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Utilization of magnetic water technology to improve seawater quality and its impact on soil properties and the growth of barley

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Abstract

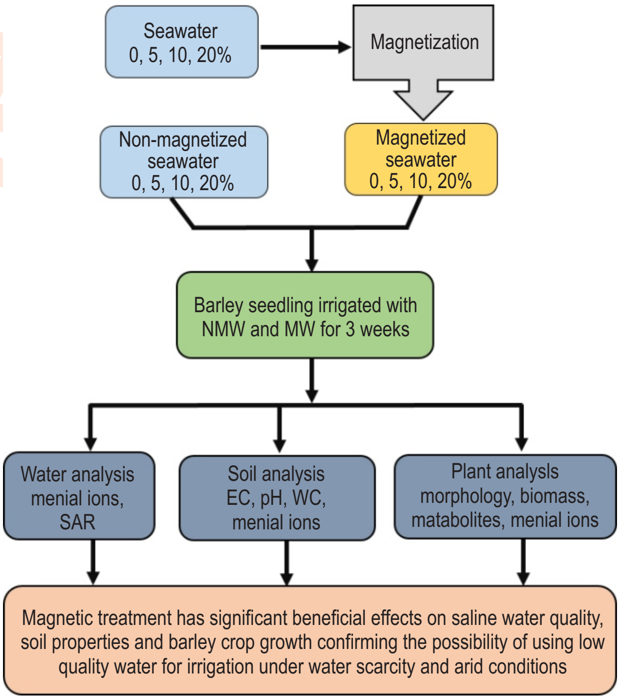
Aim: Using magnetic water technology inorder to enhance seawater quality and evaluate its impact on soil characteristics and growth performance in barley.

Methodology: A pot experiment was conducted using both magnetized water and non-magnetized water at a concentration of 5%, 10% and 20% seawater. Seawater was magnetically treated using a device that generated a magnetic field ranging from 3.5 to 136 mT.

Results: Magnetic treatment significantly improved the irrigation water quality across all seawater concentrations by reducing sodium (Na) concentration and sodium adsorption ratio (SAR) compared to non-magnetized water at equivalent salinity levels. Application of magnetized water led to a progressive decrease in soil electrical conductivity, as well as Na, Mg, and Ca concentration. Barley plants irrigated with magnetized water showed significantly enhanced morphological and physiological traits under all salinity levels. Moreover, magnetized water application significantly reduced Na, Mg, and Ca concentrations in both roots and shoots of barley.

Interpretation: The findings of this study confirm the potential of magnetized seawater as a viable alternative for irrigation in water-scarce and arid regions, offering a promising approach to enhance sustainable agriculture using low-quality water resources.

Key words: *Hordeum vulgare*, Magnetized water, Plant growth, Salinity, Soil properties



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Introduction

Agriculture sector is the largest consumer of water resources worldwide. Nevertheless, the rising water demand from urban, industrial, and domestic sectors alongside the expansion of agriculture with irrigation to deal with the growing population has led to water scarcity (Bharathi *et al.,* 2016). This intensifying shortage of freshwater presents a critical challenge for sustainable agricultural progress, principally in arid and semi-arid areas (Tan *et al.,* 2018). In response, the exploration and use of brackish water has gained importance as an alternative means to address freshwater deficits and sustain food production (Sekhon *et al.,* 2020). Nonetheless, irrigating crops with brackish water can exacerbate soil salinity and alter the properties of soil. These changes can impair water and salt movement, reduce soil aeration, and negatively affect plant growth conditions (Ren *et al.,* 2020). Consequently, such conditions may induce drought, osmotic stress, ion toxicity, and nutrient imbalances, ultimately disrupting plant metabolism and diminishing crop production (Kumar *et al.,* 2023). In several regions of Saudi Arabia, land and water resources are seriously threatened by salinity.

The primary challenge in this context is the seasonal fluctuations in salt stress throughout the growing period, caused by addition of irrigation water or leaching of salts. Numerous studies have reported that a significant portion of cultivated lands in Saudi Arabia are affected by varying degrees of salinity (Al-Hassoun, 2009; Elhag, 2016). This issue is further exacerbated by the increasing salinity of irrigation water, as agriculture in Saudi arabia relies predominantly on groundwater sources. Extreme extraction of freshwater reduces the aquifer pressure, thereby accelerating the horizontal intrusion of seawater into the aquifers of freshwater, thereby increasing their salinity levels (Abdalla, 2016) and posing in the region's agricultural practices' sustainability. Consequently, continuous pursuit of innovative technologies to enhance the quality of irrigation water and mitigate the impact of saltinity from saline water is imperative (Abd El Baki *et al.,* 2025). Processes like magnetized treatment have gained attention in agriculture as these technologies have demonstrated their ability to enhance irrigation water quality through reduction of surface tension and viscosity, and enhancement of various characteristics (Cai *et al.,* 2009).

Magnetic water treatment is based on the principal that Lorentz force exerts pressure on the particles with opposing charges in opposite directions as water passes through a magnetic water softener (Elaoud *et al.,* 2016). This redirection enhances the rate of collision among ions with opposing charges, resulting in ion precipitation or formation of insoluble composites (Ben Amor *et al.,* 2022). One effective method for desalinating soil is magnetic treatment of saline irrigation water (Samarah *et al.,* 2021). Recent studies and reviews have increasingly highlight the influence of magnetized water irrigation on plant metabolism, growth, and development (Dobránszki, 2023; Alattar *et al.,* 2022). The influence of magnetic fields on plants is influenced by several factors, including exposure time, polarity, orientation, and field intensity. Moreover, plant responses vary by species and genotype, indicating a strong genetic dependence in the observed effects (Teixeira da Silva and Dobránszki, 2015). Interestingly, the magnetization of saline water has proved to improve soil characteristics by enhancing the availability of N and P, improving soil moisture, and boosting organic matter content. This process appears to alleviate salt stress, leading to improvement in growth and production across various plants. Additionally, enhancements have been reported in the biochemical composition of yield, including elevated levels of carbohydrates, proteins, and nutrients concentrations. Specifically, in poplar plants, magnetized saline water has been found to reduce Na levels and elevate K and and N levels, thereby enhancing plant adaptation to saline conditions (Liu *et al.,* 2019).

Barley is among the earliest cereal crops and serve as a cornerstone of agriculture. It stands as a remarkably adjustable cereal, it demonstrates versatility across diverse climatic circumstances and soil properties (Thalooth *et al.,* 2012). It thrives and produces even in conditions of drought-induced stress, low temperatures, and high salinity (Baum *et al.,* 2003). Magnetic technology can be used in agriculture as a non-conventional, economical, and eco-friendly tool. Furthermore, it can improve soil and water properties, which in turn can enhance crop and water productivity under salinity stress. Since magnetism alters the hydrogen bonds in an aqueous solution, it is reasonable to assume that treating saline water under magnetic field will alter the water quality. In view of the above, the aim of this investigation was to estimate the potential magnetized water technology in enhancing seawater quality, and to explore its influence on soil properties and growth performance of barley.

Materials and Methods

Preparation of irrigation water: Seawater was collected from the Red Sea, opposite to Jeddah Coast, Saudi Arabia. It was diluted with demineralized water to obtain different salinity levels 2, 6 and 12 dS m^{-1} equivalent to 5, 10 and 20% seawater, respectively for irrigation. For water magnetization, saline and non-saline water samples were passed through a magnetic tube (70 cm length, 2 inch diameter, 3.5 to 136 mT magnetic field intensity, produced by Delta Water, Egypt) for 15 min.

Experimental design: This study was conducted at King Abdulaziz University's Green House, Saudi Arabia, during October–January, 2023 this period offered adequate temperature and least humidity. Throughout study period, the average maximum temperature was 37 ºC per day, while the minimum was 19 ºC per day with no rainfall. Barley grains were planted in pots filled with a homogeneous mixture of sand and clay soil (2:1 ratio). These pots were irrigated with tap water at field capacity. After the appearance of third true leaf, the pots were divided into two groups. One group was watered with 0, 5, 10 and 20% of non-magnetized seawater, while the other group was irrigated with magnetized seawater under same levels. A randomized complete block design was used for this experiment in three replicates. Soil and plant samples were collected the end of experiment (three weeks after treatment) and transferred to the laboratory for further analysis. The sodium adsorption ratio was calculated in non-magnetized water and magnetized water by the formula given by Schwab *et al.* (1993). Soil extract was prepared by collecting 10 g of soil samples from each treatment and mixing with distilled water at the end of the experiment. The mixtures were kept on a shaker for 24 hr and filtrated using a Whatman filter paper. A Systronics direct digital pH meter and conductivity meter was used to measure the pH and electrical conductivity of soil solution in accordance with Conklin's (2005) methodology. Soil water content was determined following the method of Haj-Amor *et al.* (2023). A100 g of soil samples was oven-dried at 105°C for 24 hr and subsequently, weighed before being placed in the oven again until a constant weight was achieved. The percentage of water content in the soil samples was determined by the equation given below:

Water Content (%) = [(Weight of wet soil - Weight of dry soil) / Weight of dry soil] x 100

After cleaning the samples with distilled water, they were carefully pat dried with a tissue paper. For each treatment, three replicates of newly collected shoots and roots were weighed and recorded. A ruler was used to determine the shoot height and root length (cm). Maximum leaf length × maximum leaf width was multiplied by 0.703 to determine the leaf area (cm^2) (Tan *et al.,* 2018). To calculate dry weight (g), shoot and root samples were oven-dried for 48 hrs at 70 °C.

Chlorophyll a, chlorophyll b and carotenoid concentrations were estimated by UV-VIS spectroscopy in ethanol extracts at 60 °C according to Su *et al.* (2010), and quantified ($\mu g\ ml^{-1}$) using the formulas cited by Sumanta *et al.* (2014). Colorimetric anthrone method was used to measure the amount of soluble sugars in shoot samples (Fales, 1951). The amount of soluble proteins in the shoot extracts was estimate by Lowry *et al.* (1951). The concentration of free amino acids in the shoot extracts was determined spectrophotometrically according to Moore and Stein (1948). For elemental analysis, the collected drained water was filtered and kept at 4 °C. Following plant harvest, the soil samples were collected from each pot. The materials were crushed, allowed to air dry, and then sieved through a 2 mm sieve. On the other hand, a heating block was used to digest dry shoot and root samples at 180°C using an acid mixture of perchloric acid and nitric acid, the concentrations of Ca, Mg, P, K, and Na were estimated in the prepared soil, water, and plant samples on an atomic absorption spectrometer

Statistical analysis: SPSS package software, version 21.0 (SPSS, Chicago, USA), was used to statistically analyze the results. At 5% significance level (P<0.05), One-way ANOVA followed by Duncan's Multiple Range Test was applied to examine the differences between various water levels. The data were expressed as mean±S.E. RStudio version 3.5.0 was used for correlation similarity, principle co-ordinate analysis (PCoA), canonical correspondence analysis (CCA), and heatmap.2 analyses.

Results and Discussion

Currently, researchers worldwide are actively exploring production environmentally friendly techniques that involve physical and biological treatments to enhance crops production. Their finding reveal that using magnetized water which has been exposed to a magnetic field or other device in irrigation systems is a safe and environmentally sound technology that should be recommended for use in agriculture (Dobránszki, 2023). It also provides a tool for addressing the issue of freshwater shortage was to magnetize low-quality water, such as brackish, salty, or metal-contaminated water. In the present study, to explore the possible effect of magnetic field in improving seawater characteristics, both magnetized and non magnetized seawater samples were analyzed for their elemental composition and sodium adsorption ratio (SAR). Across all tested salinity levels, both non-magnetized water and magnetized water exhibited the highest concentrations of Na, followed by Ca, K, Mg and P, respectively. Notably, the observed differences in mineral concentrations between non-magnetized water and magnetized water, particularly significant reduction in Na levels in magnetized water, align with the outcomes of Wang *et al.* (2024).

On the other hand, the ion concentration significantly reduced in magnetized water compared to non-magnetized water in same seawater level. The most pronounced reduction was recorded in Na concentration that reduced by 12.6, 37.3 and 41.9% in magnetized water lower than non-magnetized water at 5, 10 and 20% seawater, respectively. This reduction in Na concentration makes magnetized water more suitable for irrigation than non-magnetized water because magnetic treatment reduces soil salinity. while calcium ion concentration reduced in MW by 8.4, 18.7 and 8.2 % and Mg concentration by 8.1, 17.2 and 10.3% lower than non-magnetized water at 5, 10 and 20% seawater correspondingly (Table 1).

Sodium adsorption ratio (SAR) significantly increased by increasing salinity concentration both in non-magnetized water and magnetized water samples. Magnetic treatment significantly reduced SAR values mainly in seawater. Similar results were recorded by Ogunlela and Yusuf (2016) who elucidated that all SAR's values for non-magnetized water exceeded the SAR's values for magnetized water for different magnetic flux densities. Water suitability for irrigation is determined by several factors, but generally, greater the SAR, less suitable the water is for irrigation (Zhang *et al.,* 2022). Lower menials' concentrations and SAR in magnetized seawater can be related to the change in the physical properties of water due to magnetic treatment. In reaction to the magnetic field, the water molecules' rotating motion decreased and their inter-cluster hydrogen bonds strengthens at the same time (Su *et al.,* 2021). As a result, when the clustering structure of water alters, its viscosity rises and surface tension declines (Cai *et al.,* 2009). Sedimentation of electrolytic materials enhances due to magnetization, resulting in colloids and the decrease in the concentration of dissolved salts (Surendran *et al.,* 2016). The chemical properties of soil samples, at the end of the experiment, were analyzed and recorded in Table 2. Electrical conductivity

Table 1: Effect of magnetic treatment on water ions concentration (mg l^{-1}) and sodium adsorption ratio (SAR) in different seawater levels

	Seawater	**Ca**	**Mg**	**P**	**K**	**Na**	**SAR (dS m^{-1})**
Non-magnetized water	0%	17.8 ± 0.1^{a}	1.13 ± 0.01^{a}	0.1 ± 0.0^{a}	0.1 ± 0.0^{a}	13.3 ± 0.1^{a}	2.8 ± 0.0^{a}
	5%	34.5 ± 1.2^{c}	16.1 ± 0.5^{c}	0.1 ± 0.0^{a}	2.1 ± 0.0^{b}	542.4 ± 10.2^{c}	20.9 ± 1.3^{d}
	10%	68.8 ± 2.1^{e}	20.3 ± 1.4^{e}	0.1 ± 0.0^{a}	4.2 ± 0.1^{d}	1493.9 ± 12.0^{e}	24.8 ± 0.6^{f}
	20%	86.2 ± 1.8^{g}	31.2 ± 2.3^{g}	0.0 ± 0.0^{a}	9.3 ± 0.4^{f}	2603.5 ± 16.6^{g}	28.6 ± 1.4^{g}
Magnetized water	0%	17.9 ± 0.2^{a}	1.2 ± 0.0^{a}	0.1 ± 0.0^{a}	0.1 ± 0^{a}	13.1 ± 0.3^{a}	2.3 ± 0.0^{b}
	5%	31.6 ± 0.1^{b}	14.9 ± 0.3^{b}	0.1 ± 0.0^{a}	2.3 ± 0.2^{b}	474.2 ± 6.1^{b}	17.7 ± 0.4^{c}
	10%	55.9 ± 0.7^{d}	16.8 ± 0.4^{d}	0.1 ± 0.0^{a}	3.5 ± 0.1^{c}	936.0 ± 17.3^{d}	20.3 ± 0.2^{d}
	20%	79.0 ± 2.4^{f}	27.9 ± 1.4^{f}	0.1 ± 0.0^{a}	7.5 ± 0.2^{e}	1512.3 ± 11.8^{f}	22.0 ± 0.3^{e}

Values carrying similar letters are not significantly different at $p<0.05$ according to DMRT

Table 2: Effects of magnetic treatment on soil chemical properties at different seawater levels

	Seawater	**pH**	**EC (dS m^{-1})**	**WC (%)**
Non-magnetized water	0%	6.1 ± 0.0^{b}	0.4 ± 0.0^{b}	8.7 ± 0.0^{a}
	5%	6.1 ± 0.1^{b}	1.4 ± 0.0^{d}	8.5 ± 0.2^{a}
	10%	5.7 ± 0.1^{a}	2.6 ± 0.0^{f}	9.3 ± 0.1^{b}
	20%	5.7 ± 0.1^{a}	5.0 ± 0.1^{h}	10.1 ± 0.1^{c}
Magnetized water	0%	5.9 ± 0.1^{b}	0.2 ± 0.0^{a}	10.0 ± 0.1^{c}
	5%	6.1 ± 0.1^{b}	0.9 ± 0.0^{c}	11.1 ± 0.1^{d}
	10%	5.7 ± 0.1^{a}	1.8 ± 0.0^{e}	12.4 ± 0.0^{e}
	20%	5.7 ± 0.1^{a}	3.0 ± 0.1^{g}	14.8 ± 0.1^{f}

(EC) of soil irrigated with MW was markedly less than that of soil irrigated with non-magnetized water at same seawater level (Table 2). Magnetized water application reduced EC 50.0, 35.7, 30.8 and 30.0%, lower than non-magnetized water at same seawater levels approximately by while, soil water content (WC) was notably higher in soil irrigated with magnetized water related to that irrigated with non-magnetized water at same salinity level. The most pronounced induction was at salinity level 20%, where soil WC in soil samples irrigated with magnetized water increased by 40% compared with soil irrigated with non-magnetized water (Table 2). Comparable results recorded for the influence of magnetic field on soil EC by Wang *et al.* (2024). In this study, both freshwater and seawater showed larger soil water contents during magnetized irrigation than under non-magnetized irrigation. There are two possible explanation first is that magnetism alters the physico-chemical properties of water. It breaks down large clusters of associated water molecules into smaller monomeric units, making water more capable of penetrating fine soil pores. This facilitates longer retention and migration of water within the soil profile, thereby increasing the moisture content in the rhizosphere (Zhang *et al.,* 2022). Second magnetic treatment reduces the surface tension and viscosity of water, which in turn affects the soil hydraulic conductivity and infiltration rate.

Considerable variations were observed between the soil extracts from soil watered using NMW and those watered using MW (Table 3). At same salinity level, the average values of soil soluble cations (Ca, Mg, and Na) were lower in magnetized water-irrigated soil than in non-magnetized water-irrigated soil. Calcium concentration in soil samples irrigated with magnetized water reduced by 9.2, 11.1, 44.4 and 21.4%, lower than non-magnetized water irrigation at salinity levels 0, 5, 10 and 20% respectively. The concentration of magnesium ions in the soil reduced due to magnetic treatment by 21%, lower than non-magnetized water irrigation only under high salinity levels.

The most pronounced reduction in response to magnetic treatment recorded for Na, where Na concentration in soil irrigated with magnetized water was 14.3, 28.2, 31.6 and 45.6 at salinity levels 0, 5, 10 and 20%, respectively. Magnetic water elevate soil characters by washing salts from the soil rhizosphere (Wang *et al.,* 2018). In contrast, the results of this investigation displayed an increase in available macronutrients (P and K) in soil samples irrigated with magnetized water compared with non-magnetized water at the same salinity level (Table 3). The phosphorus concentration in magnetized water irrigated soil increased by 43.75, 47.1 and 50.0%, while K concentration was 32.0, 46.4, and 67.7% higher than their corresponding non-magnetized water treated soil at 5, 10 and 20% seawater, respectively. Desorption of P and K from soil adsorbed on the colloidal complex may be impacted by magnetic treatment of water, which could increase its availability to plants, and thus, boost plant growth (Maheshwari and Grewal, 2009). Mostafazadeh-Fard *et al.* (2012) reported that irrigation with magnetized brackish water significantly increased the downward movement of chloride and sodium ions, facilitating the leaching of

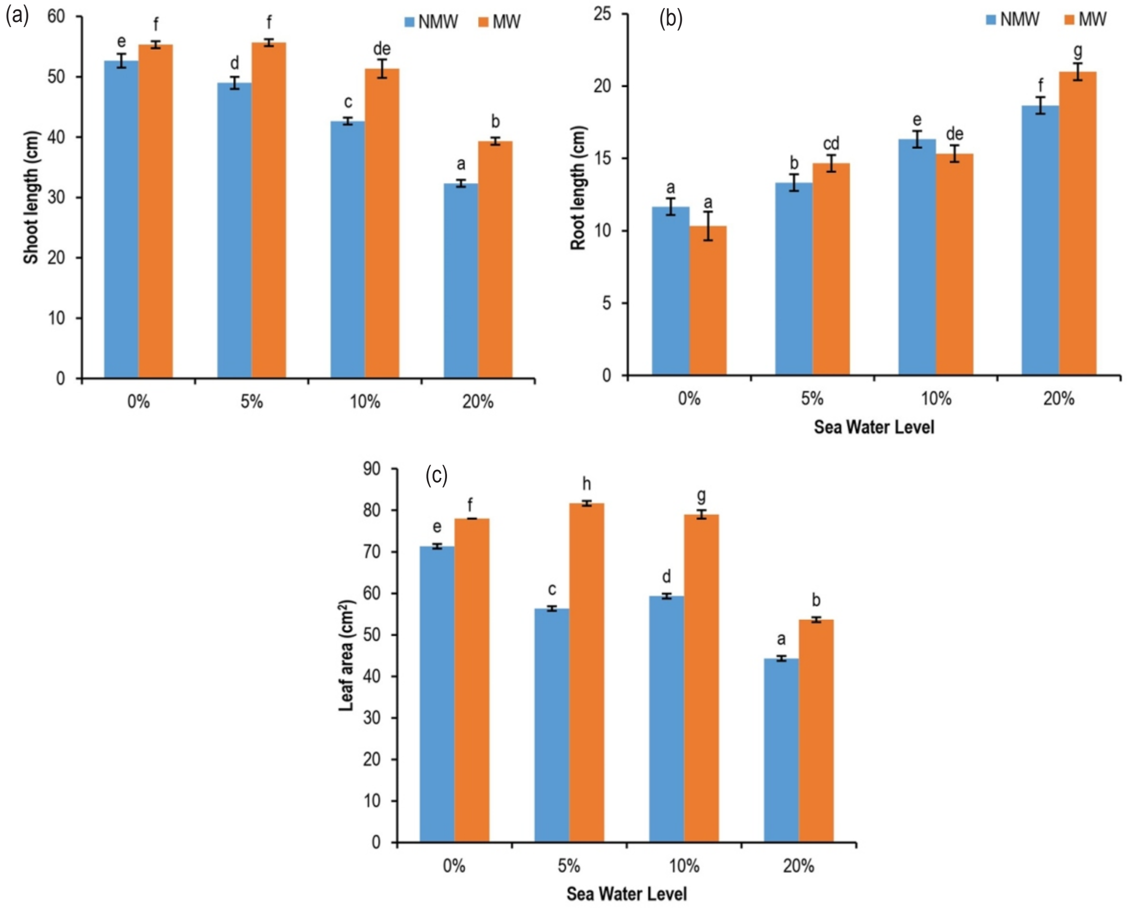


Fig. 1: (a) shoot length, (b) root length and leaf area (c) of barely when irrigated with non-magnetized water (NMW) and magnetized water (MW) at different sea water levels. Bars carrying similar letters are not significantly different at $p<0.05$.

base ions from the soil. The reduced molecular cluster size and lower contact angle of magnetized water enable it to penetrate finer soil pores more effectively. This allows for improved interaction between water and soil salts, promoting transport of salts through convection and diffusion, and thereby increasing leaching efficiency (Selim *et al.,* 2013). Furthermore, desalination through magnetic treatment has been found to increase the soil organic carbon and nitrogen content (Zhao *et al.,* 2021), enhance ion exchange capacity, and improve ion composition in the soil. These changes support the uptake of relatively immobile nutrients by plants (Çelik *et al.,* 2008). These findings are consistent with the results of the current study, indicating that magnetized water irrigation not only promotes salt dissolution and downward movement but also reduces soil salinity and enhances the availability of nutrients. This offers a promising strategy for utilizing seawater and rehabilitating saline soils for agriculture.

The effects of water magnetization on barely growth under salinity stress in the current study was evaluated through various growth parameters, including many morphological and physiological traits. The interactive effects of magnetic treatment and varying seawater concentrations variously influenced the morphological characters (Fig. 1). Under non-magnetized water conditions, the the shoot length and leaf area reduced gradually by increasing the seawater level, the maximum reduction of 38.8 and 37.9% was found at highest salinity level with respect to control (Fig. 1, c). When irrigated with magnetized water, barely the shoot length and leaf area significantly enhanced compared to non-magnetized water at that same seawater level. The most pronounced increase was recorded at 5 and 10% seawater, where shoot length enhanced by 13.6, 20.2% and leaf area enhanced by 45.1, 33.2% correspondingly compared to non-magnetized water treated barely (Fig. 1 a,c). On the other hand, root length increased gradually by increasing salinity level under non-magnetized water irrigation (Fig. 1 b).

Increasing salinity levels, under non-magnetized water condition, significantly reduced the shoot fresh weight and dry weight in addition to root fresh weight and dry weight reaching reduction values of 57.0, 50.0, 58.5 and 62.5%, respectively, lower than tap water at 20% seawater level (Fig. 2 a-d). However, irrigation with magnetized water significantly increased all

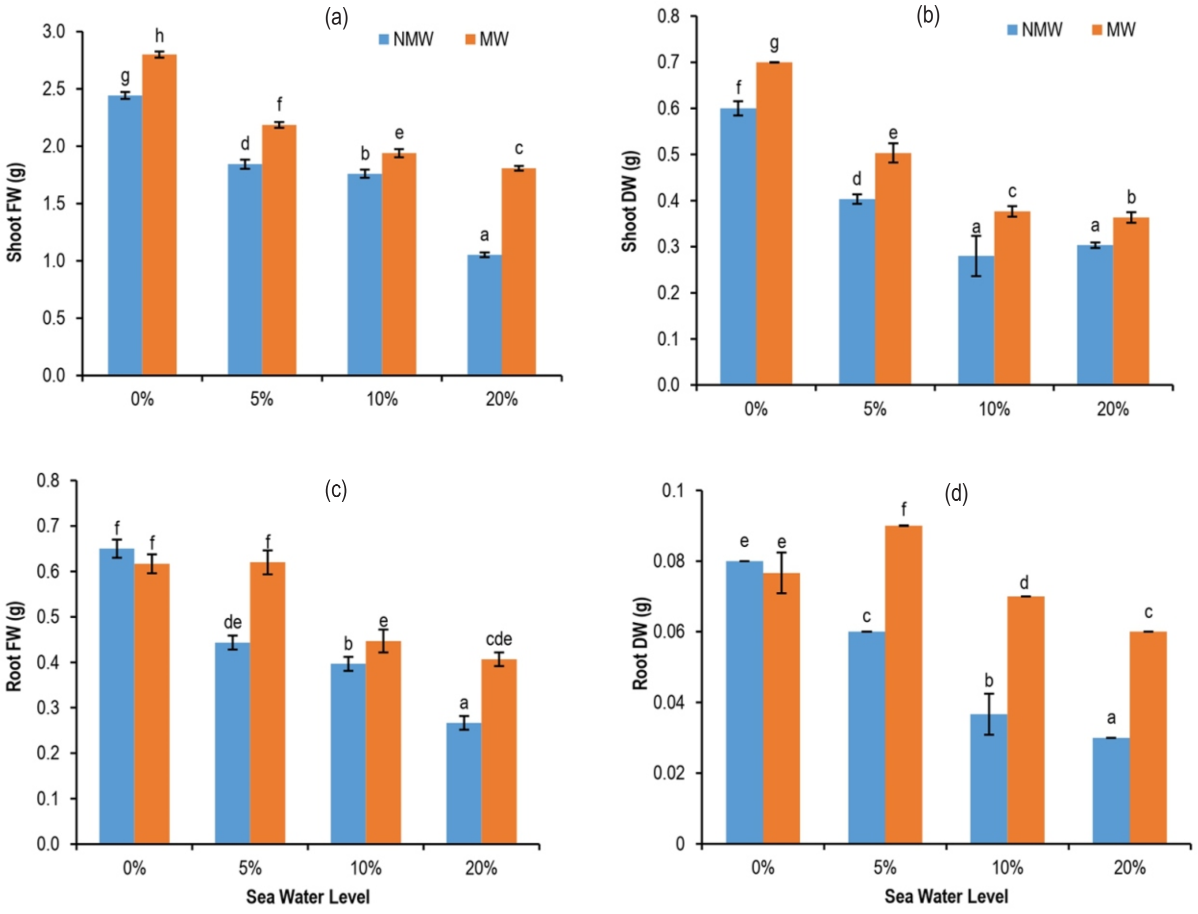


Fig. 2: (a) shoot fresh weight (FW), (b) shoot dry weight (DW), (c) root fresh weight and (d) root dry weight of barely when irrigated with non-magnetized water (NMW) and magnetized water (MW) at different sea water levels. Bars carrying similar letters are not significantly different at $p<0.05$.

Table 3: Effects of magnetic treatment on soil minerals concentration (mg kg^{-1}) at different seawater levels

	Seawater	Ca	Mg	P	K	Na
Non-magnetized water	0%	14.2±0.4^{b}	1.4±0.0^{a}	1.3±0.0^{a}	1.2±0.0^{a}	56.2±2.1^{a}
	5%	18.0±0.4^{d}	2.4±0.0^{b}	1.6±0.0^{b}	2.5±0.0^{b}	1254.4±14.3^{d}
	10%	37.4±1.1^{e}	4.3±0.1^{d}	1.7±0.0^{c}	2.8±0.0^{c}	1821.1±16.2^{e}
	20%	44.3 ±1.9^{g}	10.9±0.4^{f}	2.8±0.1^{f}	3.1±0.1^{d}	3666.5±20.7^{g}
Magnetized water	0%	12.9±0.2^{a}	1.4±0.0^{a}	1.3±0.0^{a}	1.2±0.0^{a}	48.8±3.1^{b}
	5%	16.1±0.1^{c}	2.4±0.0^{b}	2.3±0.0^{d}	3.3±0.2^{d}	900.2±13.1^{c}
	10%	20.8±1.2^{d}	3.4±0.1^{c}	2.5±0.0^{e}	4.1±0.2^{e}	1245.5±12.2^{d}
	20%	34.8±1.5^{f}	8.7±0.2^{e}	4.2±0.1^{g}	5.2±0.1^{f}	1996.1±23.7^{f}

biomass parameters compared to non-magnetized water at same seawater level. Shoot fresh weight and dry weight of magnetized water treated plants increased approximately by 16.7, 21.22, 14.1, 72.4% and 16.7, 25.0, 35.7, 20% higher than NMM treated plants under 0, 5, 10 and 20% seawater level (Fig 2. a, b). Root biomass increased in MW treatment only under saline conditions, where in MW-treated plants, root fresh weight increased by 40.9, 12.5, and 51.6%, while root dry weight increased by 50.0, 75.0, and 100% higher than NMW-treated plants under seawater levels 5, 10 and 20% respectively (Fig 2. c,d). The effect of magnetized water at different salinity levels on the photosynthetic pigments of barley leaves are illustrated in Fig. 3. Under non-magnetized water treament, increasing salinity levels led to a gradual decrease in chlorophyll b and carotenoids concentrations, while chlorophyll a concentration increased. However, magnetized water treatment did not significantly alter Chl a concentrations

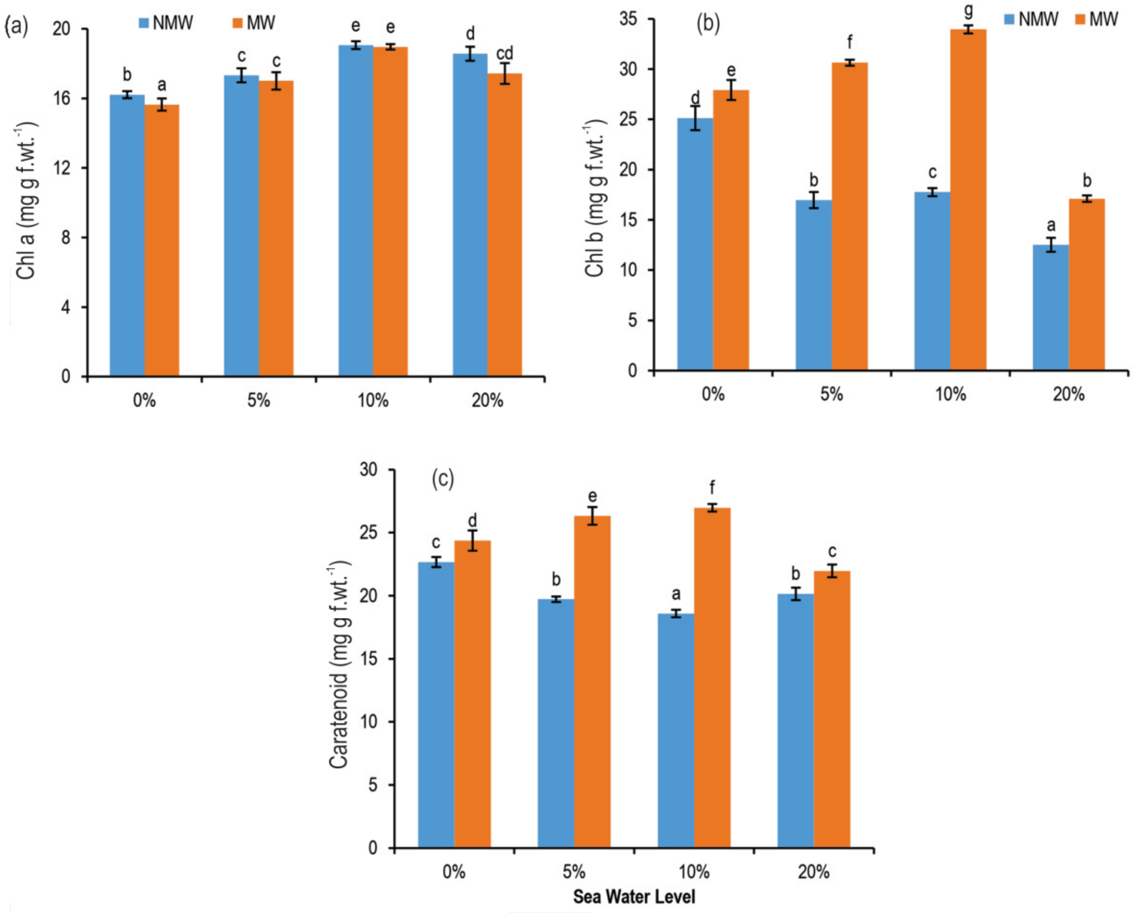


Fig. 3: (a) chlorophyll a (Chl a), (b) chlorophyll b (Chl b) and (c) carotenoids (Carot.) of barely when irrigated with non-magnetized water (NMW) and magnetized water (MW) at different sea water levels. Bars carrying similar letters are not significantly different at $p<0.05$.

Table 4: Effects of magnetic treatment on shoot minerals (mg kg^{-1}) at different seawater levels

	Seawater	Ca	Mg	P	K	Na
Non-magnetized water	0%	2.6 ± 0.1^{a}	1.1 ± 0.0^{a}	2.3 ± 0.0^{d}	2.9 ± 0.0^{d}	2.5 ± 0.0^{b}
	5%	4.6 ± 0.1^{d}	1.3 ± 0.0^{b}	2.2 ± 0.1^{c}	2.4 ± 0.0^{c}	4.1 ± 0.0^{c}
	10%	6.0 ± 0.1^{g}	3.1 ± 0.1^{d}	1.9 ± 0.1^{b}	2.1 ± 0.0^{b}	21.1 ± 0.9^{g}
	20%	6.8 ± 0.2^{h}	4.3 ± 0.0^{f}	1.2 ± 0.0^{a}	0.9 ± 0.0^{a}	24.9 ± 1.2^{h}
Magnetized water	0%	2.8 ± 0.0^{b}	1.2 ± 0.1^{ab}	2.3 ± 0.1^{d}	2.8 ± 0.1^{d}	1.7 ± 0.0^{a}
	5%	4.3 ± 0.0^{c}	1.7 ± 0.0^{c}	3.3 ± 0.1^{e}	4.2 ± 0.1^{e}	7.2 ± 0.1^{d}
	10%	5.4 ± 0.1^{e}	2.9 ± 0.1^{d}	4.1 ± 0.1^{f}	4.6 ± 0.2^{g}	14.9 ± 0.3^{e}
	20%	5.7 ± 0.1^{f}	3.5 ± 0.1^{e}	4.9 ± 0.2^{g}	3.5 ± 0.0^{f}	15.4 ± 1.1^{f}

under varied (Fig. 3 a). In contrast, Chl b and carotenoids levels significantly increased in response to magnetized water treatment both under both saline and non-saline conditions. The Chl b concentrations in barely plants irrigated with magnetized water were 11.2, 80.6, 91.2 and 36.0%, higher than plants treated with non-magnetized water at varied sea levels respectively (Fig. 3 b). Similarly, carotenoids concentrations increased by 7.5, 33.5, 45.2 and 9.1 in magnetized water-treated plants, at 0, 5, 10 and 20% seawater respectively (Fig. 3 c). The increase in pigment concentration may contribute to improved photosynthetic efficiency and overall growth performance and metabolic processes of barley under magnetized water treatment, even in saline conditions as confirmed by the increasing of soluble sugars and proteins and free amino acids concentration (Fig. 4).

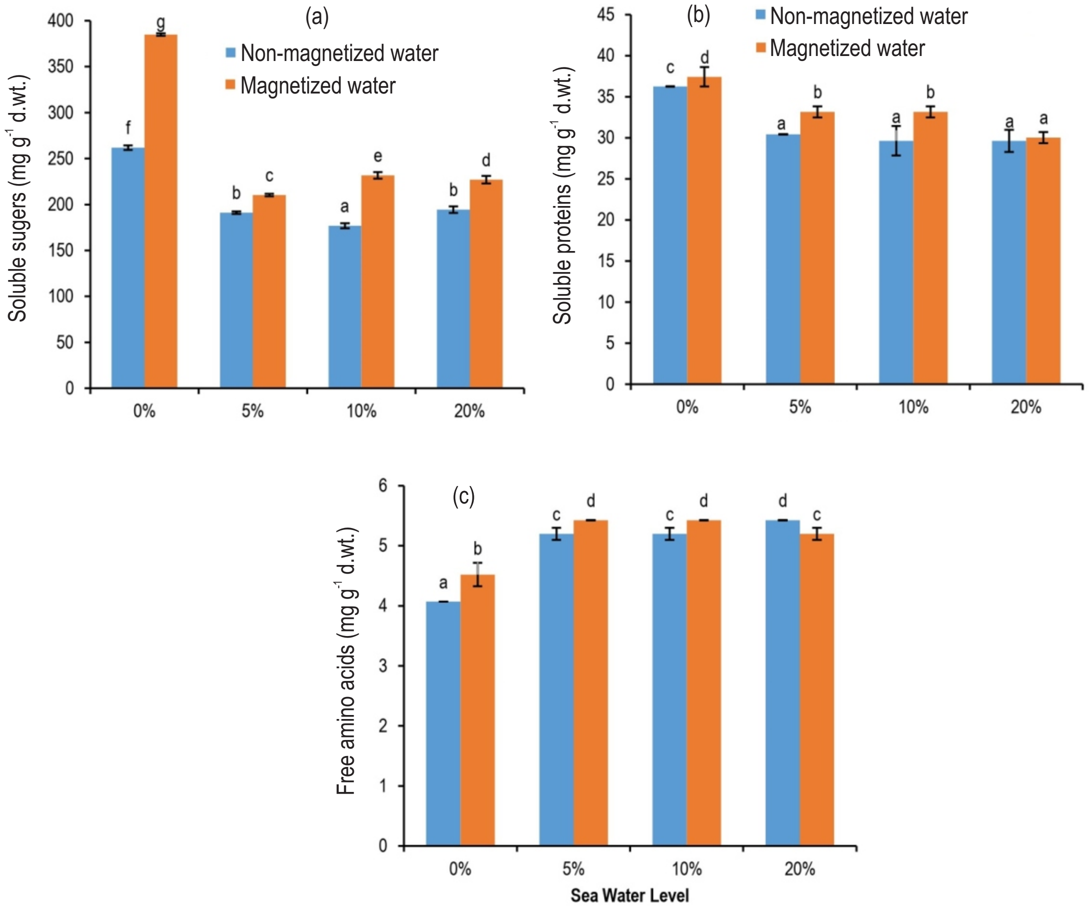
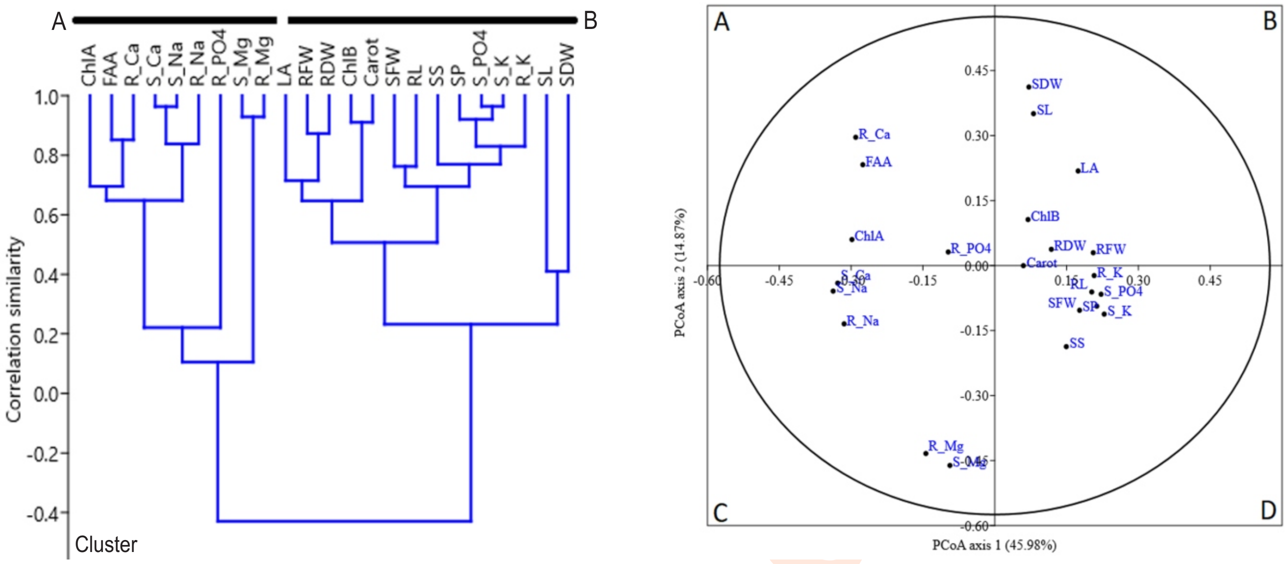


Fig. 4: (a) soluble carbohydrates, (b) soluble proteins and (c) free amino acids of barely shoots when irrigated with non-magnetized water (NMW) and magnetized water (MW) at different sea water levels. Bars carrying similar letters are not significantly different at $p<0.05$.

Table 5: Effects of magnetic treatment on root minerals (mg kg^{-1}) at different seawater levels

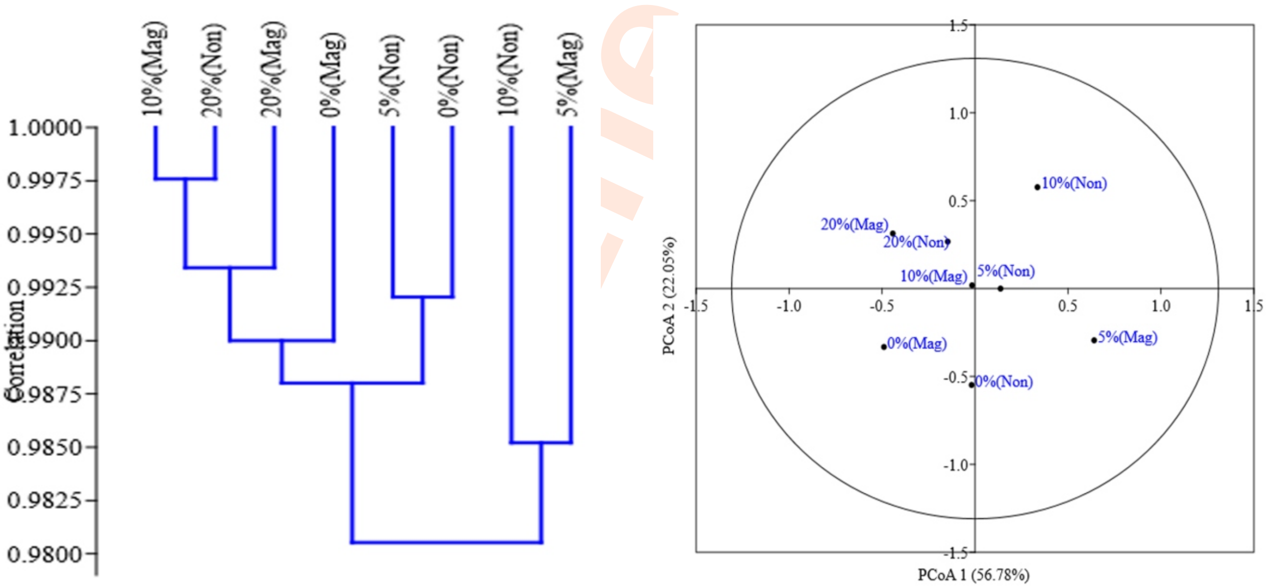
	Seawater	Ca	Mg	P	K	Na
	0%	6.1± 0.2^{b}	1.0±0.0^{b}	2.8±0.0^{a}	6.0±0.1^{a}	0.5± 0.0^{b}
Non-magnetized water	5%	12.7±0.3^{e}	1.3±0.0^{c}	2.6±0.0^{b}	6.6±0.2^{c}	6.7± 0.3^{e}
	10%	17.3±0.8^{g}	2.7±0.1^{e}	3.4±0.1^{d}	7.1±0.2^{d}	8.8± 0.2^{f}
	20%	19.1± 0.8^{h}	6.0±0.2^{g}	3.9±0.1^{e}	6.4±0.3^{b}	17.9±0.9^{h}
	0%	5.4±0.1^{a}	0.97±0.0^{a}	2.8±0.0^{a}	6.0± 0.9^{a}	0.4±0.0^{a}
Magnetized water	5%	10.1±0.9^{c}	1.3±0.0^{c}	2.9±0.0^{c}	7.2±0.3^{d}	5.2±0.1^{c}
	10%	14.9±0.7^{f}	1.5±0.0^{d}	4.2±0.1^{f}	8.3±0.3^{e}	6.1±0.1^{d}
	20%	10.8±0.2^{d}	3.8±0.1^{f}	5.1±0.0^{g}	9.2±0.2^{f}	12.3±0.7^{g}

Furtheremore, magnetic treatment significanly reduced the Na concentration in barley shoots and roots under saline coditions. It is noteworthy that P and K concentrations improved in barely tissues as affected by seawater magnetization (Tables 4, 5). In accordance with the results of this study, Hozayn *et al.* (2021) reported that magnetized saline irrigation water, increases barley growth parameters as well as photosynthetic pigments, resulting in an increase in grain yield compared to irrigation with non-magnetized saline water. A previous study showed that magnetized water treatment could increase root growth, improve the capacity for selective absorption of mineral ions, and prevent excessive uptake of Na^+ by cells, thereby reducing the inhibitory effect of salt stress on plant growth (Mousa *et al.,* 2013). Therefore, in this study root fresh weight and dry weight of barely seedlings under magnetized water irrigation were significantly higher than non-magnetized water. More absorbent hairs are



(a) (b)

Fig. 5: Correlation coeffients: (a) Cluster analysis and (b) Principle co-ordinate analysis among all estimated plant variables. SL: shoot length; RL: root length; LA: leaf area; SFW: shoot fresh weight; RFW: root fresh weight; SDW: shoot dry weight; RDW: root dry weight; ChlA: chlorophyll a; ChlB: chlorophyll b; Carot: carotenoids; FAA: free amino acids; SS: soluble sugars; SP: soluble proteins; S-Ca, S-Mg, S-PO4, S-K, S-Na: Ca, Mg, Na, P and Na concentrations in shoot; R-Ca, R-Mg, R-PO4, R-K, R-Na: Ca, Mg, Na, P and Na concentrations in root.



(a) (b)

Fig. 6: Correlation coeffients: (a) Cluster analysis and (b) Principle co-ordinate analysis among treatments. Mag: magnetized water; Non: non-magnetized water; 0%, 5%, 10% and 20%: sea water levels.

produced by plants in response to magnetically treated water (Taimourya *et al.,* 2015). Thus, by promoting root tissue differentiation for the purpose of increasing the root elongation volume and radicle elongation, magnetized water can enhance the roots' ability to absorb nutrients (Hozayn *et al.,* 2019). As a result, magnetized water treatment can enhance crop nutrition and water absorption and increase the crops' economic qualities at later stages. Based on the correlation coeffients among all estimated variables, there are two main groups those negatively correlated (Fig. 5). The cluster analysis showed that Ca, Mg and

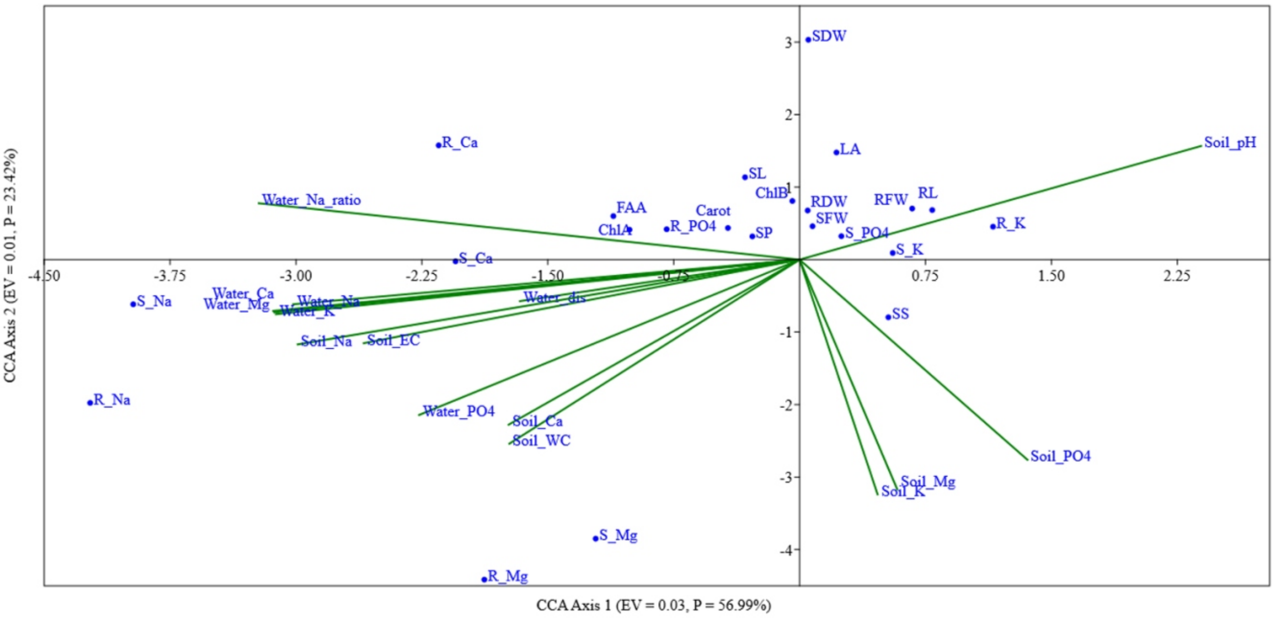
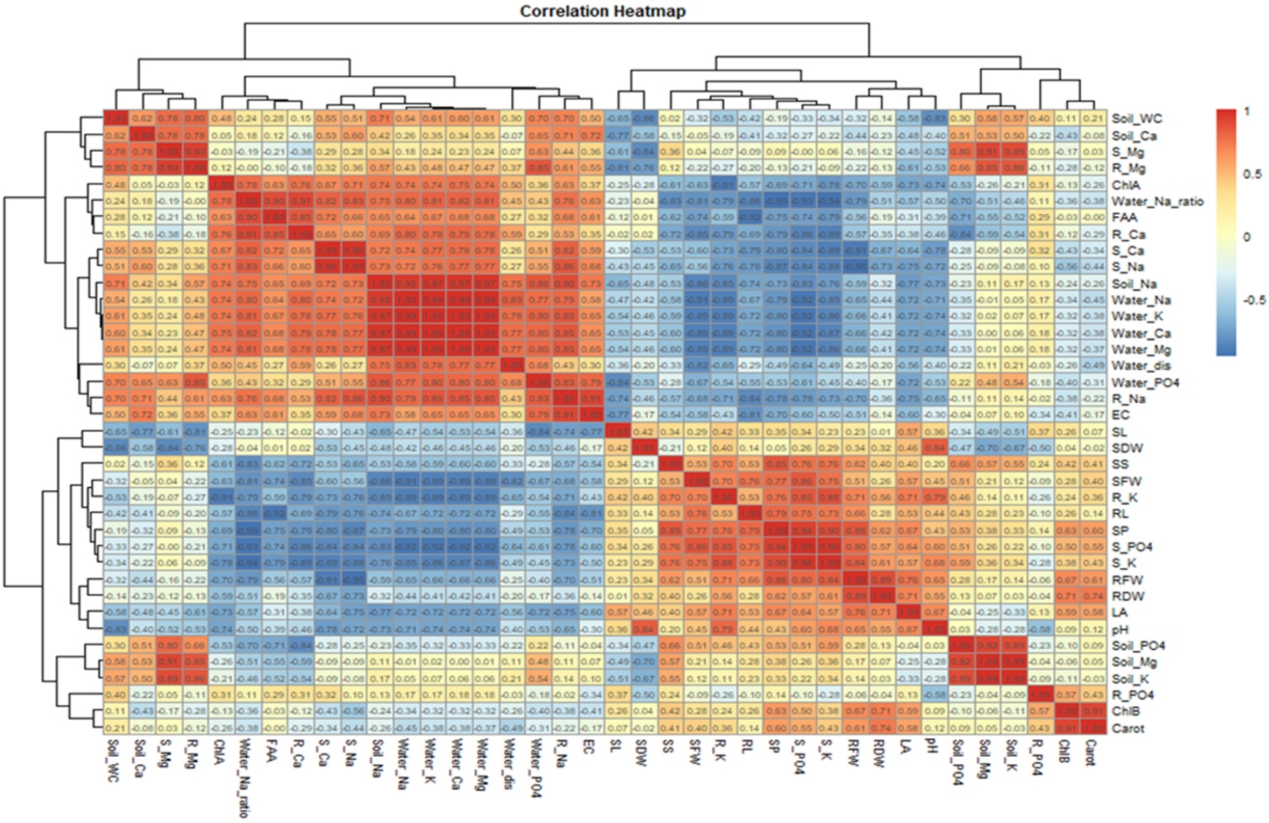


Fig. 7: Canonical correspondence analysis (CCA) shows the relations among plant variables and surrounding factors (water and soil). The abbreviations of plant variables are shown in figure 5. Soil factors: Soil EC: soil electrical conductivity; Soil-WC: soil water content; Soil-Ca, Soil-Mg, Soil-PO4, Soil-K, Soil-Na: Ca, Mg, Na, P and Na concentrations in soil samples. Water factors: Water-Na-ration: sodium adsorption ratio in water; Water-Ca, Water -Mg, Water -PO4, Water -K, Water -Na: Ca, Mg, Na, P and Na concentrations in water samples.



	Soil_WC	Soil_Ca	S_Mg	R_Mg	ChlA	Water_Na_ratio	FAA	R_Ca	S_Ca	S_Na	Soil_Na	Water_Na	Water_K	Water_Ca	Water_Mg	Water_dis	Water_PO4	R_Na	EC	SL	SDW	SS	SFW	R_K	RL	SP	S_PO4	S_K	RFW	RDW	LA	pH	Soil_PO4	Soil_Mg	Soil_K	R_PO4	ChlB	Carot
Soil_WC	1.00	0.62	0.78	0.80	0.48	0.24	0.28	0.15	0.55	0.51	0.71	0.54	0.61	0.60	0.61	0.30	0.70	0.70	0.50	-0.65	-0.86	0.02	-0.32	-0.53	-0.42	-0.19	-0.33	-0.34	-0.32	-0.14	-0.58	-0.83	0.30	0.58	0.57	0.40	0.11	0.21
Soil_Ca	0.62	1.00	0.78	0.78	0.05	0.18	0.12	-0.16	0.53	0.60	0.42	0.26	0.35	0.34	0.35	-0.07	0.65	0.71	0.72	-0.77	-0.58	-0.15	-0.05	-0.19	-0.41	-0.32	-0.27	-0.22	-0.44	-0.23	-0.48	-0.40	0.51	0.53	0.50	-0.22	-0.43	-0.08
S_Mg	0.78	0.78	1.00	0.93	-0.03	-0.19	-0.21	-0.38	0.29	0.28	0.34	0.18	0.24	0.23	0.24	0.07	0.63	0.44	0.36	-0.61	-0.84	0.36	0.04	-0.07	-0.09	0.09	-0.00	0.06	-0.16	-0.12	-0.45	-0.52	0.80	0.91	0.89	0.05	-0.17	0.03
R_Mg	0.80	0.78	0.93	1.00	0.12	-0.00	-0.10	-0.18	0.32	0.36	0.57	0.43	0.48	0.47	0.47	0.37	0.85	0.61	0.55	-0.81	-0.76	0.12	-0.22	-0.27	-0.20	-0.13	-0.21	-0.09	-0.22	-0.13	-0.61	-0.53	0.66	0.85	0.86	-0.11	-0.28	-0.12
ChlA	0.48	0.05	-0.03	0.12	1.00	0.78	0.63	0.76	0.67	0.71	0.74	0.74	0.74	0.75	0.74	0.50	0.36	0.63	0.37	-0.25	-0.28	-0.61	-0.63	-0.91	-0.57	-0.69	-0.71	-0.78	-0.70	-0.59	-0.73	-0.74	-0.53	-0.26	-0.21	0.31	-0.13	-0.26
Water_Na_ratio	0.24	0.18	-0.19	-0.00	0.78	1.00	0.90	0.91	0.82	0.83	0.75	0.80	0.81	0.82	0.81	0.45	0.43	0.76	0.63	-0.23	-0.04	-0.83	-0.81	-0.79	-0.86	-0.95	-0.93	-0.94	-0.79	-0.51	-0.57	-0.50	-0.70	-0.51	-0.46	0.11	-0.36	-0.38
FAA	0.28	0.12	-0.21	-0.10	0.63	0.90	1.00	0.85	0.72	0.66	0.65	0.64	0.67	0.68	0.68	0.27	0.32	0.68	0.61	-0.12	0.01	-0.62	-0.74	-0.59	-0.92	-0.75	-0.74	-0.79	-0.56	-0.19	-0.31	-0.39	-0.71	-0.55	-0.52	0.29	-0.03	-0.00
R_Ca	0.15	-0.16	-0.38	-0.18	0.76	0.91	0.85	1.00	0.65	0.60	0.69	0.80	0.78	0.79	0.78	0.59	0.29	0.53	0.35	-0.02	0.02	-0.72	-0.85	-0.79	-0.69	-0.79	-0.86	-0.89	-0.57	-0.35	-0.38	-0.46	-0.84	-0.59	-0.54	0.31	-0.12	-0.29
S_Ca	0.55	0.53	0.29	0.32	0.67	0.82	0.72	0.65	1.00	0.96	0.72	0.74	0.77	0.78	0.78	0.26	0.51	0.82	0.59	-0.30	-0.53	-0.53	-0.60	-0.73	-0.79	-0.80	-0.84	-0.89	-0.91	-0.67	-0.64	-0.78	-0.28	-0.09	-0.09	0.32	-0.43	-0.34
S_Na	0.51	0.60	0.28	0.36	0.71	0.83	0.66	0.60	0.96	1.00	0.73	0.72	0.76	0.77	0.77	0.27	0.55	0.86	0.68	-0.43	-0.45	-0.65	-0.56	-0.76	-0.76	-0.87	-0.84	-0.88	-0.95	-0.73	-0.75	-0.72	-0.25	-0.09	-0.08	0.10	-0.56	-0.44
Soil_Na	0.71	0.42	0.34	0.57	0.74	0.75	0.65	0.69	0.72	0.73	1.00	0.95	0.97	0.97	0.97	0.75	0.86	0.90	0.73	-0.65	-0.48	-0.53	-0.86	-0.85	-0.74	-0.73	-0.83	-0.76	-0.59	-0.32	-0.77	-0.73	-0.23	0.11	0.17	0.13	-0.24	-0.26
Water_Na	0.54	0.26	0.18	0.43	0.74	0.80	0.64	0.80	0.74	0.72	0.95	1.00	0.99	0.99	0.99	0.83	0.77	0.79	0.58	-0.47	-0.42	-0.58	-0.91	-0.89	-0.67	-0.79	-0.92	-0.85	-0.65	-0.44	-0.72	-0.71	-0.35	-0.01	0.05	0.17	-0.34	-0.45
Water_K	0.61	0.35	0.24	0.48	0.74	0.81	0.67	0.78	0.77	0.76	0.97	0.99	1.00	1.00	1.00	0.78	0.80	0.85	0.65	-0.54	-0.46	-0.59	-0.89	-0.89	-0.72	-0.80	-0.92	-0.86	-0.66	-0.41	-0.72	-0.74	-0.32	0.02	0.07	0.17	-0.32	-0.38
Water_Ca	0.60	0.34	0.23	0.47	0.75	0.82	0.68	0.79	0.78	0.77	0.97	0.99	1.00	1.00	1.00	0.77	0.80	0.85	0.65	-0.53	-0.45	-0.60	-0.89	-0.89	-0.72	-0.80	-0.92	-0.87	-0.66	-0.42	-0.72	-0.74	-0.33	0.00	0.06	0.18	-0.32	-0.38
Water_Mg	0.61	0.35	0.24	0.47	0.74	0.81	0.68	0.78	0.78	0.77	0.97	0.99	1.00	1.00	1.00	0.77	0.80	0.85	0.65	-0.54	-0.46	-0.60	-0.89	-0.89	-0.72	-0.80	-0.92	-0.86	-0.66	-0.41	-0.72	-0.74	-0.33	0.01	0.06	0.18	-0.32	-0.37
Water_dis	0.30	-0.07	0.07	0.37	0.50	0.45	0.27	0.59	0.26	0.27	0.75	0.83	0.78	0.77	0.77	1.00	0.68	0.43	0.30	-0.36	-0.20	-0.33	-0.82	-0.65	-0.29	-0.49	-0.64	-0.49	-0.25	-0.20	-0.56	-0.40	-0.22	0.11	0.21	-0.03	-0.26	-0.49
Water_PO4	0.70	0.65	0.63	0.85	0.36	0.43	0.32	0.29	0.51	0.55	0.86	0.77	0.80	0.80	0.80	0.68	1.00	0.83	0.79	-0.84	-0.53	-0.28	-0.67	-0.54	-0.55	-0.53	-0.61	-0.45	-0.40	-0.17	-0.72	-0.53	0.22	0.48	0.54	-0.18	-0.40	-0.31
R_Na	0.70	0.71	0.44	0.61	0.63	0.76	0.68	0.53	0.82	0.86	0.90	0.79	0.85	0.85	0.85	0.43	0.83	1.00	0.91	-0.74	-0.46	-0.57	-0.68	-0.71	-0.84	-0.78	-0.78	-0.73	-0.70	-0.36	-0.75	-0.65	-0.11	0.11	0.14	-0.02	-0.38	-0.22
EC	0.50	0.72	0.36	0.55	0.37	0.63	0.61	0.35	0.59	0.68	0.73	0.58	0.65	0.65	0.65	0.30	0.79	0.91	1.00	-0.77	-0.17	-0.54	-0.58	-0.43	-0.81	-0.70	-0.60	-0.50	-0.51	-0.14	-0.60	-0.30	-0.04	0.07	0.10	-0.34	-0.41	-0.17
SL	-0.65	-0.77	-0.61	-0.81	-0.25	-0.23	-0.12	-0.02	-0.30	-0.43	-0.65	-0.47	-0.54	-0.53	-0.54	-0.36	-0.84	-0.74	-0.77	1.00	0.42	0.34	0.29	0.42	0.33	0.35	0.34	0.23	0.23	0.01	0.57	0.36	-0.34	-0.49	-0.51	0.37	0.26	0.07
SDW	-0.86	-0.58	-0.84	-0.76	-0.28	-0.04	0.01	0.02	-0.53	-0.45	-0.48	-0.42	-0.46	-0.45	-0.46	-0.20	-0.53	-0.46	-0.17	0.42	1.00	-0.21	0.12	0.40	0.14	0.05	0.26	0.29	0.34	0.32	0.46	0.84	-0.47	-0.70	-0.67	-0.50	0.04	-0.02
SS	0.02	-0.15	0.36	0.12	-0.61	-0.83	-0.62	-0.72	-0.53	-0.65	-0.53	-0.58	-0.59	-0.60	-0.60	-0.33	-0.28	-0.57	-0.54	0.34	-0.21	1.00	0.53	0.70	0.53	0.85	0.76	0.76	0.62	0.40	0.40	0.20	0.66	0.57	0.55	0.24	0.42	0.41
SFW	-0.32	-0.05	0.04	-0.22	-0.63	-0.81	-0.74	-0.85	-0.60	-0.56	-0.86	-0.91	-0.89	-0.89	-0.89	-0.82	-0.67	-0.68	-0.58	0.29	0.12	0.53	1.00	0.70	0.76	0.77	0.86	0.75	0.51	0.26	0.57	0.45	0.51	0.21	0.12	-0.09	0.28	0.40
R_K	-0.53	-0.19	-0.07	-0.27	-0.91	-0.79	-0.59	-0.79	-0.73	-0.76	-0.85	-0.89	-0.89	-0.89	-0.89	-0.65	-0.54	-0.71	-0.43	0.42	0.40	0.70	0.70	1.00	0.53	0.76	0.85	0.88	0.71	0.56	0.71	0.79	0.46	0.14	0.11	-0.26	0.24	0.36
RL	-0.42	-0.41	-0.09	-0.20	-0.57	-0.86	-0.92	-0.69	-0.79	-0.76	-0.74	-0.67	-0.72	-0.72	-0.72	-0.29	-0.55	-0.84	-0.81	0.33	0.14	0.53	0.76	0.53	1.00	0.79	0.75	0.73	0.66	0.28	0.53	0.44	0.43	0.28	0.23	-0.10	0.26	0.14
SP	-0.19	-0.32	0.09	-0.13	-0.69	-0.95	-0.75	-0.79	-0.80	-0.87	-0.73	-0.79	-0.80	-0.80	-0.80	-0.49	-0.53	-0.78	-0.70	0.35	0.05	0.85	0.77	0.76	0.79	1.00	0.94	0.90	0.86	0.62	0.67	0.43	0.53	0.38	0.33	0.14	0.63	0.60
S_PO4	-0.33	-0.27	-0.00	-0.21	-0.71	-0.93	-0.74	-0.86	-0.84	-0.84	-0.83	-0.92	-0.92	-0.92	-0.92	-0.64	-0.61	-0.78	-0.60	0.34	0.26	0.76	0.86	0.85	0.75	0.94	1.00	0.96	0.80	0.57	0.64	0.60	0.51	0.26	0.22	-0.10	0.50	0.55
S_K	-0.34	-0.22	0.06	-0.09	-0.78	-0.94	-0.79	-0.89	-0.89	-0.88	-0.76	-0.85	-0.86	-0.87	-0.86	-0.49	-0.45	-0.73	-0.50	0.23	0.29	0.76	0.75	0.88	0.73	0.90	0.96	1.00	0.84	0.61	0.57	0.68	0.59	0.36	0.34	-0.28	0.38	0.43
RFW	-0.32	-0.44	-0.16	-0.22	-0.70	-0.79	-0.56	-0.57	-0.91	-0.95	-0.59	-0.65	-0.66	-0.66	-0.66	-0.25	-0.40	-0.70	-0.51	0.23	0.34	0.62	0.51	0.71	0.66	0.86	0.80	0.84	1.00	0.89	0.76	0.65	0.28	0.17	0.14	-0.06	0.67	0.61
RDW	-0.14	-0.23	-0.12	-0.13	-0.59	-0.51	-0.19	-0.35	-0.67	-0.73	-0.32	-0.44	-0.41	-0.42	-0.41	-0.20	-0.17	-0.36	-0.14	0.01	0.32	0.40	0.26	0.56	0.28	0.62	0.57	0.61	0.89	1.00	0.71	0.55	0.13	0.07	0.03	-0.04	0.71	0.74
LA	-0.58	-0.48	-0.45	-0.61	-0.73	-0.57	-0.31	-0.38	-0.64	-0.75	-0.77	-0.72	-0.72	-0.72	-0.72	-0.56	-0.72	-0.75	-0.60	0.57	0.46	0.40	0.57	0.71	0.53	0.67	0.64	0.57	0.76	0.71	1.00	0.67	-0.04	-0.25	-0.33	0.13	0.59	0.58
pH	-0.83	-0.40	-0.52	-0.53	-0.74	-0.50	-0.39	-0.46	-0.78	-0.72	-0.73	-0.71	-0.74	-0.74	-0.74	-0.40	-0.53	-0.65	-0.30	0.36	0.84	0.20	0.45	0.79	0.44	0.43	0.60	0.68	0.65	0.55	0.67	1.00	0.03	-0.28	-0.28	-0.58	0.09	0.12
Soil_PO4	0.30	0.51	0.80	0.66	-0.53	-0.70	-0.71	-0.84	-0.28	-0.25	-0.23	-0.35	-0.32	-0.33	-0.33	-0.22	0.22	-0.11	-0.04	-0.34	-0.47	0.66	0.51	0.46	0.43	0.53	0.51	0.59	0.28	0.13	-0.04	0.03	1.00	0.92	0.89	-0.23	-0.10	0.09
Soil_Mg	0.58	0.53	0.91	0.85	-0.26	-0.51	-0.55	-0.59	-0.09	-0.09	0.11	-0.01	0.02	0.00	0.01	0.11	0.48	0.11	0.07	-0.49	-0.70	0.57	0.21	0.14	0.28	0.38	0.26	0.36	0.17	0.07	-0.25	-0.28	0.92	1.00	0.99	-0.04	-0.06	0.05
Soil_K	0.57	0.50	0.89	0.86	-0.21	-0.46	-0.52	-0.54	-0.09	-0.08	0.17	0.05	0.07	0.06	0.06	0.21	0.54	0.14	0.10	-0.51	-0.67	0.55	0.12	0.11	0.23	0.33	0.22	0.34	0.14	0.03	-0.33	-0.28	0.89	0.99	1.00	-0.09	-0.11	-0.03
R_PO4	0.40	-0.22	0.05	-0.11	0.31	0.11	0.29	0.31	0.32	0.10	0.13	0.17	0.17	0.18	0.18	-0.03	-0.18	-0.02	-0.34	0.37	-0.50	0.24	-0.09	-0.26	-0.10	0.14	-0.10	-0.28	-0.06	-0.04	0.13	-0.58	-0.23	-0.04	-0.09	1.00	0.57	0.43
ChlB	0.11	-0.43	-0.17	-0.28	-0.13	-0.36	-0.03	-0.12	-0.43	-0.56	-0.24	-0.34	-0.32	-0.32	-0.32	-0.26	-0.40	-0.38	-0.41	0.26	0.04	0.42	0.28	0.24	0.26	0.63	0.50	0.38	0.67	0.71	0.59	0.09	-0.10	-0.06	-0.11	0.57	1.00	0.91
Carot	0.21	-0.08	0.03	-0.12	-0.26	-0.38	-0.00	-0.29	-0.34	-0.44	-0.26	-0.45	-0.38	-0.38	-0.37	-0.49	-0.31	-0.22	-0.17	0.07	-0.02	0.41	0.40	0.36	0.14	0.60	0.55	0.43	0.61	0.74	0.58	0.12	0.09	0.05	-0.03	0.43	0.91	1.00

Fig. 8: Correlation Heatmap analysis of all investigated plant, soil and water variables. The abbreviations are shown in Figures 5, 7.

Na of both plant organisms, roots P, free amino acids and Chlorophyll a were separated in group A. This group was negatively correlated with the remaining plant morphological and physiological traits (root and shoot fresh weight, root and shoot dry weight, leaf area) (Fig. 5 a). Hence, separated traits of group B behaved in a completely opposite manner. Principle co-ordinate analysis (PCoA) added another dimension to the division (Fig. 5 b) revealed that the first two PCoA axes captured about 61% of the cumulative percentages of all PCoA axes. These two pivots (X and Y axes) showed clear contradiction and illustrated a division of the variables into four separated groups. For example; soluble sugars and proteins and shoot fresh weight (quadrate B) were negatively correlated with leaf area, shoot length and shoot dry weight (Quadrate D) (Fig. 5 b). Treatments classification according to their correlations is a trial to observe the trends of their harmonzation. Cluster analysis showed significant correlations ($r^2 > 0.98$) (Fig. 6 a). However, the same statistical techneque were illustrated in PCoA (Fig. 6 b). Also, X and Y axes captured about 72% of the cumunlative percentages of all PCoA axes. Approximately, 10% sea level (Non-magnetized) separated on the upper right quadrate, 20% sea level (MW and NMW) on the upper left quadrate.

Canonical correspondence analysis (CCA) was carried out to explain the regression impact of environmental gradients (soil and water) on plant variables (Fig. 7). Lines represent the soil and water variations and points represent the plant variables. Closer points to a line refer to higher regression coefficients. CAA analysis indicated that plant fresh weight and dry weight were highly correlated with soil pH. Soluble sugars were highly correlated with soil P. Soluble proteins, total free amino acids, Chl a, carotenes, shoot and root Ca were highly correlated with water Na adsorption ratio. Shoot and root Na contents were highly correlated with water Na, Ca, Mg content and soil EC. Shoot and root Mg contents were highly correlated with Soil Ca content. The outcome of CCA have been further supported by correlation heatmap analyses of several factors at various treatments (Fig. 8). The various band patterns and cluster dispersion of heatmap showed a strong positive correlation between several variables such as soil water content and Ca content, shoot and root Mg content. Similarly, a strong positive correlation was observed between water SAR, Na, K, Ca Mg, P content; soil, root and shoot Ca Na, Chl a and free amino acids content. Furthermore, a considerable positive association between their K and P content and FW and DW, leaf area, and shoot and root length was noted. These findings clarified how the expression and correlation of variables under investigation are affected differently by various interactions between salinity and magnetic water treatment.

The findings of this study showed that magnetic treatment of seawater significantly improved its quality, as evidenced by a reduction in the SAR. Additionally, magnetized seawater had a beneficial effect on soil properties by lowering EC and Na concentration, while enhancing soil moisture content and availability of essential macronutrients, particularly P and K. These improvements in water and soil quality contributed to enhanced growth performance of barley watered with MW. Related to NMW, irrigation with MW despite high salinity levels resulted in noticeable induction in some important growth traits. While these results under controlled glasshouse conditions are promising, further research under field conditions is necessary to confirm the potential of magnetic seawater treatment as a viable strategy for improving crop productivity in saline environments.

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