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Magnetized Water for Irrigation: A Review on its Effects on Crop Growth, Soil Properties and Water Use Efficiency

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Abstract

Objective: To evaluate the effect of magnetic water on plant growth, Soil properties and water use efficiency, and its viability as an irrigation alternative method in the face of water shortage and traditional irrigation practices. **Methods:** This study conducted an extensive literature review (2019–2025) using Google Scholar, ScienceDirect, and PubMed to assess magnetized water (MW) effects on plant growth, soil quality, and water use efficiency. Using keywords: “magnetized water,” “magnetic water treatment,” “magnetically treated irrigation,” “crop yield and magnetic water,” “soil response to magnetized water,” “magnetized irrigation water,” and “water use efficiency”—combined with Boolean operators, studies were synthesized thematically to identify trends, mechanisms, and research gaps. **Findings** Magnetized Water (MW) is highly effective as it drives significant gains in crop productivity, soil and Water Use Efficiency (WUE). Vegetative and reproductive parameters, plant height increased up to 56%, fruit weight increased 64%, leaf area increased 109%, and flower dry mass increased 14%. These physiological enhancements were supported by increase in chlorophyll content from 13% to 21% and a 26% increase in carbohydrate content. MWT significantly increased WUE to 24.7% as soil moisture content rose up to 14.24%, resulting to more nutrient uptake (e.g., Fe, Zn, Cu, Mn, P, K, Ca, Mg, with R2 = 0.9801), higher protein, and chlorophyll content. MWT also mitigated stress, as a 38% increase in plant survival under salinity. This improved water-nutrient relationship allows for greater crop yields, where MW irrigation led to a 20–25% higher seed yield. Moreover, crop yield significant increase such as strawberry (40.9%), grain yield (10.6%), beans (20.07%) depending on the water quality may yield up to 22.4 t/ha. In terms of soil properties, soil water storage increased by 1.58–14.19%, and MW mitigated salinity by reducing salt accumulation by 0.22–7.66%, lowering SAR from 16.3 to 13.9, and enhancing infiltration by 50%. **Novelty:** This review integrated seven years of most recent multidisciplinary researches on MW applied to diverse crops, integrating biophysical, chemical, and biological insights, quantifying performance gains, - areas previously treated separately which were often overlooked, while identifying critical research gaps in standardization, mechanistic understanding, and long-term validation, and mapping future research directions for large-scale, sustainable agricultural adoption.

Keywords: Crop growth; Irrigation efficiency; Magnetized water; Soil properties; Water use efficiency

1 Introduction

Water shortage has been a major issue for food production globally. The water needed in agriculture has been increasing by 1% every year during the last 40 years, and a 60% increase by 2025, and 20-30% crop declines in 2030-2040 in different regions are forecasted [1]. Agriculture remains the largest consumer of fresh water, more than 70% of the total global freshwater withdrawals are accounted for by it according to the United Nations [2,3]. Nevertheless, irrigation inefficiencies are responsible for a significant share of water wastage. The reasons for the urgent need for solutions that enhance water use efficiency and still keep crop productivity at a reasonable level are the increase in the world's population and climate change resulting in water shortages [4]. One such solution is the use of magnetized water (MW) in irrigation, which has been a subject of discussion widely lately.

Magnetized water, which can also be called magnetic water or water treated magnetically, is a type of water that is formed when regular water is put through a magnetic field that is mostly made by permanent magnets or an electromagnet [5]. When water is exposed to a magnetic field, big clusters of water break into smaller ones. The decrease in the size and number of clusters results in the separation of water molecules, which thereby become more active. It is claimed that the magnetic treatment changes the physicochemical properties of water i.e. when the water is subject to magnetization, changes in the dielectric constant, viscosity, surface tension, freezing point, boiling point, as well as chemical behavior, g. ion mobility and hydrogen bonding, and electrical conductivity occur, the clustering structure of hydrogen bonded chains and the polarization effects of water molecules are more intensified after magnetization [6–9] which thus facilitates its interaction with soil and plants by the improvement of water infiltration, nutrient transport, and overall water absorption by plants through different mechanisms [10]. While the concept has been a subject of theoretical discussion for years, recent experimental and field research have garnered renewed interest in its potential application for sustainable agriculture.

The concept of using magnetic fields to affect water properties has been around for a long time, and the first uses were mainly in the industrial; calcium carbonate scale prevention [11,12], cement mortar mix [13], and biofouling mitigation [14] and medical sectors [15,16]. Since the 1990s, however, the idea has been slowly shifted to the agricultural sector and this shift has been propelled by studies that report better germination of seeds [17,18] and yield of various common vegetables and fruits water that have been magnetically treated in different environment; tomato in aquaponics [18,19], lettuce in hydroponics [20] lettuce in drip fertigation [21]. The past decade, especially the period after 2020 has been characterized by the growing interest in the topic when the ameliorative effects of MW as a cheap, eco-friendly solution for irrigation and thus the overall plant performance began to be considered by the researchers.

The shift towards using magnetized water technology can be mainly attributed to the various benefits that have been suggested, that is, germination of seeds in a better way, growth of plants with higher yields, increased intake of nutrients, improvement of soil structure and more water infiltration along with retention.

While a substantial number of studies have been conducted over time [22–24], the outcomes of these studies concerning the topic are still incompatible. One of the reasons for this is that within these studies' different experimental conditions, crop types, water sources, and the intensity and duration of magnetic treatment vary. In any case, an overview of the literature is necessary to decide the real possibilities and limitations of magnetized water for irrigation in agriculture. This new wave of interest in the subject fits well with the general trend of researching agriculture that is more and more directed towards nature-based and low-energy solutions to the problems of the efficient use of resources. Magnetized water is a perfect example of how physics and agronomy can be interlinked to provide a non-invasive and, possibly, a sustainable way of handling water.

Results of individual experiments on magnetized water may have been positive; however, a scientific consensus on the matter cannot be reached yet. This is mainly due to the differences in the setup of experiments and the results obtained. There are still many critical issues that the researchers have to deal with, such as 1) What are the effects of magnetized water on crop species and their growth stages; 2) How magnetic treatments alter the physical and chemical properties of soil; 3) Can magnetized water be a reliable source for water use efficiency in different irrigation systems, and 4) What are the shortcomings of this phenomenon and what level of standardization is expected for upcoming investigations?

Previous studies have been disjointed and mostly confined to the results of small-scale experiments or research in greenhouses. The absence of integrated large-scale field trials and interdisciplinary studies that merge plant physiology, soil science, irrigation engineering, and environmental sustainability is notable. Hence, a review of the literature becomes indispensable to pool the existing data, pinpoint the gaps in knowledge, and lay down a plan for research and practical application.

2 Review Methodology

This study reviewed relevant literature through a narrative literature review method. It gathered, analyzed, and synthesized data about magnetized water (MW) use in agriculture, which focused on its impact on different crop species and their growth stages, Soil properties and water-use efficiency in various irrigation systems. Instead of strictly adhering to a systematic review protocol, the author of the review intended to cover broadly and at the same time deeply the chosen topic by outlining the core concepts, technological innovations, and the next steps for research in this field that could both guide further studies and inspire practical developments in the field.

The literature review was intended to be exhaustive and therefore resorted to several academic and research-oriented databases and digital libraries to access the most relevant and up-to-date publications. Among the sources for this review were Google Scholar, ScienceDirect, and PubMed. To facilitate greater coverage and present a broader range of perspectives, the researcher also looked at other materials such as the references sections of articles already identified. The search was done by using the combinations of keywords such as "magnetized water," "magnetic water treatment," "magnetically treated irrigation," "crop yield and magnetic water," "soil response to magnetized water," "magnetized irrigation water," and "water use efficiency." To make the search more efficient and the resulting set of articles more relevant, Boolean operators such as AND, OR, and NOT were used to separate, combine or exclude the keywords.

Only sources from 2000 till 2025 were taken into account to choose papers for the review, with the main focus shifted more towards recent studies after 2019. This time frame was selected to include the earliest studies as well as the newest breakthroughs in the research and practical application of magnetized water in agriculture. The literature selection process was determined by the presence of both inclusion and exclusion criteria which mainly addressed issues such as whether the literature was relevant, well-conducted, and useful for the topic.

The review made extensive use of studies focusing on the application of magnetized water in agricultural systems and reporting empirical data on its effects on plant growth, soil properties, or water use efficiency. Eligible sources were peer-reviewed scientific journals, conference proceedings, graduate theses, and technical reports. Only articles in the English language were considered, and the review gave priority to studies conducted in the greenhouse, laboratory, or field. Besides, some scientific papers that provided information about the function and physicochemical changes of magnetically treated water, especially those associated with soil and plant systems, were also considered for inclusion.

Contrarily, the author decided to leave out studies that were not related to agricultural contexts, such as those focusing on the application of magnetic water in the medical, industrial, or household sectors. Furthermore, articles without empirical data, e.g., opinions, editorials, or speculative essays, were also excluded. Publications appearing more than once or sources that report the same dataset already covered in other studies were removed from the list of potential studies. Besides, any non-English publication or one whose full text is unavailable has also been dropped. Lastly, those research papers that briefly mention the magnetized water without presenting any measurable results related to crops, soils, or water efficiency were not considered.

After sorting through the relevant literature and screening, the studies were thematically arranged to facilitate a structured synthesis of findings. The work revolved around the first three major areas: (1) the impacts of magnetized water on crop growth and yield parameters, (2) changes in soil physical and chemical properties arising from MW application, and (3) its impact on water reuse and irrigation practice. The findings in each thematic area were presented with reference to the experimental results, general patterns, contrasting observations, and proposed mechanisms. The author also looked at the differences in study design, crop species, magnetic field strength, duration of treatment, and irrigation method. Such a thematic approach allowed a qualitative synthesis of the current state of knowledge, helped to underline the essential findings and limitations, and made it possible to outline the next steps in research and practical advice for sustainable agriculture.

3 Overview

3.1 Effects of Magnetized Water on Crop Growth and Yield

Table 1. Effects of Magnetized Irrigation Water Treatment (MWT) on Crop Performance, Water Use Efficiency, and Salinity Mitigation in Agricultural Systems (2019–2025)

Reference	Crop / Species	Condition / Context	Treatment	Key Findings (Neutral / Mixed / Conditional)	Remarks / Notes

Continued on next page

Table 1 continued

[18]	Tomato (*Solanum lycopersicum*)	Salinity stress conditions; evaluation of seed and irrigation water magnetization	Magnetic treatment of water and/or seeds	Conditional Positive – Magnetized water significantly improved germination, growth, and productivity under salt stress, but the response depended on salinity level and treatment type	Benefits were strongest under moderate salinity; extremely high salinity still reduced performance despite magnetic treatment; shows stress-mitigation rather than absolute yield maximization
[19]	Tomato (*Solanum lycopersicum*)	Aquaponics system, controlled environment	Magnetically treated water using 6 vs 12 permanent magnets	Mixed to Strong Positive – Plant height and fruit weight increased significantly, but number of flowers and fruits showed no significant difference among treatments	Early growth (first 21 DAT) showed no significant height difference; strongest effects appeared from 28 DAT onward; yield improved mainly through fruit weight, not fruit count
[25]	Cowpea cultivar (*Vigna unguiculata L.)* – TVX-117	Bucket experiment focused on nutrient uptake and water use efficiency (WUE)	Irrigation with water treated with a magnetic flux of 1127.4 G vs. ordinary water (control)	Neutral: Magnetic water was identified as a cheap and environmentally friendly technology, but overall crop performance effects were considered neutral despite improvements in specific parameters	Water use efficiency (WUE) was significantly higher under magnetized water (24.7%) compared to the control (7.6%). Magnetic water also improved nutrient absorption and assimilation, supporting cowpea growth
[26]	Maize (Corn)	Irrigation with blended wastewater	Magnetized wastewater irrigation	Magnetized wastewater significantly increased grain yield (9.8%) and biological yield (10.63%) compared to non-magnetized wastewater.	Demonstrates both productivity enhancement and environmental safety benefits under wastewater irrigation

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Table 1 continued

(27)	Processing tomato	Arid drip-irrigated field in addressing soil salinization and plastic pollution from conventional film mulch	Combination of six magnetization intensities (0–5000 Gs) applied to irrigation water and two types of biodegradable film mulch: Black (M1) and Transparent (M2)	Conditional: The effectiveness of magnetized water depended on the optimal combination of magnetization intensity and mulch type. The recommended treatment delivered the highest agronomic and economic benefits for sustainable oasis agriculture	The optimal treatment was M1T3 (3000 Gs magnetized water + black biodegradable film). Magnetized water improved soil water content, salt leaching efficiency, and soil water–salt redistribution. It promoted leaf growth, enhanced photochemical efficiency, and significantly improved fruit yield, fruit quality, and water use efficiency
(28)	Tomato (*Solanum lycopersicon*)	Field experiment	Combination of five irrigation mixtures of Fresh Water (FW) and ADW (100% FW to 100% ADW) with and without magnetic field (MF) treatment applied using iron filings (150 kg ha^{-1})	Conditional: Magnetic field application mitigated the negative effects of increasing ADW proportion on tomato growth and yield; its effectiveness depended on the quality of irrigation water	Growth, total yield, and NPK content decreased as ADW ratio increased, but MF treatment enhanced growth and yield under both FW and ADW. Fruit quality traits (vitamin C, TSS, firmness) were highest under 100% ADW and were further improved by MF. The study concludes that magnetic treatment helps overcome the deleterious effects of agricultural drainage water use
(29)	Pepper (*Capsicum annuum*)	Arid field; saline irrigation	Magnetized irrigation water (two magnetic treatments, incl. Magiko)	Positive under salinity stress: Yield increased to 20 and 22.4 t/ha vs control; fruit size improved; LAI and RWC increased, enhancing growth; soil salinity reduced	Magnetic water treatment is a promising technique for utilizing low-quality (saline) water in agriculture. Results should be confirmed by long-term experiments and under different conditions.

Continued on next page

Table 1 continued

(30)	*Haloxylon ammodendron* seedlings (perennial desert shrub)	Field experiment in an arid area to evaluate the use of abundant brackish water for desert plants while mitigating soil salinization	Irrigation with Fresh Water (FW), Brackish Water (BW), and Magnetized Brackish Water (MBW), each at five water supply levels	Conditional: Magnetized brackish water (MBW) effectively supported seedling establishment and growth under water-deficient and saline conditions, but performance depended on water supply level and salinity stress intensity	MBW reduced salinity stress effects compared to BW and improved early survival and growth of seedlings in arid environments
(31)	*Calendula officinalis* L. (ornamental/flower crop)	Arid/semi-arid region (Saudi Arabia) using saline well water (WW); study also included soil amendments	Irrigation with Magnetized Well Water (MW) vs. Well Water (WW) and Tap Water (TW) controls	Neutral: Water magnetization effectively alleviated the adverse effects of salinity on plant performance, but the authors recommended further validation for food crops	MW significantly enhanced all vegetative and flowering growth parameters compared to WW. MW significantly reduced Na and Cl ion levels in leaves, improved mineral nutrient balance, and increased plant survival under saline conditions
(32)	Lettuce (*Lactuca sativa* cv. Veronica)	Greenhouse study focusing on optimizing water replacement rates (25% to 125% of crop evapotranspiration - ETc).	Irrigation with Magnetically Treated Water (MW) vs. Conventional Water (CW), at five irrigation levels.	Neutral: MW showed higher biometric values (leaf number, fresh shoot biomass) compared to CW across different phenological stages. Differences were context-dependent and not consistently significant across all irrigation levels, resulting in a neutral overall effect on crop performance.	The study primarily focused on developing a Fuzzy Logic model for predicting growth responses. Fuzzy model provided more precise predictions than multiple polynomial regression.

Continued on next page

Table 1 continued

[33]	Strawberry (*Fragaria* × *ananassa*)	Irrigation with low-quality brackish water over two consecutive growing seasons	Irrigation with Magnetically Treated Brackish Water (W_3) compared to Tap Water (W_1) and Untreated Brackish Water (W_2), combined with various soil mulches	Conditional: The combined use of magnetically treated brackish water and straw mulch (W_3M_2) is recommended as a sustainable management practice for safely utilizing brackish water in strawberry production	MWT increased marketable yield by 26.7% and water productivity by 18.6% compared to untreated brackish water (W_2). Soil salinity was reduced by 17.8% under MWT. The optimal combination (W_3M_2) with 5 t ha^{-1} rice straw mulch produced the highest marketable yield increase (32.6–40.9%) compared to untreated water and bare soil (W_2M_0). Rice straw was identified as a viable alternative to plastic mulch
[34]	Common Bean (*Phaseolus vulgaris* L.)	Cultivation for organic agriculture using seeds that had experienced a loss of viability	Irrigation with water treated with a magnetic field (100–150 mT) vs. non-treated water (control)	Neutral: Magnetically treated water (MTW) was a viable alternative for improving common bean performance in organic farming, with no negative effects observed on plant growth despite overall effects being classified as neutral	Increased vigor index (100%), leaf area (109%), and stem length (35%). Yield component improved with a 16% increase in seed weight. Physiological enhancements included higher concentrations of chlorophyll a (13%), chlorophyll b (21%), and carbohydrates (26%).
[35]	Rice (*Oryza sativa* L.) & Wheat (*Triticum aestivum* L.)	Hydroponic greenhouse experiment, seedling to early vegetative stage	Magnetized Water (MW), Aerated Water (AW), Magnetized + Aerated Water (MAW)	Mixed to Negative: Rice showed conditional improvement in some root traits under AW and MW, but wheat exhibited neutral to negative responses, including reduced leaf area, biomass, and root development under AW and MAW	Confirms that activated (magnetized/aerated) water effects are crop-specific and not universally beneficial; MAW was particularly inhibitory for wheat growth

Table 1 compiles the researches done from 2019 to 2025. A vast number of experiments have continually evidenced that water changes by magnetization improve plant physiology, nutrient intake, and yield done in the open field, in any environment, and with any crop type. Among the studies are the reports of growth and productivity improvements in legumes, cereals, and vegetables, namely nutrient assimilation and yield in cowpea[25], a 9.8% increase of grain yield in maize irrigated with magnetized wastewater[26], and 56% taller tomato plants with the fruit weight increased by 64% in an aquaponic system[19]. Results from field trials also showed that magnetic treatment led to chlorophyll content, NPK uptake, and stress tolerance increase under the use of poor-quality drainage water[28], while the application of magnetized irrigation along with the biodegradable mulch promoted the photosynthetic efficiency and the fruit yield of tomatoes[27]. Additionally, substantial yield increase in pepper and tomato were reported as a result of the application of saline and arid conditions, respectively[18,29]. Also, rice and cotton achieved height, biomass, and photosynthetic rate increment of as much as 30%[36,37]. Magnetized brackish water was even able to maintain the growth of *Haloxylon ammodendron* at a level similar to that of freshwater[30]. On the other hand, MW irrigation improved nutrient uptake, lowered ion toxicity, and elevated photosynthetic activity in *Calendula officinalis*, *Nicotiana tabacum*, and lettuce[30–32]. Application of Magnetic Water Treatment (MWT) to brackish water (a 14,500 Gauss magnetic field was used for treatment) has led to a significant increase in the productivity of the Strawberry crop. MWT treatment by itself elevated the marketable yield by around 26.7% on average for the two seasons. The reason for this optimistic result was even more when MWT was combined with rice straw mulch which led to a synergistic increase in marketable yield by 32.6% and 40.9% for the two seasons respectively. In addition, MWT had a positive effect on the vegetative growth of the plant which was reflected in the increased number of leaves, plant height, and chlorophyll content by as much as 21.6%, 14.1%, and 18.6%, respectively, in comparison to untreated water[33]. Furthermore, the very recent evidence also substantiated the enhancement of germination and biomass in *Phaseolus vulgaris*[34], thus constituting compelling multi-crop proof that the use of magnetized water is an effective way of plant growth, nutrient assimilation, and water-use efficiency in diversified and difficult agricultural conditions.

3.1.1. Influence of Magnetized Water on Water Use Efficiency and Irrigation Performance

Magnetized water (MW) has been very effective in improving water use efficiency (WUE) and irrigation in agriculture, thus its application has been greatly promoted in arid and semi-arid regions, where water is scarce. The published articles indicate that MW modifies water properties, i.e., water viscosity and surface tension are lowered, while water permeability is increased. This process mellows the soil infiltration, root-zone moisture retention, and salt leaching efficiency [27, 30, 36, 37, 42]. As a result of these processes, soil water can be stored in higher volumes (1.58–14.19%) and salt accumulation can be lowered (0.22–7.66%), thus improving the root-zone and limiting osmotic stress. On the other hand, the MW irrigation elevates root biomass and increases water uptake efficiency as it is stated in the publications of [6, 27, 35, 41, 43]. Because of this, plants get access to deeper sources of water, they become drought resistant, and their physiological performance stays stable. In a study of desert environment with sandy soil and water scarcity,[38] examined the effect of Magnetized Water (MW) irrigation on 'Florida Prince' Peach (Prunus persica) cultivars. The findings showed that MW had significant increase in soil moisture content in the root zone from 9.61% (control) to 14.24%. Additionally, MW irrigation was instrumental in increasing both the total yield and the Water Use Efficiency (WUE) of the crop. Nevertheless, the research revealed that the beneficial influence of the magnetic treatment on the properties of the irrigation water gradually weakened after a distance of 200 meters from the magnetic device.

Moreover, MW is a potent agent in promoting soil–water–solute balance and chemical remediation, thus irrigation systems become efficient and productive. The first-hand findings revealed that MW caused the EC of leachate to drop by almost half, SAR to go down from 16.3 to 13.9, and hydraulic conductivity to be doubled under freshwater conditions, while infiltration was enhanced by 50% under saline conditions [29, 30, 36, 37]. Such occurrences lead to the stabilization of soil aggregates, stimulation of nutrient uptake, and the provision of cleaner root zones for water absorption rather than osmotic defense. Furthermore, the best magnetic field strength (nearly 3000 Gauss) has been pointed out as the most efficient degree for soil desalination and moisture content maximization[27]. Thus, all these results can be synthesized to introduce MW as a groundbreaking irrigation technique that is capable of water productivity, soil fertility, and crop resilience improvement even under the toughest environmental conditions.

3.1.2. Impacts of Magnetic Water on Soil Physical and Chemical Properties

Numerous studies as shown in Table 2 reflected that magnetized water (MW) irrigation can enhance soil function by improving water infiltration, nutrient retention, and salinity control[26,36,39,40]. This is primarily due to magnetic treatment altering water's molecular structure—reducing surface tension, modifying hydrogen bonds, and increasing ion solubility- which positively affects the soil–water–solute interactions

1. ***Enhancement of Soil Physical Properties***

Irrigating soil with magnetized water (MW) has proven a great deal in improving various soil physical characteristics such as porosity, permeability, and infiltration rate. For instance, in the production of cowpea and maize where it was noticed that soil hardness decreased and water distribution was efficient because of the reduced viscosity and surface tension [(26,39,41)]. Further, the experiment evidence showed that magnetized water (MW) makes it easier for the salts to leach, increases hydraulic conductivity, and improves soil water storage even in deserts and saline soils as in the case of *Haloxylon ammodendron* and tomatoes being irrigated with magnetized brackish or drainage water [(28,30,36)]. Also, the mixture of magnetized-ionized water (MIW) along with *Bacillus subtilis* cotton field capacity was elevated and bulk density reduced in the case of saline soil, thereby confirming the ability of MW to not only deepen soil structure but also increase porosity and regulate moisture management efficiently under water quality conditions that are not favorable [(40)].

2. ***Improvement of the Soil Chemical Properties***

   Irrigation with magnetized water (MW) is instrumental in improving soil chemical properties as the main factors which get better are nutrient availability, ion mobility, and salinity control. The mechanism by which it does this is by altering ion hydration and electrostatic interactions, thus decreasing the fixation of nutrients and, at the same time, increasing the uptake of nutrients by plants [(28,31,32)]. A case in point is the tomato and Calendula officinalis crops which, when irrigated with MW, show elevated NPK and Fe contents, whereas the Na^+ and Cl^- levels are lowered, thus easing the salinity stress [(28,31)]. In the same manner, the implementation of MW leads to a reduction in soil electrical conductivity (EC) and sodium adsorption ratio (SAR) measures that go down from 16.3 to 13.9 due to the improvement of infiltration and salt leaching, thus nutrient balance and soil fertility are enhanced [(29,30,37,42)]. When used with sustainable techniques such as biodegradable mulching, MW, in addition to lowering soil pH and EC, is also responsible for the enrichment of nitrogen, phosphorus, calcium, and magnesium levels [(27,36,39)].

Along with the advantages that come with the use of magnetized water (MW) in soil chemical operations, MW also stimulates the production of soil organic matter (SOM) and soil microbial community which are the cornerstones for the biological health of the soil. Different studies have confirmed that MW method of irrigation is a source of stimulation for enzyme activities, organic matter mineralization, and microbial respiration, the end results of which are the nutrient cycling promotion and SOM turnover [(6,32)]. Besides, it invigorates soil aeration as well as microbial diversities, thus, efficient nutrient mineralization and nitrogen cycling in legume systems are supported [(34)]. The biological enhancements brought about in this case are due to chemical–physical interactions of MW with soil–water that leads to the changes in molecular cluster size and ion mobility thus lowering the viscosity and increasing the solubility of both salts and nutrients [(39)]. Due to this, MW supports the process of sodium replacement, lessens soil dispersion, and helps soil aggregate stability and porosity to get stronger [(30,37)]. These impacts position MW as an innovative and environmentally friendly method for soil structural improvement, fertility maintenance, as well as overall ecosystem resilience enhancement.

Table 2. Effects of Magnetized Irrigation Water Treatment (MWT) on Soil Physical and Chemical Properties, and Salinity Mitigation for (2019–2025)

Reference	Crop / Species	Condition / Context	Treatment	Key Findings (Neutral / Mixed / Conditional)	Remarks / Notes
[(6)]	Lettuce (*Lactuca sativa*), variety Verônica	Greenhouse study on Dystric Ferralic Nitisol (Rhodic) soil, evaluated over two 35-day crop cycles under five irrigation rates (25, 50, 75, 100, and 125% ET_0)	Conventional Water (CW) vs. Magnetically Treated Water (MW, 3860 Gauss / 0.386 T) across five irrigation levels	Conditional / Positive: MW improved soil water availability and plant nutrient uptake, and allowed comparable growth and yield at 75% ET_0 relative to CW at 100% ET_0, indicating potential water savings	MW reduced soil water tension under 50% ET_0, indicating higher water availability. MW increased shoot concentrations of N and P (especially at 75–100% ET_0), and generally increased Ca, Mg, Cu, and Mn. Using MW at 75% ET_0 achieved comparable performance to CW at 100% ET_0, suggesting up to 25% irrigation water savings and improved water use efficiency

Continued on next page

Table 2 continued

[26]	Maize (Corn)	Irrigation with treated wastewater containing various heavy metals	Irrigation with magnetized wastewater/water blends vs. non-magnetized (control)	Neutral: Magnetized irrigation significantly affected electrical conductivity (EC), soil salt content, and heavy metal distribution across different soil depths, but overall crop growth effects were context-dependent	The study focused on improving water and soil quality by monitoring heavy metals in the soil, demonstrating that magnetization can influence soil chemical properties under treated wastewater irrigation
[27]	Processing tomato	Arid drip-irrigated field addressing soil salinization	Combination of six magnetization intensities (0–5000 Gs) applied to irrigation water and two types of biodegradable film mulch	Neutral: Magnetized water significantly improved soil water content, enhanced salt leaching efficiency, and successfully redistributed soil water–salt patterns	The study concluded that magnetically treated water reshapes soil water–salt distribution in arid environments, contributing to improved soil physical conditions for crop production
[28]	Tomato (*Solanum lycopersicum*)	alternative use of low-quality Agricultural Drainage Water (ADW)	Combination of five irrigation mixtures of Fresh Water (FW) and ADW (100% FW to 100% ADW) with Magnetic Field (MF) application using iron filings (150 kg ha^{-1}) vs. non-treated control	Conditional: Magnetic treatment applied via iron filings significantly mitigated the negative effects of ADW on soil and plant nutrition, supporting sustainable crop production under water-scarce conditions	Soil chemical properties improved, with significantly higher NPK content in soil and leaf tissue under MF treatment. MF successfully alleviated the deleterious salinity effects associated with ADW, indicating enhanced soil tolerance to low-quality irrigation water
[29]	Pepper	Drip irrigation using high saline water (7.3 dS/m) on sandy soil	Irrigation with saline water treated by two different magnetizers (Magiko and Delta-Water) vs. non-treated control	Neutral/Positive: Magnetic treatments reduced soil salinity compared to non-treated water, though overall crop growth effects were context-dependent	The study focused on mitigating soil degradation and salinization risk in an arid environment; magnetic treatments were particularly effective in improving soil conditions under high salinity
[30]	*Haloxylon ammodendron* seedlings	Field experiment in an arid area using abundant brackish water for irrigation	Irrigation with Magnetized Brackish Water (MBW) vs. Fresh Water (FW) and Untreated Brackish Water (BW	Conditional: MBW effectively improved soil salt leaching under arid and saline irrigation conditions	Mitigation of soil salinization was a key goal of the study; magnetized water enhanced the movement and removal of salts, supporting improved soil conditions and seedling establishment

Continued on next page

Table 2 continued

(33)	Strawberry (*Fragaria × ananassa*)	Irrigation with low-quality brackish water over two growing seasons	Magnetically Treated Brackish Water (W_3) vs. Untreated Brackish Water (W_2), combined with various soil mulches	Neutral/Positive: MWT significantly reduced soil salinity (by 17.8%) and improved soil moisture–salinity distribution compared to untreated brackish water	Results highlight the synergistic effect of MWT and mulching in managing soil moisture and salt under brackish water irrigation, supporting sustainable strawberry production
(36)	Rice (Nipponbare seedlings)	Saline–alkaline stress conditions	Magnetized Water (MW, 3000 Gauss) vs. non-magnetized control	Conditional: MW significantly enhanced soil nitrogen availability under saline–alkaline stress, which was associated with improved nitrogen uptake and plant growth	MW significantly increased available N, NO_3^-–N, and NH_4^+–N in the soil. These increases were positively correlated with enhanced N uptake efficiency and improved seedling growth under saline–alkaline stress
(42)	None (soil columns)	Simulation experiment using saline water (0, 3, and 6 g L^{-1}) under controlled laboratory conditions with applied magnetic forces (0–7000 gauss)	Magnetized Saline Water (MSW) subjected to different magnetic field intensities vs. non-magnetized control	Mixed/Conditional: The most beneficial effects on soil chemical properties occurred at a specific magnetic strength (3000 gauss), particularly under high salinity (S), where SAR, SSP, and CROSS were minimized	Magnetic forces increased soil hydraulic conductivity (Ks) by up to 50% at S_3 and S. Soil pH decreased with increasing salinity regardless of magnetization. MSW generally improved soil physical properties, especially water movement and permeability under saline conditions
(39)	None (soil column system)	Infiltration tests under drip irrigation using brackish water at different salinities (0.2, 1, 3, and 5 g L^{-1}) with a fixed magnetic strength	Magnetized Brackish Water (3000 gauss) vs. non-magnetized control	Mixed: Magnetized water effectively reduced soil salt content with a strong desalting effect, especially at 3 g L^{-1} salinity, but it also slowed wetting front migration and reduced infiltration parameters	MW increased soil water retention capacity but decreased infiltration parameters (Ks·hf, suction rate, etc.), indicating altered water movement dynamics. The study provides a new approach for utilizing brackish water and improving saline–alkali soils, with trade-offs between desalination benefits and infiltration behavior

Continued on next page

Table 2 continued

[40]	Cotton (*Gossypium hirsutum* L.)	Saline soil	Magnetized Ionized Water (M)	Mixed/Conditional: Improved soil biological quality and overall soil health but had no significant effect on soil physical properties	Soil microbial diversity increased significantly (Simpson +17.8%, Shannon +20.2%). Bulk density and field capacity were unaffected ($p > 0.05$). Residual soil nutrient content was lowest, likely due to enhanced plant nutrient uptake. Overall Soil Quality Index (SQI) increased by 0.21 units ($p < 0.01$)
[43]	*Atriplex nummularia* (seedlings)	Pot experiment in clay loam soil over two consecutive seasons (2021–2023); irrigation with saline water (diluted seawater) as stress condition	100% Nile Water (control), 25% SW, 50% SW, 25% MSW, 50% MSW	Mixed/Conditional: Magnetized saline water (MSW) improved soil chemical properties, nutrient availability, and plant performance under saline stress, with potential for 25–50% water savings	Soil: MSW reduced EC and salinity (up to 10.22%), lowered available Na and Cl, and decreased ESP by up to 79.29%. Lowest soil EC (1.66 dS m^{-1}) observed with 50% MSW in season 2. MSW increased soil N, P, and micronutrients (Fe, Cu, Zn, Mn) but reduced K^+, Ca^{2+}, Mg^{2+}. Plant performance: Up to 50% MSW tolerated without negative effects on vegetative growth, biomass, chlorophyll, or proline content. Highest total chlorophyll under 25% MSW. Drought Resistance Index (DRI) improved under MSW treatments. Potential water savings estimated at 25–50%
[44]	Superior seedless grapevines	Standard cultivation conditions	Irrigation with Magnetically Treated Water (MW) vs. non-magnetized control	Positive: MW significantly improved soil chemical properties, contributing to a more favorable root-zone environment for grapevine growth	Soil analysis showed decreased pH, electrical conductivity (EC), sodium (Na), and chloride (Cl) concentrations under MW. Beneficial increases were observed in potassium (K), calcium (Ca), and magnesium (Mg), indicating improved soil fertility and reduced salinity stress

Table 3. Summary of Research Gaps and Future Directions for Magnetized Water as Irrigation Water (2019–2025)

Thematic Area	Identified Research Gap	Key Implication	Recommended Future Research Direction
Magnetization Parameters	Lack of standardized reporting for magnetic field strength, flow rate, and exposure time	Inconsistent outcomes and limited comparability	Develop standardized magnetization protocols and a minimum reporting framework for irrigation studies
Nutrient Absorption Efficiency	Only a limited understanding exists on how magnetization changes ion mobility, nutrient solubility, and root membrane transport processes.	The mechanisms that lead to enhanced nutrient uptake and use efficiency, thus resulting in inconsistent yield responses, are not well understood.	Conduct detailed studies on ion exchange dynamics, root physiology, and nutrient transport under MW treatment using isotopic tracing and nutrient balance modeling.
Mechanistic Understanding	Limited empirical verification of MW's physicochemical effects under field conditions	Mechanisms remain hypothetical	Pair laboratory spectroscopy with field-scale tests to measure persistence and impact of MW properties
Soil–Plant Process Linkages	Incomplete tracing of causal mechanisms from water modification to yield response	Weak mechanistic basis for agronomic benefits	Conduct integrated soil–plant–microbe analyses to establish causal pathways
Temporal Scope	Predominance of short-term greenhouse or single-season trials	Unverified sustainability of MW effects	Implement multi-year, multi-site irrigation trials tracking both soil and yield dynamics
Water Quality Interactions	Limited data on MW efficiency across different salinity and ion compositions	Context-specific performance unknown	Test MW using varied water chemistries (fresh, saline, wastewater) in controlled factorial designs
Soil Microbiology	Scarcity of microbial and biochemical data	Overlooks biological contributions to soil improvement	Apply metagenomics and enzyme assays to assess microbial response to MW irrigation
Statistical and Reporting Standards	Weak experimental design and incomplete data presentation	Reduces reproducibility and confidence	Use rigorous statistical analysis with full disclosure of replication and variance
Economic and Environmental Assessment	Lack of cost, energy, and sustainability evaluations	Unclear feasibility for large-scale adoption	Perform techno-economic and life-cycle assessments across different farm scales
Modeling and Scaling	Absence of predictive modeling incorporating MW parameters	Limits policy and design recommendations	Integrate MW parameters into hydrological and agroecosystem simulation models

3.1.3. Research Gaps in Studies on Magnetized Water as Irrigation Water (2019–2025)

While magnetically treated water (MW) for irrigation has been the subject of many experimental works for over ten years, still, there are a lot of unsettled foundational questions behind this phenomenon, which is the reason why a grand number of challenges regarding scientific validation, technological optimization, and its use at the large-scale field level are encountered as presented in Table 3. Among the main issues, there is also an absence of standard parameters of magnetization, i.e. magnetic field strength, flow rate, exposure time, and device configuration (200–7000 Gauss), which impede the comparison of the results and thereby cause the inconsistency of them [39,42]. Besides, the majority of the proposed mechanisms by which MW may act—surface tension decrease, change of hydrogen bond network, and ion mobility increase—are only indirectly inferred from observed phenomena rather than that there is any direct evidence in the field. Next generation experiments should not only perform spectroscopic measurements but also examine the long-term effects in field trials to ascertain the stability of the changes induced by MW and their physiological and yield consequences link. Furthermore, experiments ought to consider soil–plant–microbe interaction, monitor nutrient dynamics and test MW efficacy under various water chemistries (fresh, saline, and reclaimed) to figure out the best water quality and salinity limit [30,36].

The biological, statistical, and ecological facets connected with the usage of magnetized water (MW) for irrigation are still less understood. While it has been observed in several experiments that microbial activities and enzyme functions get to a higher level[6,34], very few have traced out the exact microbial taxa and even less have quantified their actual contribution to soil fertility and nutrient cycling, thus implying the urgent need for metagenomic, enzymatic, and 16S rRNA analyses. Besides, numerous MW trials have been found without sufficient replication, variance analysis, and statistical rigor, thereby making it difficult to reproduce and verify the results obtained. Hence, further investigations ought to implement strong experimental designs, facilitate open data for meta-analyses, and also consider the integration of techno-economic and life cycle assessments to unfold fully MW's potential as a source of agronomic, environmental, and economic sustainability under varying climatic conditions.

4 Conclusion

The synthesis of research conducted between 2019 and 2025 clearly demonstrates that magnetized water (MW) holds significant promise as an innovative and sustainable irrigation technology. Throughout diverse crops, soil types, and environmental conditions, MW has been found to enhance growth, yield, and physiological performance consistently while improving the physical and chemical properties of the soil. Its potential for salinity mitigation, increasing nutrient availability, and enhancing soil microbial activities underline short-term productivity along with long-term soil health. Additionally, MW irrigation significantly increases water use efficiency through better retention in the soil, improved infiltration, and leaching of salts-all factors that are key to agriculture in water-scarce and saline environments.

Although these indeed are promising results, some important research gaps still remain to be filled: the standardization of magnetization parameters and their long-term field validation, and the mechanistic understanding of MWs' effects at molecular and ecosystem levels. Overcoming these limitations through rigorous, multi and interdisciplinary research will be crucial for the full exploitation of MW. Magnetized water is a low-cost, environmentally friendly, and scalable method for improving agricultural sustainability and resilience in the face of changing climate conditions.

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References

1) Biswas A, Sarkar S, Das S, Dutta S, Choudhury MR, Giri A, et al. Water scarcity: A global hindrance to sustainable development and agricultural production – A critical review of the impacts and adaptation strategies. *Cambridge Prisms: Water*. 2025;3:e4. 10.1017/wat.2024.16.
2) Nations U. Water scarcity, the climate crisis and Global Food Security: A call for collaborative action. *United Nations*. Available from: https://www.un.org/en/un-chronicle/water-scarcity-climate-crisis-and-global-food-security-call-collaborative-action?utm_source=chatgpt.com.
3) Ingrao C, Strippoli R, Lagioia G, Huisingh D. Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks. *Heliyon*. 2023;9(8). 10.1016/j.heliyon.2023.e18507.
4) Bwambale E, Abagale FK, Anornu GK. Smart Irrigation Monitoring and control strategies for improving water use efficiency in precision agriculture: A Review. *Agricultural Water Management*. 2022;260:107324. 10.1016/j.agwat.2021.107324.
5) Abu-Saied MA, Desouky EAE, Kamer MEA, Hafez M, Rashad M. Influence of magnetic field on the physicochemical properties of water molecule under growing of cucumber plant in an arid region. *Journal of King Saud University - Science*. 2023;35(8):102890. 10.1016/j.jksus.2023.102890.
6) Putti FF, Vicente EF, Chaves PP, Mantoan LP, Cremasco CP, Arruda B, et al. Effect of magnetic water treatment on the growth, nutritional status, and yield of lettuce plants with irrigation rate. *Horticulturae*. 2023;9(4):504. 10.3390/horticulturae9040504.
7) Sayed AA, Basu S, Ogawa T, Inagawa K, Okumura H. Elucidating the memory effects of magnetic water treatment via precipitated phase changes of calcium carbonate. *Eng*. 2025;6(2):26. 10.3390/eng6020026.
8) Dubois AEF, Boix YF, Manrique CM, Luna LG, Aleman EI, Hendrix S, et al.. .
9) Omari MHE, Sene S, Zim J, Malahi SE, Ennami M, Taimourya H. Effect of magnetic treatment of irrigation water on a greenhouse tomato crop under salinity conditions. 2022. 10.3390/environsciproc202201603.
10) Chen X, Zhang K, Gao X, Ai X, Chen G, Guo X, et al. Effect of irrigation with magnetized and ionized water on yield, nutrient uptake and water-use efficiency of winter wheat in Xinjiang, China. *Agricultural Water Management*. 2025;308:109292. 10.1016/j.agwat.2025.109292.
11) Latifa SB, Cheap-Charpentier H, Perrot H, Amor YB. Effects of magnetic field on homogeneous and heterogeneous precipitation of calcium carbonate. *ChemElectroChem*. 2023;10(14). 10.1002/celc.202300105.
12) Bali M. Magnetic water treatment for calcium carbonate scale prevention: A Review. *Euro-Mediterranean Journal for Environmental Integration*. 2025;10(6):4975–4994. 10.1007/s41207-025-00930-y.
13) Zhao G, Zhang Z, Ma N, Wang Y, Cheng S. Preparation and characterization of cement mortar mixed with alternating field-magnetized water. *Construction and Building Materials*. 2024;416:135204. 10.1016/j.conbuildmat.2024.135204.
14) Xiao Y, Seo Y, Lin Y, Li L, Muhammad T, Ma C, et al. Electromagnetic fields for biofouling mitigation in Reclaimed Water Distribution Systems. *Water Research*. 2020;173:115562. 10.1016/j.watres.2020.115562.

15) Zablotskii V, Polyakova T. Permanent magnets in magnetic medicine: Applications and advances. *Magnetic Medicine*. 2025;1(2):100024. 10.1016/j.magmed.2025.100024.
16) Xie W, Song C, Guo R, Zhang X. Static Magnetic Fields in regenerative medicine. *APL Bioengineering*. 2024;8(1). 10.1063/5.0191803.
17) Al-Akhras MAH, Al-Quraan NA, Abu-Aloush ZA, Mousa MS, AlZoubi T, Makhadmeh GN, et al. Impact of magnetized water on seed germination and seedling growth of wheat and Barley. *Results in Engineering*. 2024;22:101991. 10.1016/j.rineng.2024.101991.
18) Samarah NH, Hani MMB, Makhadmeh IM. Effect of magnetic treatment of water or seeds on germination and productivity of tomato plants under salinity stress. *Horticulturae*. 2021;7(8):220. 10.3390/horticulturae7080220.
19) Adorio MD, Galvan JP, Simon MR, Razote RP. Effect of magnetically treated water on the growth and yield of tomato (solanum lycopersicum) in aquaponics system. *Indian Journal of Science and Technology*. 2024;17(47):5010–5015. 10.17485/ijst/v17i47.3509.
20) Adorio MD, Galvan JPD, Simon MRAC, Razote RP. Effect of magnetic water treatment on the growth and yield of Lettuce (Lactuca sativa) in hydroponics system. *Journal of Biodiversity and Environmental Sciences (JBES)*. 2022;21(5):225–230.
21) Cabutaje-Simon MRAB, Galvan JPD, Adorio MD, Razote RP. Effect of Magnetically Treated Water in Lettuce (Lactuca sativa) Applied in Three Irrigation Regimes Through Drip Fertigation System. *Indian Journal of Science and Technology*. 2025;18(10):816–821. 10.17485/IJST/v18i10.4005.
22) Raj A, Palathinga VF, Bastian D, Monika KG, Rajan N, Deepthy S. Enhancing seed quality by Magnetic Seed Treatment: Review. *International Journal of Agriculture and Environmental Research*. 2025;11(03):805–815. 10.51193/ijaer.2025.11310.
23) Youssef EAE. Advancements in magnetized water technology: Enhancing crop yields, drought tolerance, and Environmental Sustainability: A Review. *Egyptian Journal of Agronomy*. 2025;47(3):655–662. 10.21608/agro.2025.383788.1691.
24) Mohammad G. Harnessing magnetic fields for sustainable agriculture: A study on crop growth, yield, and stress resistance. *Current Agriculture Research Journal*. 2025;12(3):1077–1089. 10.12944/carj.12.3.04.
25) Adebayo KR. Impact of magnetized irrigation water treatment on nutrients uptake and water use efficiency of cowpea cultivar (Vigna unguiculata L.). *UMYU Scientifica*. 2024;3(2):164–172. 10.56919/usci.2432.018.
26) Khoshravesh M, Pourgholam-Amiji M. The effect of irrigation with magnetized wastewater on soil heavy metals, water productivity and heavy metals in aerial parts and grains of maize. *Applied Water Science*. 2024;14(8). 10.1007/s13201-024-02244-w.
27) Zhou Z, Liu J, Zhang J, Li W, Wen Y, Chen R, et al. Combining magnetized water with biodegradable film mulching reshapes soil water-salt distribution and affects processing tomatoes' yield in the arid drip-irrigated field of Northwest China. *Agricultural Water Management*. 2024;303:109021. 10.1016/j.agwat.2024.109021.
28) El-Zawily AES, Meleha M, El-Sawy M, El-Attar EH, Bayoumi Y, Alshaal T. Application of magnetic field improves growth, yield and fruit quality of tomato irrigated alternatively by fresh and agricultural drainage water. *Ecotoxicology and Environmental Safety*. 2019;181:248–254. 10.1016/j.ecoenv.2019.06.018.
29) Jamil I, Elmokh F, Tlig W, Nagaz K. Effect of magnetic water irrigation on growth, yield of pepper and soil salinization in an arid environment. *Journal of Oasis Agriculture and Sustainable Development*. 2023;5(5):59–70. 10.56027/JOASD.312023.
30) Guo Y, Wang Q, Zhao X, Li Z, Li M, Zhang J, et al. Field irrigation using magnetized brackish water affects the growth and water consumption of haloxylon ammodendron seedlings in an arid area. *Frontiers in Plant Science*. 2022;13. 10.3389/fpls.2022.929021.
31) Elhindi KM, Al-Mana FA, Algahtani AM, Alotaibi MA. Effect of irrigation with saline magnetized water and different soil amendments on growth and flower production of Calendula officinalis L. plants. *Saudi Journal of Biological Sciences*. 2020;27(11):3072–3078. 10.1016/j.sjbs.2020.09.015.
32) Putti FF, Cremasco CP, Neto AB, Barbosa AC, Júnior JF, Reis AR, et al. Fuzzy modeling development for lettuce plants irrigated with magnetically treated water. *Plants*. 2023;12(22):3811. 10.3390/plants12223811.
33) Abdelfattah A, Awad M, Sorour O. Synergistic effects of magnetic water treatment and mulching on crop and soil moisture-salinity distribution. *Scientific Reports*. 2025;15(1). 10.1038/s41598-025-98802-6.
34) Boix YF, Dubois AF, Quintero YP, Alemán EI, Victório CP, Aguilera JG, et al. Magnetically treated water in Phaseolus vulgaris L.: An alternative to develop organic farming in Cuba. *Plants*. 2023;12(2):340. 10.3390/plants12020340.
35) Yang X, Fan J, Ge J, Luo Z. Effect of irrigation with activated water on root morphology of hydroponic rice and wheat seedlings. *Agronomy*. 2022;12(5):1068. 10.3390/agronomy12051068.
36) Ma C, Li Q, Song Z, Su L, Tao W, Zhou B, et al. Irrigation with magnetized water alleviates the harmful effect of saline–alkaline stress on Rice Seedlings. *International Journal of Molecular Sciences*. 2022;23(17):10048. 10.3390/ijms231710048.
37) Yi G, Quanjiu W, Kang W, Jihong Z, Kai W, Yang L. Spring irrigation with magnetized water affects soil water-salt distribution, emergence, growth, and photosynthetic characteristics of cotton seedlings in southern Xinjiang, China. *BMC Plant Biology*. 2023;23(1). 10.1186/s12870-023-04199-7.
38) Hamza AH, Menesi AM, Aalaf AH, Elbeltagi A, Elwakeel AE, Salem A, et al. Influence of the magnetic field on the characteristics of sandy soil, groundwater, fruit quality, and peach water productivity at different irrigation distances in a desert environment. *Applied Water Science*. 2025;15(9). 10.1007/s13201-025-02593-0.
39) Wang D, Wang Z, Zhang J, Zhang Y, Chen P. Effects of salinity of magnetized water on water–salt transport and infiltration characteristics of soil under drip irrigation. *Agronomy*. 2024;14(12):2873. 10.3390/agronomy14122873.
40) Jiang Z, Wang Q, Ning S, Lin S, Hu X, Song Z. Application of magnetized ionized water and bacillus subtilis improved saline soil quality and cotton productivity. *Plants*. 2024;13(17):2458. 10.3390/plants13172458.
41) Zedan AT, Khedr A, Rashad M. Effect of irrigation water and nitrogen fertilizer on growth and productivity of cowpea crop with magnetized water. *Misr Journal of Agricultural Engineering*. 2021;0(0):0–0. 10.21608/mjae.2021.101856.1050.
42) Abdelghany AE, Abdo AI, Alashram MG, Eltohamy KM, Li J, Xiang Y, et al. Magnetized Saline Water Irrigation Enhances Soil Chemical and Physical Properties. *Water*. 2022;14(24):4048. 10.3390/w14244048.
43) Hegazy AA, EL-Boraie EA, Soliman E, Said M, Rady O, El-Seedy ME. Effect of magnetized saline water on nutrients and chemical properties of water, soil and biochemical attributes of atriplex nummularia. *Journal of Soil Sciences and Agricultural Engineering*. 2025;16(6):187–196. 10.21608/jssae.2025.386515.1290.
44) Awad O, Ahmed AF. Influences of magnetically treated water on physicochemical properties of water and soil, vegetative growth, biochemical content, fruit quality, and yield of superior grapevines. *Egyptian Journal of Soil Science*. 2025;65(1):0–0. 10.21608/ejss.2025.346187.1942.