantity of salts in the soil was lower with treated water.

The results deduced from the water salt balance were confirmed by those from the soil salt balance. Regarding the efficiency of irrigation water (water saving) when exposed to ET, it is conceivable that water saving in the case of irrigation with salt water can be achieved on the leaching dose. Thus, a higher the dose means more obvious and significant TE effects. Soil water content was monitored, and the results showed that soil irrigated with electromagnetic treated water retains a slightly higher moisture content than soil irrigated with untreated water. On the practical side, and in terms of “water saving”, the leaching dose usually recommended can be reduced without increasing soil salinity. So, instead of the 30% leaching fraction recommended for a water content of 3 g/l, a fraction of just 20% would be sufficient to save 10% water while maintaining the same soil salinity.

The study carried out with different treatment durations revealed a highly significant increase in the volume and salinity of drained water as TE duration increased. At soil level, an increase in ET duration induces an increase in soil water content of around 2.5%. Finally, it can be concluded that the electromagnetic treatment has a clear and positive effect on improving the salts leaching regardless of their concentrations in the irrigation water.

Acknowledgments : This research and innovation study is being carried out within the framework of the MOBIDOC scheme, funded by the European Union as part of the Science With And For Youth “SWAFY” project and administered by the National Agency for the promotion of scientific research, ENI/2022/432 – 485.

References

1. Vaghefi S A, Mousavi S J, Abbaspour K C, Srinivasan R and Yang H 2014 Analyses of the impact of climate change on water resources components, drought and wheat yield in semiarid regions: Karkheh River Basin in Iran *Hydrol. Process.* **28** 2018–32
2. Daliakopoulos I N, Tsanis I K, Koutroulis A, Kourgialas N N, Varouchakis A E, Karatzas G P and Ritsema C J 2016 The threat of soil salinity: A European scale review *Sci. Total Environ.* **573** 727–39
3. Famiglietti J S 2014 The global groundwater crisis *Nat. Clim. Change* **4** 945–8
4. Taimourya H, Bourarach E-H, Harif A E, Hassanain N, Masmoudi L, Baamal L and Oussible M 2015 Évaluation de la productivité du chou pommé (Brassica oleracea), sous l’effet de l’irrigation avec une eau traitée magnétiquement, dans la région de Casablanca (Maroc) *Rev. Marocaine Sci. Agron. Vét.* **3** 27–36
5. Wada Y, Lo M-H, Yeh P J-F, Reager J T, Famiglietti J S, Wu R-J and Tseng Y-H 2016 Fate of water pumped from underground and contributions to sea-level rise *Nat. Clim. Change* **6** 777–80
6. Khaskhoussy K, Bouhlel M, Dahmouni M and Hachicha M 2023 Performance of different magnetic and electromagnetic water treatment devices on soil and two tomato cultivars *Sci. Hortic.* **322** 112437
7. Lin L, Jiang W, Xu X and Xu P 2020 A critical review of the application of electromagnetic fields for scaling control in water systems: mechanisms, characterization, and operation *Npj Clean Water* **3**

8. Moon J-D and Chung H-S 2000 Acceleration of germination of tomato seed by applying AC electric and magnetic fields *J. Electrost.* **48** 103–14
9. Galland P and Pazur A 2005 Magnetoreception in plants *J. Plant Res.* **118** 371–89
10. Nimmi V and Madhu G 2009 Effect of pre-sowing treatment with permanent magnetic field on germination and growth of chilli (Capsicum annum. L.). *undefined*
11. Rady M M 2012 A novel organo-mineral fertilizer can mitigate salinity stress effects for tomato production on reclaimed saline soil *South Afr. J. Bot.* **81** 8–14
12. Roy S J, Negrão S and Tester M 2014 Salt resistant crop plants *Curr. Opin. Biotechnol.* **26** 115–24
13. Singh M, Kumar J, Singh S, Singh V P and Prasad S M 2015 Roles of osmoprotectants in improving salinity and drought tolerance in plants: a review *Rev. Environ. Sci. Biotechnol.*
14. Topaloglu D, Tilki Y M, Aksu S, Yilmaz T N, Celebi E E, Oncel S and Aydiner C 2018 Novel technological solutions for eco-protective water supply by economical and sustainable seawater desalination *Chem. Eng. Res. Des.* **136** 177–98
15. Burn S, Hoang M, Zarzo D, Olewniak F, Campos E, Bolto B and Barron O 2015 Desalination techniques — A review of the opportunities for desalination in agriculture *Desalination* **364** 2–16
16. Zlotopolski V 2017 The Impact of magnetic water treatment on salt distribution in a large unsaturated soil column *Int. Soil Water Conserv. Res.* **5** 253–7
17. Abdelghany A E, Abdo A I, Alashram M G, Eltohamy K M, Li J, Xiang Y and Zhang F 2022 Magnetized Saline Water Irrigation Enhances Soil Chemical and Physical Properties *Water* **14** 4048
18. Teixeira da Silva J A and Dobránszki J 2016 Magnetic fields: how is plant growth and development impacted? *Protoplasma* **253** 231–48
19. Wang S S S, Chang M-C, Chang H-C, Chang M-H and Tai C Y 2012 Growth Behavior of Aragonite under the Influence of Magnetic Field, Temperature, and Impurity *Ind. Eng. Chem. Res.* **51** 1041–9
20. Toledo E J L, Ramalho T C and Magriotis Z M 2008 Influence of magnetic field on physical–chemical properties of the liquid water: Insights from experimental and theoretical models *J. Mol. Struct.* **888** 409–15
21. Silva A K A, Luciani N, Gazeau F, Aubertin K, Bonneau S, Chauvierre C, Letourneur D and Wilhelm C 2015 Combining magnetic nanoparticles with cell derived microvesicles for drug loading and targeting *Nanomedicine Nanotechnol. Biol. Med.* **11** 645–55
22. Ben Amor H, Elaoud A, Ben Salah N and El Moueddeb K 2017 International Journal of Advance Industrial Engineering Effect of Magnetic Treatment on Surface Tension and Water Evaporation
23. Chang K-T and Weng C-I 2006 The effect of an external magnetic field on the structure of liquid water using molecular dynamics simulation *J. Appl. Phys.* **100** 043917
24. Holysz L, Szczes A and Chibowski E 2007 Effects of a static magnetic field on water and electrolyte solutions *J. Colloid Interface Sci.* **316** 996–1002
25. Han X, Peng Y and Ma Z 2016 Effect of Magnetic Field on Optical Features of Water and KCl Solutions *Opt. - Int. J. Light Electron Opt.* **127**
26. Mercier A, Bertaux J, Lesobre J, Gravouil K, Verdon J, Imbert C, Valette E and Héchard Y 2016 Characterization of biofilm formation in natural water subjected to low-frequency electromagnetic fields *Biofouling* **32** 287–99
27. Piyadasa C, Yeager T R, Gray S R, Stewart M B, Ridgway H F, Pelekani C and Orbell J D 2018 Antimicrobial effects of pulsed electromagnetic fields from commercially available water treatment devices – controlled studies under static and flow conditions *J. Chem. Technol. Biotechnol.* **93** 871–7
28. Pradnya U, Prof A, Rahul D, Pandit R, Wadekar A, Student M and Professor A 2016 PERFORMANCE EVALUATION OF MAGNETIC FIELD TREATED WATER ON CONVECTIONAL CONCRETE CONTAINING FLYASH *Int. J. Sci. Technol. Manag.* **5** 68–77
29. Wang Y, Wei H and Li Z 2018 Effect of magnetic field on the physical properties of water *Results Phys.* **8** 262–7
30. Cai R, Yang H, He J and Zhu W 2009 The effects of magnetic fields on water molecular hydrogen bonds *J. Mol. Struct.* **938** 15–9
31. Parsons S A, Wang B-L, Judd S J and Stephenson T 1997 Magnetic treatment of calcium carbonate scale—effect of pH control *Water Res.* **31** 339–42
32. Cai R, Yang H, He J and Zhu W 2009 The effects of magnetic fields on water molecular hydrogen bonds *J. Mol. Struct.* **938** 159
33. Wang Y, Wei H and Li Z 2018 Effect of magnetic field on the physical properties of water *Results Phys.* **8** 262–7
34. Moosa G M, Khulaef jabbar H, Khraibt A C, Shandi N R and Braich M S K A 2015 Effect of Magnetic Water on Physical Properties of Different Kind of Water, and Studying Its Ability to Dissolving Kidney Stone *J. Nat. Sci. Res.* **5** 85
35. Abd-Elrahman W 2019 Effect of Repeated Magnetization Process of Water on the Waterand Soil Properties as well as Lettuce Yield *Ann. Agric. Sci. Moshtohor* **57** 1–10

36. Mostafa H 2020 Influence of magnetised irrigation water on the fertigation process and potato productivity *Res. Agric. Eng.* **66** 43–51
37. Fakhri N, Mehdaoui H Y, Elloumi N and Kallel M 2018 Magnetic Treatment Effects on Salt Water and Tomato Plants Growth *Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions* Advances in Science, Technology & Innovation ed A Kallel, M Ksibi, H Ben Dhia and N Khélifi (Cham: Springer International Publishing) pp 1095–7
38. Elhindi K M, Al-Mana F A, Algahtani A M and Alotaibi M A 2020 Effect of irrigation with saline magnetized water and different soil amendments on growth and flower production of Calendula officinalis L. plants *Saudi J. Biol. Sci.* **27** 3072–8
39. Mghaiouini R, Benzbiria N, Belghiti M E, Belghiti H E, Monkade M and El bouari A 2020 Optical properties of water under the action of the electromagnetic field in the infrared spectrum *Mater. Today Proc.* **30** 1046–51
40. Dobránszki J 2023 From mystery to reality: Magnetized water to tackle the challenges of climate change and for cleaner agricultural production *J. Clean. Prod.* **425** 139077
41. Quan K, Zhang Z, Chen H, Ren X, Ren Y, Peterson B W, van der Mei H C and Busscher H J 2019 Artificial Channels in an Infectious Biofilm Created by Magnetic Nanoparticles Enhanced Bacterial Killing by Antibiotics *Small Weinh. Bergstr. Ger.* **15** e1902313
42. Wang L, Meng Z and Zheng Y 2021 Engineering Magnetic Micro/Nanorobots for Versatile Biomedical Applications *Adv. Intell. Syst.* **3**
43. Xinxin M, Wang L, Wang P, Liu Z, Hao J, Wu J, Chu G, Huang M, Mair L O, Huang C, Xu T, Ying T, Tang X, Chen Y, Cai X and Zheng Y 2022 An electromagnetically actuated magneto-nanozyme mediated synergistic therapy for destruction and eradication of biofilm *Chem. Eng. J.* **431** 133971
44. Lu D, Shen W, Cao J, Lu T, Cui B and Fu Z 1999 Effect of magnetized water on the mice given high doses of antineoplastic drugs *J. Shanghai Univ. Engl. Ed.* **3** 81–3
45. Bali M, Yosra M and Nadia A 2016 Effects of magnetic treatment on scaling power of hard waters *Sep. Purif. Technol.* **171** 88–92
46. Trueba A, García S, Otero F M, Vega L M and Madariaga E 2015 The effect of electromagnetic fields on biofouling in a heat exchange system using seawater *Biofouling* **31** 19–26
47. Sohaili J, Shi H S, Lavania-Baloo, Zardari N H, Ahmad N and Muniyandi S K 2016 Removal of scale deposition on pipe walls by using magnetic field treatment and the effects of magnetic strength *J. Clean. Prod.* **139** 1393–9
48. Sergio M M and Nuria B B 2021 Review of Techniques to Reduce and Prevent Carbonate Scale. Prospecting in Water Treatment by Magnetism and Electromagnetism *Water* **13** 2365
49. Ghernaout D, Ghernaout B, Saiba A, Boucherit A and Kellil A 2009 Removal of humic acids by continuous electromagnetic treatment followed by electrocoagulation in batch using aluminium electrodes *Desalination* **239** 295–308
50. Yavuz C T, Prakash A, Mayo J T and Colvin V L 2009 Magnetic separations: From steel plants to biotechnology *Chem. Eng. Sci.* **64** 2510–21
51. Sisay M., Münch D, Egelandsdal B, Bjerke F, Wergeland I and Martinsen Ø G 2021 Combined 0.2 T static magnetic field and 20 kHz, 2 V/cm square wave electric field do not affect supercooling and freezing time of saline solution and meat samples *J. Food Eng.* **311** 110710
52. Merlin G, Noamen O, Evelyne G, Eric V, Gilles C and Marc H 2015 Hydraulic continuity and biological effects of low strength very low frequency electromagnetic waves: Case of microbial biofilm growth in water treatment *Water Res.* **83** 184–94
53. Fojt L, Strašák L, Vetterl V and Šmarda J 2004 Comparison of the low-frequency magnetic field effects on bacteria Escherichia coli, Leclercia adecarboxylata and Staphylococcus aureus *Bioelectrochemistry* **63** 337–41
54. Piyadasa C, Thomas R. Y, Stephen R. G, Matthew B. S and Harry F R 2015 The effect of electromagnetic fields, from two commercially available water treatment devices, on bacterial culturability | Water Science and Technology | IWA Publishing
55. Salmen S H, Alharbi S A, Faden A A and Wainwright M 2018 Evaluation of effect of high frequency electromagnetic field on growth and antibiotic sensitivity of bacteria *Saudi J. Biol. Sci.* **25** 105–10
56. Ambashta R D and Sillanpää M 2010 Water purification using magnetic assistance: A review *J. Hazard. Mater.* **180** 38–49
57. Hachicha M, Kahlaoui B, Khamassi N, Misle E and Jouzdan O 2018 Effect of electromagnetic treatment of saline water on soil and crops *J. Saudi Soc. Agric. Sci.* **17** 154–62
58. Faridvand S, Amirnia R, Tajbakhsh M, El Enshasy H A and Sayyed R Z 2021 The Effect of Foliar Application of Magnetic Water and Nano-Fertilizers on Phytochemical and Yield Characteristics of Fennel *Horticulturae* **7** 475
59. Azimi S M, Sheridan S D, Ghannad-Rezaie M, Eimon P M and Yanik M F 2018 Combinatorial programming of human neuronal progenitors using magnetically-guided stoichiometric mRNA delivery *eLife* **7** e31922

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 23 August 2024 doi:10.20944/preprints202408.1660.v1

60. Baghel L, Kataria S and Guruprasad K N 2018 Effect of static magnetic field pretreatment on growth, photosynthetic performance and yield of soybean under water stress *Photosynthetica* **56** 718–30
61. Sutiyanti E and Rachmawati D 2021 The effect of magnetized seawater on physiological and biochemical properties of different rice cultivars *Biodiversitas J. Biol. Divers.* **22**
62. Taimourya H, Oussible M, Baamal L, Bourarach E, Hassanain N, Masmoudi L and EL Harif A 2018 Magnetically Treated Irrigation Water Improves the Production and the Fruit Quality of Strawberry Plants (Fragaria × ananassa Duch.) in the Northwest of Morocco *J. Agric. Sci. Technol. B* **8**
63. Gamboa C H, Vezzani F M, Kaschuk G, Favaretto N, Cobos J Y G and da Costa G A 2020 Soil-Root Dynamics in Maize-Beans-Eggplant Intercropping System under Organic Management in a Subtropical Region *J. Soil Sci. Plant Nutr.* **20** 1480–90
64. Abedinpour M and Rohani E 2016 Effects of magnetized water application on soil and maize growth indices under different amounts of salt in the water *J. Water Reuse Desalination* **7** 319–25
65. Hilal M H and Hilal M M (National R C 2000 Application of magnetic technologies in desert agriculture. 2.-effect of magnetic treatments of irrigation water on salt distribution in olive and citrus fields and induced changes of ionic balance in soil and plant *Egypt. J. Soil Sci. Egypt*
66. Shabrangy A and Majd A 2009 Effect of Magnetic Fields on Growth and Antioxidant Systems in Agricultural Plants *Prog. Electromagn. Res. Symp.* **2**
67. Surendran S, O. S and E.j. J 2016 The impacts of magnetic treatment of irrigation water on plant, water and soil characteristics *Agric. Water Manag.* **178** 21–9
68. Yadollahpour A and Rashidi S 2017 Effect of magnetic field on optical features of water and KCl solutions - ScienceDirect
69. Mostafazadeh-Fard B, Khoshravesh M, Mousavi S-F and Kiani A-R 2011 Effects of Magnetized Water and Irrigation Water Salinity on Soil Moisture Distribution in Trickle Irrigation *J. Irrig. Drain. Eng.* **137** 398–402
70. Zhou B, Yang L, Chen X, Ye S, Peng Y and Liang C 2021 Effect of magnetic water irrigation on the improvement of salinized soil and cotton growth in Xinjiang *Agric. Water Manag.* **248** 106784
71. Soliman M D, Haimaa F and Zaky, S haimaa F 2017 EFFECT OF IRRIGATION WITH MAGNETIC SALINE GROUND WATER ON SOIL AND GRAPE CROP *J. Environ. Sci.*
72. Alkhazan M M K and Saddiq A A N 2010 The effect of magnetic field on the physical, chemical and microbiological properties of the lake water in Saudi Arabia *J. Evol. Biol. Res.* **2** 7–14
73. Lee S H, Jeon S I, Kim Y S and Lee S K 2013 Changes in the electrical conductivity, infrared absorption, and surface tension of partially-degassed and magnetically-treated water *J. Mol. Liq.* **187** 230–7
74. Gudigar A and Hebbara M 2018 Effect of Magnetic Treatment on Leaching Efficiency of Salts *Int. J. Curr. Microbiol. Appl. Sci.* **7** 3363–7
75. Yadollahpour A and Rashidi S 2015 Therapeutic Applications of Electromagnetic Fields in Musculoskeletal Disorders: A Review of Current Techniques and Mechanisms of Action *Biomed. Pharmacol. J.* **7** 23–32
76. Chibowski E and Szcześ A 2018 Magnetic water treatment-A review of the latest approaches *Chemosphere* **203**
77. Karaivazoglou N A, Papakosta D K and Divanidis S 2005 Effect of chloride in irrigation water and form of nitrogen fertilizer on Virginia (flue-cured) tobacco *Field Crops Res.* **92** 61–74
78. Hamza J N 2019 Investigation on using magnetic water technology for leaching high saline-sodic soils *Environ. Monit. Assess.* **191** 519
79. Kadhim K N and Al-Rufaye A H R 2018 Experimental Study of Magnetization Effect on Ground Water Properties
80. Yap C W, Lee H S, Loo J and Mohd N 2021 Electron generation in water induced by magnetic effect and its impact on dissolved oxygen concentration *Sustain. Environ. Res.* **31**
81. Zúñiga O, Benavides J A, Ospina-Salazar D I, Jiménez C O and Gutiérrez M A 2016 Magnetic treatment of irrigation water and seeds in agriculture *Ing. Compet.* **18** 217–32
82. Mohamed A I M and Bassem M E 2013 Effect of irrigation with magnetically treated water on faba bean growth and composition - Journal Issues
83. Raheem L H A 2018 Leaching of Salt Affected Silty Loam Soil by using Magnetized Water 5
84. Hilal M and Anwar N 2016 Vital Role of Water Flow and Moisture Distributionin Soils and the Necessity of a New Out-Look and Simulation Modeling of Soil- Water Relations *J. Am. Sci.* **13** 6–18
85. Gabrielli C, Jaouhari R, Maurin G and Keddam M 2001 Magnetic water treatment for scale prevention *Water Res.* **35** 3249–59
86. Al-Ogaidi A A M, Wayayok A, Rowshon M K and Abdullah A F 2017 The influence of magnetized water on soil water dynamics under drip irrigation systems *Agric. Water Manag.* **180** 70–7
87. Moussa M, Hallaire V, Michot D and Hachicha M 2020 Micro- and macrostructure changes of soil under irrigation with electromagnetically treated water *Soil Tillage Res.* **203** 104690
88. Amer M 2014 EFFECTS OF MAGNETIZED LOW QUALITY IRRIGATION WATER ON SOME SOIL PROPERTIES AND SOYBEAN YIELD (Glycine max L.) UNDER SALT AFFECTED SOILS CONDITIONS. *J Soil Sci Agric Eng Mansoura Univ* **5** 1377–88

89. Mohamed A I and Ebead B M 2013 EFFECT OF MAGNETIC TREATED IRRIGATION WATER ON SALT REMOVAL FROM A SANDY SOIL AND ON THE AVAILABILITY OF CERTAIN NUTRIENTS . *Vol.* **2** 9
90. Hassan D, Mohammed R, Akol A, Kadhim T and Hikmat I 2016 Effect of magnetization of fresh and salt water for irrigation in some of the physical characteristics of the soil and the growth of wheat *Int. J. Innov. Res. Sci. Eng. Technol.* **5**
91. Haq Z ul, Iqbal M, Jamil Y, Anwar H, Younis A, Arif M, Fareed M Z and Hussain F 2016 Magnetically treated water irrigation effect on turnip seed germination, seedling growth and enzymatic activities *Inf. Process. Agric.* **3** 99–106
92. Raeisi Vanani H, Toudeshki A, Shayannejad M, Ostad-Ali-Askari K, Ramesh A, Singh V and Eslamian S 2017 Wastewater and Magnetized Wastewater Effects on Soil Erosion in Furrow Irrigation *Int. J. Res. Stud. Agric. Sci. IJRSAS* **3** 1–14
93. Maheshwari B L and Grewal H S 2009 Magnetic treatment of irrigation water: Its effects on vegetable crop yield and water productivity *Agric. Water Manag.* **96** 1229–36
94. Hilal H, El-Fakhrani Y, Mabrouk S S, Mohamed A and Ebead B M 2012 Effect of Magnetic Treated Irrigation Water on Salt Removal from a Sandy Soil and on the Availability of certain Nutrients *Int. Conf. Egypt. Soil Sci. Soc. ESSS 4th Int. Conf. Water Requir. Field Irrig. Dep. 5-8 Novemb. 2012 Ameria Alex. Egypt*
95. Kronenber 2011 GMX International - MagnetoHydroDynamics
96. AL-Mosawi K A, Mohammed A and Al-Hadi S 2019 Effect of Magnified and Equality of Irrigation Water in the Soil Saturated Hydraulic Conductivity and the Soil Water Infiltration in Clay Loam Soil During the Growth Stages of Barley Crop (Hordium Vulgare L.) *J. Eng. Appl. Sci.* **14** 10114–21
97. Papadopoulos C, Efthimiadou E K, Pissas M, Fuentes D, Boukos N, Psycharis V, Kordas G, Loukopoulos V C and Kagadis G C 2020 Magnetic fluid hyperthermia simulations in evaluation of SAR calculation methods *Phys. Medica Eur. J. Med. Phys.* **71** 39–52
98. Abdul-Raheem L H and Azzubaidi R Z 2021 Evaluation of Using Magnetized Water in Leaching Salts in Sandy Loam Soil *J. Eng.* **27** 35–46