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Effect of Magnetized Saline Water on Nutrients and Chemical Properties of Water, Soil and Biochemical Attributes of *Atriplex nummularia*

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ABSTRACT

In this study, *Atriplex* seedlings were cultivated during the 2021–2022 and 2022–2023 seasons at the Faculty of Agriculture, Mansoura University, Egypt in order to evaluate effects of saline irrigation water on plant performance at different concentrations of diluted seawater. The irrigation treatments included: 100% Nile water (control), 25% saline water, 50% saline water, 25% magnetized saline water, and 50% magnetized saline water. Seawater was used as a source of saline water and was diluted with Nile water. Thereafter, magnetization process was carried out using a magnetic water treatment device. Results showed that magnetized saline water (MSW) resulted in a decrease in water pH and the water salinity which has a positive impact on soil, water and plant properties, where decrease in soil salinity was observed by 8.63% and 10.22% using 25% and 50% magnetized saline water, while enhanced soil nutrients availability and plant content of macro and micronutrients (e.g. N, P, Cu, Zn, and Mn). Irrigation with magnetized saline water effectively reduced soil concentrations of available Na, Cl and ESP. Moreover, *Atriplex* plants tolerated up to 50% magnetized saline water with no significant negative impact on vegetative growth, fresh and dry weight, chlorophyll and proline content compared to the control treatment. Additionally, 25% and 50% magnetized saline water achieved higher drought resistance indices (DRI) than their non-magnetized counterparts in both seasons. Also, These treatments demonstrated high potential to save about 25–50% of the total irrigation water required for *Atriplex* cultivation during various growth stages.

Keywords: magnetic saline water, *Atriplex*, soil nutrients.

INTRODUCTION

Among the Chenopodiaceae family, *Atriplex* is the most diverse genus. It is commonly found in the Karoo region of Southern Africa and in subtropical saline environments along the Mediterranean. *Atriplex* species are capable of growing to significant heights in urban areas with saline soils, typically where water and soil pollution are prevalent (Mulas and Mulas, 2004). These species are notable for their high biomass production, efficient use of solar energy, and strong resistance to both drought and salinity (Lombardi *et al.*, 2022). Forage *Atriplex* also contributes meaningfully to livestock diets, particularly in arid conditions where water and vegetation are scarce, by supplementing grass forage and supporting year-round grazing (Falasca *et al.*, 2014).

Consequently, treating saline water and reusing it for irrigation is considered one of the most efficient methods to address water scarcity in agriculture.

Salinity is one of the most critical environmental challenges in agriculture, affecting approximately 6% of cultivated land globally (Rabhi *et al.*, 2010). Elevated soil salinity significantly reduces plant growth and crop productivity (Nounjan *et al.*, 2012). In Egypt and many other countries, a key agricultural issue is the reliance on poor-quality irrigation water with high salinity levels (Amer *et al.*, 2014). Reclaiming saline and arid lands requires further

research and the adoption of appropriate cultivation strategies to ensure agricultural sustainability.

Magnetic water treatment operates on the principle that as water flows through a magnetic device, a Lorentz force acts on each ion in opposite directions. This redirection increases the frequency of collisions between oppositely charged ions, promoting the formation of insoluble compounds or metal precipitates (Moon and Chung, 2000). Applying magnetic treatment to saline irrigation water has shown promise as an effective method for soil desalination. It reduces the hydration shells around colloids and salt ions, enhances salt crystallization, accelerates coagulation, and increases salt solubility (Hilal and Hilal, 2000a). In a study conducted in Egypt, salt accumulation persisted longer in pots irrigated with untreated saline water ($EC = 8.2 \text{ dS m}^{-1}$) compared to those irrigated with magnetized saline water (Hilal and Hilal, 2000b). When water is treated with a magnetic field, its physical and chemical properties are changes, which can improve soil properties and plant growth (Aladjadjiyan, 2010; Talat Rashad, 2022). Irrigation water deficiency is a bigger issue worldwide, particularly in arid and semi-arid areas where agricultural practices is the main source of income. Innovative approaches to water management are needed to solve this challenge such as reuse magnetically treated of wastewater in agriculture. Using magnetically treated water for irrigation is one such strategy that is

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becoming more and more popular. Magnetized water treatment has shown great promise in environmental and agricultural applications, as well as in the conservation of water resources, which will soon be important (Yadollahpour *et al.*, 2014).

Various studies have explored eco-friendly magnetic water treatments to enhance plant growth and productivity under salinity stress, with a focus on promoting sustainable agriculture (Aly *et al.*, 2015; Abobatta, 2019; Mohamed and Sherif, 2020). Abdelghany *et al.* (2022) examined the impact of magnetic forces on physicochemical characteristics of soil at varying salinity levels and depths, utilizing soil columns in a controlled laboratory setting. Magnetic treatment enhanced the hydraulic conductivity and infiltration parameters while decreasing the pH and electrical conductivity of the soil.

These results emphasized the importance of the magnetization of saline water for sustainably improving soil characteristics. Magnetized water systems are increasingly considered effective for reclaiming saline soils and improving the usability of poor-quality water in agriculture. Irrigation with magnetically water improved in all the measures tested such as physicochemical properties, biochemical content, quality characteristics and yield indicators of fruits and nutrients uptake. In addition, several chemical properties of soil showed also reductions such as pH, EC, Na, and Cl concentrations (Awad and Ahmed, 2025).

The findings indicate that more nutrients from the top layer were dissolved in the water that had been magnetically treated. However, the middle and bottom soil layers showed a notable rise in the content of nutrients. This demonstrated how water that has been magnetically treated can increase the nutrients that are available to the plant in its root zone (Hassan, 2015). When irrigating Guinea grass plants with magnetically-treated seawater, the content of proline was significantly decreased while the content of chlorophyll a, b, and carotenoids in the leaves was significantly increased (Alfaidi *et al.*, 2017). Magnetized treated seawater irrigation alongside with biofertilizer was more beneficial in decreased salinity stress. Which led to increase height growth, leaves area and root length, nitrogen, phosphorus and potassium % content in leaves. While led to reduced total chlorophyll in leaves, total carbohydrate in stem and absorption sodium% which led to the increases in ratio K : Na (Sarhan *et al.*, 2020). Using magnetically treated seawater to irrigate three different wheat cultivars or using magnetized wheat seeds improved seed germination, shoot length, and root length (El-Mugrbi *et al.*, 2022).

The primary objective of this study was to assess the influence of magnetized water treatment in mitigating the effects of saline water irrigation stress on soil nutrients availability and Chemical Properties of Water, Soil and Biochemical Attributes and Growth of *Atriplex Nummularia*.

MATERIALS AND METHODS

Experimental Design and Treatments

Two pot experiments were conducted at the Arboretum of Ornamental Plants, Horticulture Department, Faculty of Agriculture, Mansoura University, Egypt, during two consecutive winter seasons (2021/2022 and 2022/2023).

The aim was to investigate the effects of saline water irrigation at different concentrations on growth parameters, physiological traits, drought resistance index

percentage, and selected chemical constituents of 6-month-old *Atriplex* seedlings.

The experiment included five treatments: 100% Nile water (control), 25% saline water (25%SW) water, 50% saline water (50% SW), 25% magnetized saline water (25%MSW), and 50% magnetized saline water (50%MSW). Seawater was used as a source of saline water in different proportions and diluted with Nile water. then the magnetization process was carried out using a magnetic water treatment device. These treatments were arranged in a completely randomized block design (CRBD) with three replicates. A total of 90 seedlings (5 treatments × 3 replicates × 6 seedlings) were transplanted into pots (30 cm in diameter, 30 cm in depth, and 7 kg soil capacity) filled with a 1:1 (v/v) mixture of sand and clay soil. Transplanting was performed on October 10 in both seasons.

After 15 days of initial irrigation with Nile water, *Atriplex* seedlings were subjected to saline water treatments. To determine the appropriate irrigation volumes, five pots filled with the soil mixture (without seedlings) were used to measure water consumption for each saline treatment level. Weighing was performed every three days, and the amount of water lost was added accordingly throughout the experiment. Field capacity was calculated following the method described by Cong *et al.* (2014).

Basal doses of nitrogen, phosphorus, and potassium were applied using ammonium sulfate, single superphosphate, and potassium sulfate at rates of 140 mg kg⁻¹ (N), 60 mg kg⁻¹ (P₂O₅), and 40 mg kg⁻¹ (K₂O), respectively, at 25, 45, and 65 days after planting. In addition, calcium nitrate was applied weekly as a foliar spray starting 25 days after planting and continued until the end of the experiment. All standard agronomic practices were followed throughout the study. In each season, three plants were randomly selected from each experimental unit for analysis.

Magnetized irrigation water was prepared using Magnolith permanent magnets (EWL Umelttechnik GMBH, Germany), which consist of south and north poles arranged to pass through 88 cascaded magnetic fields. This system was connected to the irrigation pipeline (2-inch internal diameter), and the magnetic field strength ranged between 2000–4000 Gauss (Fig. 1).

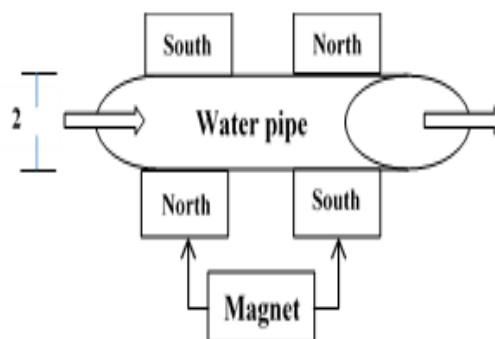


Fig. 1. The magnetisation tool

Analysis

Particle size distribution of soil comprising sand, silt, and clay was determined using the pipette method, following Gee and Bauder (1986). Soil pH and electrical conductivity (EC) were measured in a 1:2.5 soil-to-water suspension using a

Hanna 211 pH meter and a Jenco 3173 EC meter, respectively, as described by Gavrilescu (2021) and Pansu (2006).

Available phosphorus (P) was extracted using 0.5 mol L⁻¹ sodium bicarbonate (NaHCO₃, pH 8.5) and measured with a spectrophotometer. Available nitrogen (N) was extracted using 2.0 M KCl and quantified using the automatic Kjeldahl method. The concentrations of total carbon and nitrogen in plant samples were measured using a CNS analyzer (Thermo Scientific Flash 2000).

Plant samples were digested using concentrated nitric acid (HNO₃, 65%) and hydrogen peroxide (H₂O₂, 30%) in a microwave digestion system (Ethos Easy Milestone), following the method described by Lu (1999). Total

phosphorus, potassium, and the micronutrients copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn) in plant tissues were determined according to AOAC (1990). Macronutrients and micronutrients in both plant and water samples were determined using an Inductively Coupled Plasma Spectrophotometer (ICP). Available potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and micronutrients in the soil were extracted with 1.0 M ammonium acetate (NH₄CH₃CO₂ @ pH 7.0) and analyzed using an ICP (model ICP/Thermo Scientific iCAP 7400). Table 1 presents the average physical and chemical properties of the soil mixture across the two seasons. The chemical composition of the irrigation water used in the experiment is shown in Table 2.

Table 1. Physical and chemical properties of experimental farm soil (average of two seasons)

Particle size distribution%	Clay (%)	Silt (%)		Sand (%)		Soil texture						
	29.23	28.02		42.75		clay loam						
Soil pH	EC(dS m ⁻¹)	Soluble Ions (mmol L ⁻¹)								Available (mg kg ⁻¹)		
1:2.5 suspension	1:2.5 extract	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	N	P	K
7.78	0.41	1.82	1.14	0.89	0.25	ND	1.07	3.07	0.84	127	46	510

* ND; Not detected

Table 2. Chemical analysis of used water in the experiment during both seasons.

Water type	pH	EC	Soluble ions (mg L ⁻¹)									
			1 st season									
			Na	Ca	Cl	K	Mg	Fe	Cu	Zn	Mn	P
NW	7.52	1.2	205.3	43.4	135.2	11.0	17.8	0.25	ND	0.01	0.23	0.60
25 % SW	7.43	26.4	4728.1	821.7	5913.2	198.8	524.1	0.78	0.12	0.08	0.22	0.38
50 % SW	7.38	35.4	6124.0	1537.0	8025.0	305.4	727.0	0.91	0.15	0.03	0.22	0.32
25 % MSW	7.63	15	2564.9	496.5	3379.0	89.9	311.4	0.88	0.11	0.07	0.30	0.53
50 % MSW	7.58	25	4157.6	789.9	5744.2	160.5	597.3	1.10	0.13	0.10	0.34	0.43
Water type	pH	EC	2 nd season									
			Na	Ca	Cl	K	Mg	Fe	Cu	Zn	Mn	P
			Na	Ca	Cl	K	Mg	Fe	Cu	Zn	Mn	P
			Na	Ca	Cl	K	Mg	Fe	Cu	Zn	Mn	P
			Na	Ca	Cl	K	Mg	Fe	Cu	Zn	Mn	P
			Na	Ca	Cl	K	Mg	Fe	Cu	Zn	Mn	P
NW	7.65	1.22	204.0	47.8	141.7	14.43	16.0	0.24	ND	ND	0.23	0.59
25 % SW	7.55	25.96	4914.4	845.4	6034.7	220.4	484.8	0.78	0.10	0.19	0.21	0.41
50 % SW	7.47	35.64	5698.7	1471.8	7936.0	303.0	706.0	0.89	0.14	0.03	0.22	0.35
25 % MSW	7.81	15.53	2644.1	513.6	3415.7	86.6	320.0	0.89	0.12	0.09	0.28	0.51
50 % MSW	7.68	24.92	4121.4	798.2	5684.6	163.0	582.0	1.11	0.13	0.11	0.33	0.43

Plant height, stem diameter, and number of branches per plant were recorded at three time points: 50, 100, and 150 days after planting. Total fresh and dry weights per plant were measured at 150 days after planting. Stem diameter was measured using a vernier caliper at 15 cm above the soil surface.

The drought resistance index (DRI) was calculated using the formula reported by Bidinger *et al.* (2007):

$$DRI (\%) =$$

$$(\text{Mean total dry weight of water-stressed plants} / \text{Mean total dry weight of control plants irrigated with normal water}) \times 100.$$

Photosynthetic pigments (chlorophyll a + b and carotenoids) were quantified using the method of Sadasivam and Manickam (1992). Proline content was determined colorimetrically using ninhydrin complex formation in toluene, with absorbance measured at 528 nm against a standard L-proline calibration curve. Fresh leaves were homogenized in 5 mL of 3% (w/v) sulfosalicylic acid and centrifuged at 10,000 rpm for 10 minutes. Two milliliters of the supernatant were reacted with ninhydrin reagent and toluene to determine proline concentration (mg g⁻¹ dry weight), following the procedure outlined by Mohamad *et al.* (2021).

Statistical Analysis:

Data from the present study were statistically analyzed using Statistix software, Version 9 (Statistix, 2008).

Treatment means (saline water irrigation types) were compared using the least significant difference (LSD) test at

the 5% probability level. Differences between treatment means were considered statistically significant when they exceeded the LSD value. To identify the statistical difference between multiple mean values at the 95% significance level, the Duncan test was employed.

RESULTS AND DISCUSSION

Results

Soil pH, EC and Nutrient Availability

Magnetized saline water (MSW) resulted in a decrease in some water properties such as sodium, calcium, chloride, potassium, magnesium, copper (Cu), pH and water salinity. Conversely, the content of iron, zinc, manganese and phosphorus increases in magnetized water (Table 2). These results had a positive impact on soil, water and plant properties.

During the second season, the use of magnetized saline water (MSW) led to a reduction in both soil pH and EC. The lowest recorded soil pH value was 8.18 when 25% of the saline water was magnetized, where the reduction rate was 2.7%. The electrical conductivity (EC) of soil that was irrigated with magnetically treated water was significantly lower than that of soil that was watered with saline water that was not magnetized, the lowest soil EC value (1.66 dS m⁻¹) was observed when 50% of the saline water was magnetized, with a decrease rate of 44.9%. Also in the first season, a decrease in soil salinity was observed by 8.63% and 10.22%

using 25% and 50% magnetized saline water, respectively compared to the untreated one. (Table 3). Overall, soil pH and EC were markedly reduced after irrigating Atriplex plants with magnetized saline water.

Furthermore, the effects of both non-magnetized and magnetized saline water on available soil N, P, K, Ca, Mg, Na, and Cl are presented in Table 3. Magnetized saline water significantly increased the availability of soil nitrogen (N) and phosphorus (P) compared to untreated saline water. Conversely, the availability of potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^+) and chloride (Cl^-) in

the soil was significantly reduced by the magnetized saline water treatment. A similar trend was observed for exchangeable sodium percentage (ESP) under both types of saline water irrigation.

The current study also found an increase in the availability of soil micronutrients (Fe, Cu, Zn, and Mn), particularly under irrigation with magnetized saline water. This suggests that magnetization may enhance the solubility and availability of these nutrients. The concentrations of nutrients extracted from soils irrigated with magnetized water were considerably higher than those from non-magnetized sites.

Table 3. Effect of magnetized saline water irrigation on soil nutrients availability

Water type	1 st season													
	Soil pH	EC (dS m ⁻¹)	N	P	K	Ca	Mg	Na	Cl	Fe	Cu	Zn	Mn	ESP
	1:2.5	1:2.5			mg kg ⁻¹				cmol.kg ⁻¹			mg kg ⁻¹		%
NW	8.25b	1.42e	67.31a	29.76a	535.15a	1668.80e	717.15d	921.62e	0.47e	1.31a	0.42bc	0.12d	1.4d	4.74c
25 % SW	8.41a	2.2c	44.03c	18.81d	319.26c	2117.66c	978.90b	2446.20b	4.73c	0.26e	0.39c	0.25c	1.31d	6.76b
50 % SW	8.19b	5.38a	56.52b	14.73e	449.15b	2581.92b	1059.75a	2984.14a	8.30a	0.52c	0.45b	0.37b	1.70c	7.83a
25 % MSW	8.42a	2.01d	52.5bc	24.47b	318.57c	2025.19d	803.11c	1327.94d	2.77d	0.46d	0.44b	0.003e	1.96b	1.4e
50 % MSW	8.24b	4.83b	72.77a	19.88c	443.86b	2801.80a	989.86b	1911.80c	6.29b	1.21b	0.54a	0.45a	2.15a	2.02d
F - test	**	**	**	**	**	**	**	**	**	**	**	**	**	**
	2 nd season													
NW	8.33bc	1.53c	70.32bc	30.08a	531.2a	1829.57d	997.17c	910.81e	0.55e	1.29a	0.50a	0.18d	1.68c	4.90c
25 % SW	8.41ab	2.93a	62.26c	22.66d	437.52b	2467.66b	1129.46b	2148.68b	4.16a	0.36e	0.28d	0.23c	1.27e	7.36b
50 % SW	8.26cd	3.01a	67.4bc	21.82e	418.89c	2633.09a	1206.16a	3027.99a	3.79b	0.40d	0.35c	0.25b	1.39d	9.01a
25 % MSW	8.18d	2.94a	74.23b	28.46b	319.83d	1887.72c	724.00d	1418.60d	2.61d	0.46c	0.39c	0.27a	1.87b	1.97e
50 % MSW	8.47a	1.66b	85.57a	24.77c	246.51e	1824.14e	689.82e	1829.43c	2.96c	0.95b	0.44b	0.27a	2.02a	2.48d
F - test	**	**	**	**	**	**	**	**	**	**	**	**	**	**

Additionally, ESP decreased under magnetized saline water irrigation throughout all seasons compared to untreated saline water. the maximum decrease of exchangeable sodium percentage determined in first season with 25% MSW (79.29%). While, in the second season, the percentage reduction in ESP using 25% magnetized saline water was 73.23% relative to 25% saline water without magnetization.

Plant Nutrient Content

Table 4 compares the nutrient contents in Atriplex plants irrigated with both untreated and magnetized saline water at a 25% and 50% concentration. In general, irrigation with magnetized saline water increased plant contents of K and P, while N and C content was significantly affected, particularly under 50% MSW treatment. However, no

significant differences in N concentration were observed between magnetized and non-magnetized treatments in the second season.

Micronutrient content (Cu, Zn, and Mn) was notably enhanced in all magnetized treatments during both the first and second seasons. Specifically, in the second season, the contents of Cu, Zn, and Mn in Atriplex plants irrigated with 25% magnetized saline water were 22.90, 53.07, and 48.11 mg kg⁻¹, respectively, compared to 9.00, 37.29, and 44.09 mg kg⁻¹ in plants irrigated with 25% non-magnetized saline water. On the contrary, no significant differences in Fe concentration were observed between magnetized and unmagnetized treatments in both seasons.

Table 4. Effect of magnetic treatment on nutrients content of atriplex plants after 150 days from planting date

Water type	1 st season											
	N	C	P	K	Na	Ca	Mg	C/N	Fe	Cu	Zn	Mn
				%				Ratio		mg kg ⁻¹		
NW	3.19b	29.26c	0.29c	3.16a	11.72b	1.26b	1.10b	9.17b	53.27a	14.03c	57.22a	38.91c
25 % SW	3.09b	29.55c	0.29c	2.82b	13.06a	1.37a	1.28a	9.57a	41.08a	9.94d	43.41b	36.12c
50 % SW	3.42a	32.45a	0.32bc	1.94e	11.37bc	1.08c	0.93c	9.49a	44.35a	8.81e	35.29c	35.70c
25 % MSW	3.15b	30.33b	0.39ab	2.54d	10.60d	1.23b	0.95c	9.63a	56.42a	18.69b	52.80a	48.47b
50 % MSW	3.42a	32.36a	0.43a	2.71c	10.95cd	1.07c	0.92c	9.46a	63.26a	26.13a	57.06a	55.22a
F -test	**	**	*	**	**	**	**	**	NS	**	**	**
Water type	2 nd season											
	N	C	P	K	Na	Ca	Mg	C/N	Fe	Cu	Zn	Mn
				%				Ratio		mg kg ⁻¹		
NW	3.22a	29.47c	0.29b	3.23b	11.52b	1.22c	1.10b	9.15b	54.99a	14.20c	52.98a	41.41cd
25 % SW	3.13a	29.5c	0.3b	3.05b	12.18a	1.39a	1.00c	9.42a	52.41a	9.00e	37.29c	44.09bc
50 % SW	3.23a	31.72b	0.32b	2.36d	11.06c	1.05d	0.99c	8.73d	46.81a	9.24d	46.27b	37.46d
25 % MSW	3.18a	32.28a	0.43a	3.22b	9.39d	1.23bc	0.87d	8.96c	67.93a	22.9b	53.07a	48.11b
50 % MSW	3.31a	28.54d	0.48a	3.35a	12.51a	1.27b	1.23a	8.88cd	70.83a	30.66a	56.37a	57.67a
F -test	NS	**	**	**	**	**	**	**	NS	**	**	**

* ND; Not detected

NS; Non-significant

Growth Parameters

As shown in Figure 2 and Table 5, Atriplex plant height, stem diameter, and number of branches per plant were significantly affected by irrigation with both magnetized and non-magnetized seawater. These reductions were notable at 100 and 150 days after planting during both seasons. Magnetized seawater at 25% and 50% significantly improved

growth parameters compared to non-magnetized seawater at the same concentrations in both seasons. For example, the increase in plant height using 25% magnetized seawater was approximately 13.51% and 1.94% in the first season, and 25.16% and 38.13% in the second season after 100 and 150 days from planting, respectively.

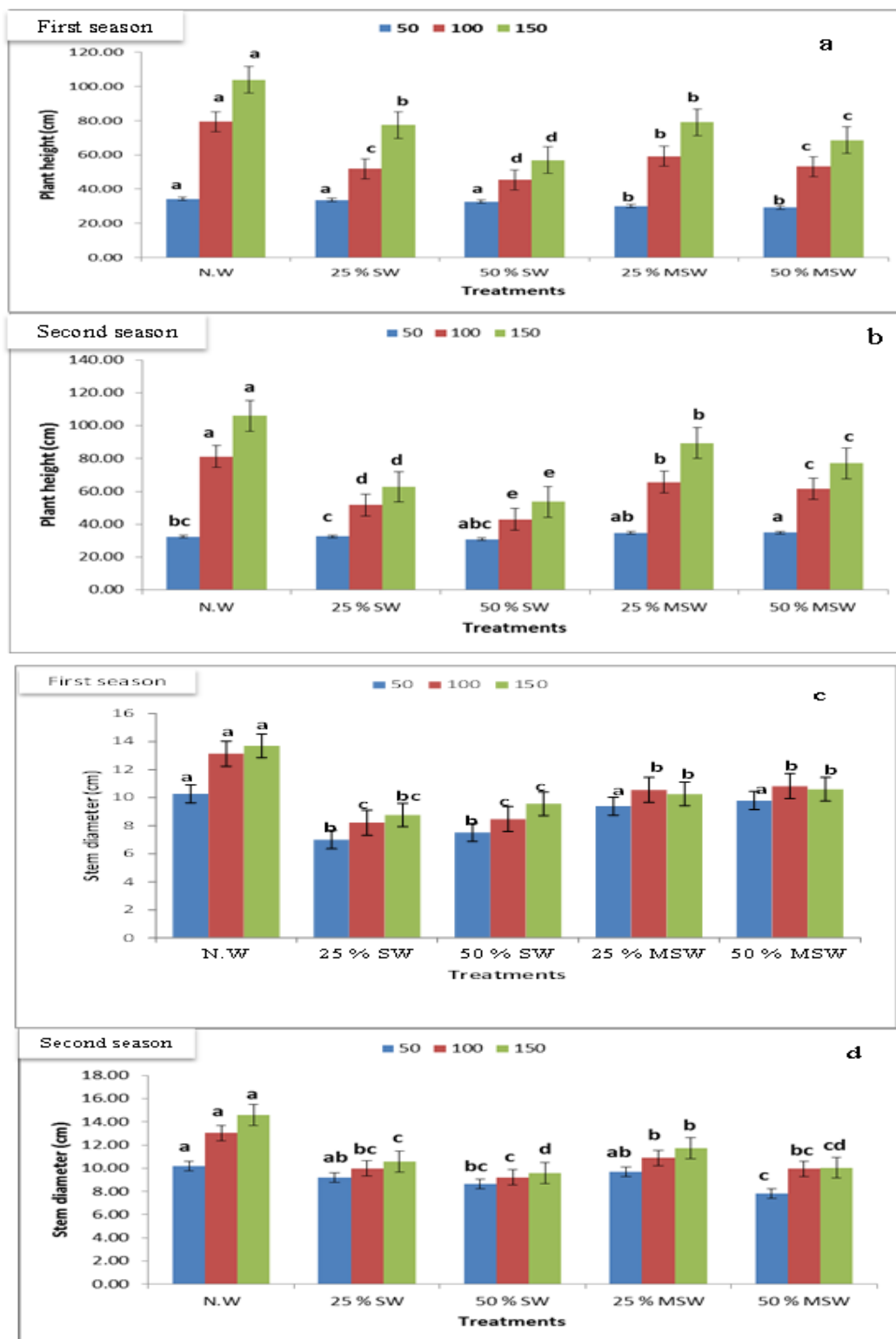


Fig. 2. Effect of magnetized saline water on atriplex nummularia plants hight (cm) (a and b) and stem diameter (cm) (c and d) after 50, 100 and 150 days from planting

Table 5. Effect of magnetized saline water irrigation on total plant fresh and dry weights and number of branches of

Water type	Number of branches/d			Fresh weight (g)	Dry weight (g)
	50	100	150	150	150
1 st season					
NW	8.67a	11.83a	17.00a	1103.40a	61.02a
25 % SW	9.00a	11.33a	14.83a	492.10d	30.62d
50 % SW	7.83a	11.17a	13.83a	353.40e	23.95e
25 % MSW	8.50a	12.17a	16.50a	812.50b	54.73b
50 % MSW	9.0a	13.00a	18.67a	598.60c	37.33c
F-test	NS	NS	NS	**	**
2 nd season					
NW	8.33a	11.00b	17.00a	940.61a	41.96a
25 % SW	8.50a	11.33b	13.67a	492.05d	31.40b
50 % SW	9.67a	11.83b	14.17a	257.65e	17.23c
25 % MSW	8.33a	14.83a	18.17a	843.50b	41.43a
50 % MSW	8.33a	11.17b	15.67a	626.48c	41.23a
F-test	NS	*	NS	**	**

atriplex plants after 50, 100 and 150 days from planting.

All irrigation treatments, regardless of magnetization, recorded significantly lower total fresh and dry weights of Atriplex compared to the control in both seasons (Table 5). Nevertheless, significant differences in biomass (fresh and dry weights) were observed between magnetized and non-magnetized seawater irrigation. Specifically, in the 1st and 2nd seasons, total dry weight increased by approximately (78.74% and 31.94%) and (55.87% and 139.29%) respectively, under 25% and 50 % magnetized seawater compared to non-magnetized seawater of the same concentration.

Drought Resistance Index (DRI%)

As presented in Table 6, the drought (salt) resistance index—a reliable indicator of salinity tolerance—was 100% for control plants irrigated with regular water. Remarkably, this index also reached 100% in Atriplex plants irrigated with either

freshwater or 25% magnetized saline water in the second season. This suggests that magnetic treatment plays a vital role in enhancing Atriplex tolerance to salinity, likely by increasing herb dry weight. Generally, 25% and 50% magnetized saline water achieved higher drought resistance indices than their non-magnetized counterparts in both seasons.

Table 6. Effect of magnetized saline water irrigation concentrations on drought resistance index (DRI) (%) of atriplex plants after 150 days from planting date

Treatments	1st season	2nd season
NW	100.00a	100.00a
25% SW	45.30d	54.80c
F-test	32.21e	28.09d
25% MSW	76.68b	100.60a
50% MSW	56.49c	71.72b
F-test	**	**

Biochemical Content of Atriplex

In the first season, compared to the control, irrigation with saline water led to an increase in total chlorophyll content (Table 7). The highest chlorophyll (a, b and a+b) values were observed at 25% MSW (3.07, 1.52 and 4.59 mg 100 g⁻¹, respectively), exceeding all other treatments tested. Total Carotenoids content increased in treatments irrigated with 25 % MSW in 1st season (2.76 mg 100 g⁻¹) compared to the control, with an increase rate of 14.52%. While, total proline content increased in treatments irrigated with 50% saline water (SW) in both seasons, reaching 9.41 mg g⁻¹ and 8.99 mg g⁻¹, respectively, compared to the control, with an increase rate of 186.01% and 161.33%, respectively. The results of irrigation with magnetized water indicate a decrease in the concentration of proline in the plant,, which indicates the importance of irrigation with magnetized saline water compared to non-magnetized saline water.

Table 7. Effect of saline water irrigation concentrations on chlorophyll a, b and a+b and carotenoids contents and proline content of atriplex plants after 150 days from planting date

Water type	Chlorophyll "a"	Chlorophyll "b"	Chlorophyll "a+b"	Carotenoids content	Proline content
	mg 100 g ⁻¹				mg g ⁻¹
	1st season				
NW	2.92ab	1.12c	4.04b	2.41ab	3.29c
25 % SW	2.88abc	1.18bc	3.95bc	2.33b	6.24b
50 % SW	2.54c	1.32b	3.86bc	2.59ab	9.41a
25 % MSW	3.07a	1.52a	4.59a	2.76a	3.83c
50 % MSW	2.68bc	0.73d	3.41c	2.29b	4.59bc
F-test	NS	**	*	NS	**
2nd season					
NW	2.90a	1.16b	4.06a	2.43a	3.44c
25 % SW	2.38b	1.28ab	3.66a	2.17a	6.44b
50 % SW	2.67ab	1.16b	3.83a	2.40a	8.99a
25 % MSW	2.64ab	1.10b	3.73a	2.30a	3.92c
50 % MSW	2.59ab	1.38a	3.97a	2.37a	4.41c
F-test	NS	*	NS	NS	**

Discussion

Soil pH, EC and Nutrient Availability

We noticed an unclear trend in the pH results in the experiment. According to the literature, the pH change varies from experiment to experiment, and the experimental settings were a major factor in these variations (Hassan, 2015) . Soil salinity increased with rising water salinity in the absence of magnetic treatment. However, when magnetized water was used for irrigation, soil salinity decreased due to enhanced

leaching of salts to deeper soil layers. Our results are consistent with Hassan, (2015) and Jawad *et al.*, (2023), who found that when comparing magnetically treated water to untreated water, the pH and electrical conductivity decreased. During this process, soluble salts moved with the soil water, either temporarily adsorbing to soil particles or precipitating when concentrations exceeded solubility limits. Magnetized water has been shown to increase the solubility of inorganic salts—especially those typically considered insoluble—by

enhancing the bonding of salt ions with surrounding water molecules. This reduces the likelihood of salt precipitation (Xin *et al.*, 2024).

As a result, magnetized saline water was able to dissolve more salts in the topsoil, effectively transporting them to deeper layers. This demonstrates the remarkable capacity of magnetized water to aid in salt leaching and drainage. These findings align with the results of Hachicha *et al.* (2018), who reported significantly reduced soil EC, Na⁺, and Cl⁻ levels when saline water was magnetically treated, compared to non-treated saline irrigation.

Similarly, other studies using molecular dynamics simulations have revealed that magnetic fields reduce the force between water and salt ions. Specifically, when a chloride solution is exposed to a magnetic field intensity of 0.2 T, there is a reduction in solvent-separated ion pairs and an increase in contact ion pairs. This results in a lower anion diffusion coefficient and a higher cation diffusion coefficient (Guo *et al.*, 2011; Mohamed and Ebead, 2013). Therefore, magnetization effectively reduces soil salinity after saline water irrigation.

Soils irrigated with magnetized saline water showed a positive shift in pH compared to those irrigated with non-magnetized saline water, likely due to the buffering effect of magnetic treatment. Several authors have reported that magnetic treatment alters soil mineral solubility and pH, thereby enhancing nutrient uptake by plants (Sarraf *et al.*, 2020b; Faridvand *et al.*, 2021).

Magnetized water may improve phosphorus availability by reducing calcium phosphate formation due to decreased calcium concentrations. Furthermore, magnetic treatment has been linked to reduce salt ion concentrations, which promotes salt crystallization and coagulation. This enhances the adsorption of phosphorus and nitrogen on soil colloids and improves fertilizer efficiency and nutrient mobility in the soil (Mohamed and Ebead, 2013; Abd-Elrahman and Shalaby, 2017).

Additionally, magnetized water enhances soil moisture retention, improves the solubility of mineral elements, and decreases both soil salinity and alkalinity. These favorable conditions promote microbial proliferation, which further increases nitrogen availability (Jiang *et al.*, 2024). Collectively, these findings suggest that magnetically treated irrigation water offers significant benefits for nutrient availability and helps mitigate the adverse effects of saline irrigation.

Plant nutrient content

Magnetized water may also enhance the desorption of elements from soil colloids, making them more available to plants and thereby supporting improved growth and productivity. In the present study, Atriplex plants irrigated with magnetized saline water exhibited increased concentrations of phosphorus and potassium, indicating greater nutrient uptake, assimilation, and translocation within the plant. These improvements likely contributed to better plant health and growth.

Duarte Diaz *et al.* (1997) reported that magnetic treatment improved nutrient absorption in tomatoes. Similarly, Hilal *et al.* (2002) found that magnetically treated water significantly increased phosphorus levels in citrus leaves. Hozayn *et al.* (2016) also observed notable differences in micronutrient concentrations between plants irrigated with magnetized and non-magnetized water. The magnetic effect

enhances nutrient leaching, root absorption, and transport within the plant, thereby increasing microelement content. Grewal and Maheshwari (2011) reported significantly higher levels of K, Ca, Zn, Fe, and Mn in snow peas and chickpeas irrigated with magnetically treated water compared to controls. Overall, magnetic field treatment of saline irrigation water has been shown to significantly improve the availability of macro- and micronutrients in both soil and plants.

Growth Parameters

Despite plant height, stem diameter and number of branches per plant of Atriplex were decreased by using with or without magnetized sea water for irrigating compared to control (irrigated with normal water), but we noticed also from data presented indicate that plant height, stem diameter and number of branches per plant of Atriplex were decreased by using with or without magnetized sea water for irrigating compared to control (irrigated with normal water). These findings are consistent with previous research. Aly *et al.* (2015) observed improved growth in Valencia orange trees irrigated with magnetized water. El-Gindy *et al.* (2018) reported that using magnetic technology with low-salinity irrigation water (1,000 mg L⁻¹) significantly improved pear seedling growth, while higher salinities (4,000–5,000 mg L⁻¹) without magnetic treatment were detrimental. Similarly, Hozayn *et al.*, (2021) found that magnetized saline water improved all measured growth parameters (plant height, branches number per plant as well as dry matter of total plant) in canola cultivars compared to saline water without magnetization.

Drought Resistance Index (DRI%)

Increasing the concentration of saline water, whether magnetized or not, progressively decreased the drought resistance index (DRI) during both seasons. Supporting this trend, Trebbi *et al.* (2007) reported enhanced stress resistance in tobacco plants exposed to extremely low-frequency magnetic fields. Similarly, Migahid *et al.*, (2019) found that magnetic fields enhanced the salinity tolerance of *Silybum marianum*. The results underscore the potential for magnetic treatment of saline water to revolutionize crop production by improving water and nutrient use efficiency and increasing stress tolerance (Sarraf *et al.*, 2020a).

Biochemical Content of Atriplex

Atriplex plants tolerated magnetized saline water up to a 50% concentration without any significant reduction in leaf chlorophyll percentage relative to the control. Might be, total chlorophyll content in Atriplex leaves increased following foliar application of calcium nitrate (3 g L⁻¹) applied weekly from 25 days after planting until the end of the experiment in both seasons; however, the increase was not statistically significant. But it is known that Calcium is a vital macronutrient that contributes to cell wall structure, acts as an intracellular messenger, facilitates the uptake of other nutrients, and regulates enzymatic activity, and Several authors have reported that Calcium's most definitive physiological role is in stabilizing the cell wall by increasing rigidity. it is essential for proper cell wall organization (Burstrom, 1968). Furthermore, chlorophyll fluorescence parameters in NaCl-stressed plants improved following foliar Ca(NO₃)₂ application, indicating a partial alleviation of salinity stress (Murillo-Amador *et al.*, 2006). Also, Calcium ions can also alleviate damage from sodium and chloride in sensitive crops. For instance, in salt-stressed strawberry plants, shoot and root dry weights improved when a 10 mM

calcium nitrate foliar spray was applied (Yildirim *et al.*, 2009). In *Calendula officinalis*, using saline water (3000 ppm) combined with potassium silicate (8 cm³ L⁻¹) increased chlorophyll a, chlorophyll b, and proline contents in the leaves (Attia and Elbohy, 2019). Under salinity stress, rice plants benefited from foliar sprays of Ca(NO₃)₂, which helped mitigate stress effects by enhancing dry matter accumulation, increasing grain yield, and improving photosynthesis-related traits (Lombardi *et al.*, 2022).

Our results illustrate that the highest salinity treatment (50% saline water_SW) caused significant increases of proline concentrations, one common reaction to hyperosmotic salinity is proline accumulation, which is thought to play a role in the process of salt resistance. Also, Total carotenoids content increased in treatments irrigated with 25 % MSW. These results are consistent with the findings of some other studies, Proline a proteinogenic amino acid with unique conformational rigidity, accumulates in plant tissues under various stress conditions, such as drought and salinity (Abdelhamid *et al.*, 2013; Tabot and Adams, 2014). Additionally, proline enhances antioxidant defenses, boosts growth and physiological functions, and improves anatomical features in salt-stressed plants (Dawood *et al.*, 2014). When irrigating Guinea grass plants with seawater magnetically, the content of proline was significantly decreased while the content of chlorophyll a, b, and carotenoids in the leaves was significantly increased (Alfaidi *et al.*, 2017). Proline plays a critical role in osmoregulation, contributing to plant adaptation under adverse environmental conditions like salinity. It also helps stabilize membranes and proteins, supports growth, and serves as a reserve of carbon, nitrogen, and energy. Also, Its accumulation is often accompanied by increases in sugars, sugar alcohols, and other nitrogen-containing solutes such as quaternary amino acid derivatives (Mansour, 2000).

CONCLUSION

In this study, irrigation with magnetized saline water effectively reduced soil concentrations of available Na⁺ and Cl⁻. A similar trend was observed for exchangeable sodium percentage (ESP), where magnetized saline water had a mitigating effect compared to non-magnetized saline water. Additionally, magnetized saline water enhanced the solubility of essential soil macro and micronutrients such as N, P, Cu, Zn, and Mn, which may have contributed to improved plant growth and overall plant health. Compared to the control treatment in the first season, irrigation with varying concentrations of saline water resulted in increased total chlorophyll content during both the first and second seasons. Notably, the highest values for these parameters were recorded under the 25% magnetized saline water (MSW) treatment. Furthermore, total proline content was significantly increased under the 50% saline water (SW) treatment compared to the control in both seasons, indicating a possible stress adaptation response. In conclusion, although the current study provides a basic understanding of the use of magnetized saline water in irrigation, further research is needed to provide much-needed insights into the use of magnetized seawater for irrigating salinity-tolerant crops, which could potentially free up Nile water for irrigating non-salinity-tolerant crops.

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تأثير المياه المالحة الممغنطة على العناصر الغذائية والخصائص الكيميائية للتربة والصفات الكيموحيوية لنبات الأتريلكس نومولاريا

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الملخص

في هذه الدراسة، زُرعت شتلات الأتريلكس خلال موسمي ٢٠٢٢-٢٠٢٣ و ٢٠٢٣-٢٠٢٤ في كلية الزراعة، جامعة المنصورة، مصر. قُيِّمت آثار مياه الري المالحة على النباتات باستخدام تركيزات مختلفة من مياه البحر المخففة. وشملت معاملات الري: ١٠٠٪ مياه نيل (كنترول)، ٢٥٪ مياه مالحة، ٥٠٪ مياه مالحة، ٢٥٪ مياه مالحة ممغنطة، و ٥٠٪ مياه مالحة ممغنطة. استُخدمت مياه البحر كمصدر للمياه المالحة، وخُفِّفت بمياه النيل، ثم أُجريت عملية المغطاة باستخدام جهاز مغطاة المياه. أظهرت النتائج أن المياه المالحة الممغنطة (MSW) أدت إلى انخفاض في درجة حموضة وملوحة مياه الري مما كان له تأثير إيجابي على خصائص التربة والماء والنبات، حيث لوحظ انخفاض في ملوحة التربة بنسبة ٨,٦٣٪ و ١٠,٢٢٪ باستخدام ٢٥٪ و ٥٠٪ من المياه المالحة الممغنطة، في حين تم تحسين توافر العناصر الغذائية في التربة ومحتوى النبات من العناصر الغذائية الكبرى والصغرى مثل النيتروجين والفوسفور والنحاس والزنك والمنجنيز. أدى الري بالمياه المالحة الممغنطة إلى تقليل تركيز الصوديوم والكلوريد المتاحة في التربة وأيضاً نسبة الصوديوم المتبادل. علاوة على ذلك، تحلّت نباتات أتريلكس ما يصل إلى ٥٠٪ من المياه المالحة الممغنطة دون أي تأثير سلبي يُذكر على النمو الخضري، والوزن الطازج والجاف، ومحتوى الكلوروفيل والبرولين، مقارنة بمعاملة الكنترول. إضافة إلى ذلك، حققت المياه المالحة الممغنطة بنسبة ٢٥٪ و ٥٠٪ مؤشرات مقاومة الجفاف (DRI) والتي كانت أعلى من نظيراتها غير الممغنطة في كلا الموسمين. كما أظهرت هذه المعاملات إمكانية توفير ما بين ٢٥٪ و ٥٠٪ من إجمالي مياه الري اللازمة لزراعة أتريلكس خلال مراحل نموها المختلفة.