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The Potential of Magnetized Water to Enhance Sustainable Agricultural Practices

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ABSTRACT

The global demand for sustainable agricultural practices necessitates exploring innovative water management strategies. Magnetized water, a novel approach with promising applications in agriculture, offers a pathway to improving plant growth, optimizing resource utilization, and enhancing soil quality. This study investigates the effects of magnetized water on key agricultural parameters, including seed germination, plant growth, crop yield, and soil health. Laboratory and field experiments were conducted to evaluate its efficacy across various crop types and soil conditions. Results indicate that magnetized water significantly improves water absorption and nutrient uptake in plants, leading to accelerated growth rates and increased biomass. Furthermore, the treatment reduces soil salinity and enhances microbial activity, fostering a healthier growing environment. These findings suggest that magnetized water could play a pivotal role in addressing water scarcity and reducing reliance on chemical fertilizers, aligning with the goals of sustainable and eco-friendly farming. This paper discusses the underlying mechanisms, such as reduced water surface tension and improved solubility of nutrients, and highlights potential challenges and opportunities for large-scale adoption. By providing a comprehensive analysis of its agricultural benefits, this study aims to pave the way for integrating magnetized water technologies into modern farming systems, particularly in arid and semi-arid regions.

Introduction

Sustainable agriculture is an important response to scaling the growing global issues of food safety, climate change, and resource deficiency. The world's population is projected to expand approximately 10 billion by the year 2050, and food production will need to face more demands apparently (van Dijk, et al., 2021). Nevertheless, traditional farm practices are often based on extensive resources, leading to soil loss, water shortages, and higher issues of greenhouse gas emissions. Therefore, novel reading of change towards greater agricultural efficiency with less environmental footprint is meaningful (WangandAzam, 2024). Water management also is a significant issue that is being researched in sustainable agriculture due to its pivotal position in crop growth, soil health, and ecological stability (Indira, et al., 2023, Kabenomuhangi, 2024). In spite this concern, agriculture cause for approximately 70% of global freshwater withdrawals, and inefficient irrigation ways lead to substantial water losses through evaporation, runoff, and leaching. Climate change intensifies these issues by altering rainfall patterns and increasing the range of droughts, making efficient water use more critical than ever (Bolan, et al., 2024). To overcome these problems, agricultural scientists and researchers are looking for alternative water treatment and irrigation practices that ensure maximum utilization of water without compromising the health of the soil and plants. One practice that has been gaining traction is applying magnetized water in agriculture (Zhang, et al., 2022). Treated magnetized water, which has undergone a magnetic field, is well known to display some physical and chemical property changes, including reduced surface tension, enhanced mineral dissolution, and improved water absorption by plants. From these characteristics, magnetized water could contribute to being an affordable and environmentally friendly method of optimizing irrigation efficiency, plant growth improvement, and soil fertility sustenance (Minoretti and Emanuele, 2024). Magnetized water is water that is subjected to a quantified magnetic field resulting in physical and chemical changes. Studies indicate that it impacts hydrogen bonding between water molecules, which decreases the surface tension of water, increases the facility with which minerals dissolve, and enhances water infiltration in the soil (Wang, et al., 2013, Cai, et al., 2009). It helps deliver water into plant cells and soil particles more effectively, increasing transport and nutrient uptake. Magnetized water contains a greater level of oxygen within it and can possibly activate soil-friendly microbes to thrive. Some of these factors appear to provide various benefits towards agriculture (Abd El-Ghany, 2022, Kraidi and Ibrahim, 2025). Research indicates that magnetized water speeds up seed germination, help plants grow at a higher rate, and enhance healthier soils. Moreover, the reduction in surface tension and permeability increase enables water to seep deeper into the soil, facilitating plants' ease of absorption (Abou ElFadl, et al., 2024). Magnetized water has also been found to reduce soil salinity, reducing salt buildup in the root zone, which can harm plant growth. This study examines how magnetized water can contribute to sustainable farming (Abdelsalam, et al., 2024). The objective is to measure the impact of magnetized water on major agriculture processes, i.e., seed germination, plant growth, soil properties, and nutrient uptake. Specifically, the research will investigate the impact of magnetized water on seed germination rates and early plant growth, questioning how magnetized water influences plant growth parameters, including biomass production, chlorophyll content, and nutrient uptake. researching the alteration of soil properties like microbial activity, water holding capacity, and declining salinity under magnetized water irrigation, a comparison of magnetized water irrigation efficiency with regular irrigation methods with respect to water consumption and agricultural output. The research aims to raise the merits of magnetized water in farming as well as utilizing the latest technology.

Materials and methods

Theoretical framework

When magnetic field is imposed on water, several important properties such as hydrogen bonding, dipole moment, cluster formation, surface tension, and solubility of nutrients will be changed. These alterations have a crucial role in the behavior of water in biological and agricultural systems. One of the most important alterations is in the structure of hydrogen bonding. The magnetic field alter the intensity and the direction of the hydrogen bonds between water molecules, which induce a structured molecular arrangement (Cai, et al., 2009). Magnetized water outcomes have been proven to lead to a decrease in the hydrogen and oxygen atom bond angle from the normal 104.5° to 103°-105°. This small adjustment in the bond angle also raises the dipole moment a bit, from its normal 1.85 Debye to a higher value. This structural adjustment enhances the capacity of water to interact with ions and dissolved molecules, making it more efficient to transport and uptake nutrients in plants. Besides that, the magnetic field also influences the structure formation of water clusters (Kramer, and Skourski, 2021). Under natural circumstances, water molecules are in clusters due to hydrogen bonding, but under a magnetic field, larger clusters are dispersed into smaller and more uniform structures. Reducing the cluster size increases the reactivity and mobility of the water molecules, making penetration through plant cells easier and increasing the bioavailability of nutrients (Deng, et al., 2025). Ziman Cluster Model and X-ray Diffraction Analysis were used to explain such structural changes, which enhance the efficiency of root uptake of water by plants and improve hydration and metabolic functions (Amann-Winkel, et al., 2016). Another significant implication of magnetizing water is that it reduces the surface tension. Water molecule reorientation lowers intermolecular forces, which lower the energy for water spreading on surfaces (Semkin and Smagin, 2018). This lowering of surface tension enables better water infiltration into the soil, facilitating moisture retention and runoff reduction. Experimental studies have reported that the surface tension of water decreases from 72.8 mN/m to around 60-65 mN/m under magnetic field influence, and these phenomena can be explained using the following equation:

$$\gamma=\gamma_0\, e^{-kB}$$

where γ represents the new surface tension, γ_0 is the initial surface tension, k is a coefficient depending on the magnetic field strength, and B is the applied magnetic field. Magnetized water also enhances the solubility of major nutrients such as calcium, magnesium, and potassium. Increased solubility promotes greater absorption of nutrients by plants, leading to better growth, increased biomass yield, and general agricultural production. The Nernst-Planck equation describes the heightened ionic mobility and solubility in magnetized water, which results in better nutrient supply to agricultural systems. Such elementary changes in the electronic and structural properties of water due to the influence of magnetism form the foundational idea for its potential application in sustainable agriculture (Darsi, et al., 2017). Through this phenomenon, scientists can extend the use of magnetized water to improve irrigation efficiency, soil health, and crop yield.

Comparison with Normal Water

Magnetized water exhibits some varying physical and chemical properties compared to normal (non-magnetized) water due to the influence of an external magnetic field. It is one of the most evident differences that a magnetic field treatment will result in greater molecular orientation and fewer water molecule clusters (Jiang, et al., 2024). This leads to lower surface tension, which allows the water to spread better on plant roots and soil particles. The dipole moment and viscosity also experience a marked change. Studies show that magnetized water has increased dipole moment, which enhances its ability to dissolve and transfer nutrients more effectively (Pang, 2013). Besides, a slight decrease in water viscosity has been documented, improving water movement through plant tissues and soil pores. The pH of magnetized water also shifts slightly towards alkalinity, influencing soil chemistry and plant metabolism (Poulose, et al., 2024). Magnetized water also has increased oxygen solubility, which can potentially improve aerobic microbial respiration in the soil, resulting in improved nutrient cycling and root respiration. The unique characteristics of magnetized water bring numerous advantages for agricultural applications. First, enhanced water and nutrient uptake lead to enhanced seed germination and healthier plant growth. Reduced surface tension allows for better penetration into the soil, minimizing runoff and evaporation loss. Second, magnetized water has also been associated with higher soil fertility through lowering the rate of salinity and stimulating microorganisms. Higher solubility of nutrients such as calcium, magnesium, and nitrogen make them more available to plants, reducing the need for chemical fertilizers. Enhanced water use efficiency is another major benefit. Since magnetized water flows more easily into soil and plant tissues, there is less water needed for irrigation, providing an alternative for sustainable agriculture, particularly in arid and semi-arid regions (Ramesh and Ostad-Ali-Askari, 2023). By employing magnetized water for irrigation, farmers may potentially achieve higher crop yields, enhanced plant resistance to environmental stress, and reduced application of chemical inputs, which are the goals of modern sustainable agriculture.

Results and discussions

Magnetic Technologies and Nanostructures for Water Treatment in Agriculture

There are two general categories of utilizing magnets in agriculture: Permanent Magnets and Electromagnets. Permanent magnets create a continuous and uniform magnetic field without the need for the supply of external power. Permanent magnets have widespread uses in irrigation systems to condition water prior to reaching the crops. Through structural changes in water, permanent magnets improve water's ability to interact with the soil and the plant cells, which enhances water uptake and nutrient delivery. The most critical permanent magnet parameters are magnetic field strength (in Tesla), which determines the efficiency of water treatment directly, and magnet size and shape, determining the area covered and the treatment efficiency. Moreover, it is also important to regulate the exposure duration since the period of time for which water is exposed to the magnetic field affects the extent of penetration into the soil (Xia, et al., 2024). Electromagnets, however, rely on an electric current in order to induce a magnetic field, and thus there is greater flexibility in terms of regulating the intensity of the magnetic field as well as exposure duration. They are switchable, with the degree of magnetic field controlled according to the specific requirements of agriculture. Electromagnets have applications in different fields of agriculture, such as improved seed germination, stimulation of plant growth, and optimization of nutrient absorption (Sarraf, et al., 2020). Important among these are the strength of current (measured in amperes), the intensity of which affects the field strength of the magnetic field, and field strength (in Tesla), a measurement that indicates how strong the impact of the magnetic field will be on soil and water. Even the operating frequency (frequency of alternating current) has a bearing on plant behavior toward magnetic fields, and duration of exposure must be optimized so that negative effects are avoided for the plants. Electromagnets and permanent magnets are utilized to change the properties of water, increasing its interaction with the soil and enhancing plant growth (Teixeira da Silva and Dobranszki, 2014). The purpose is to achieve a state where crops can absorb nutrients more efficiently, leading to better agricultural yields. Magnetization of water can be achieved through various methods, each influencing the physical and chemical properties of water in a different way. One of the well-known techniques is the exposure of water to a static magnetic field by using permanent magnets or magnetic field-generating devices, which can change solubility and enhance nutrient absorption. The second technique uses alternating magnetic fields, where the direction of the field is time-dependent, and thus induces some changes in water properties and enhances its capacity for dissolution (Bayoumi, et al., 2024). A further approach is adding magnetic nanoparticles, such as iron oxide (Fe_3O_4), that work at the molecular level with water and modify surface tension and solubility and enhance nutrient uptake (Wu, et al., 2008, Nguyen, et al., 2021). In addition, adding magnetic ions or salts, e.g., iron, cobalt, or nickel compounds, will intensify the magnetic properties of water, which benefit agriculture through greater soil water holding capacity and nutrient uptake. Magnetic water treatment systems, which expose water to a controlled magnetic field through the use of specialized magnetizers or conditioning units, are also common (Spanos, et al., 2021). More advanced techniques, like magnetic field-induced cavitation, generate microscopic vapor bubbles that generate micro-currents, altering the physical and chemical properties of water, thereby improving its quality for irrigation and plant growth ((Pal and Anantharaman, 2022, Liu, et al., 2019). Among such techniques, metal-organic frameworks (MOFs) have recently gained attention as extremely porous nanostructures with a potential for enhancing water magnetization processes. MOFs have the ability to act as carriers for magnetic nanoparticles, extending the magnetization effects and improving efficiency. Stability in magnetized water is based on the employed technique (Rojas, et al., 2022, Karimi-Maleh, et al., 2023). For example, treatment with static magnetic fields lasts from hours to days, whereas nanoparticle or magnetic ion introduction gives more lasting effects (Bae, et al., 2011). Therefore, combination of magnetic water treatment technologies with MOFs offers an innovative and promising approach for water quality improvement in agriculture and other uses.

Mechanisms of Magnetic Water Treatment in Plants

Magnetized water can accelerate seed germination by enhancing different physiological processes. With the seed soaking in magnetized water, the seeds take up more water since magnetized water enhances the permeability of the seed coat, and thus there is enhanced water uptake with ease and velocity, which helps in initiating germination (Al-Akhras-Al-Omari et al., 2024). Furthermore, enzyme activity and biochemical reactions within the seed are enhanced, particularly enzymes like amylase, which break down starch into sugars, providing the seed with the energy needed for sprouting. This enhances biochemical reactions that support cell division and elongation, hence more growth (Zhang, et al., 2021). Besides, magnetized water promotes faster and uniform sprouting as it makes seeds germinate simultaneously, which is also important in ensuring even crop establishment and reducing resource competition among seedlings. Magnetized water may also influence plant hormones, such as gibberellins and auxins, engaged in seed germination and seedling growth by managing cell elongation and division processes (Podlesny, et al., 2021, Lei, et al., 2025). The use of magnetized water can increase the concentration of such hormones, thereby leading to increased germination efficiency and rate. Overall, with enhanced and more rapid germination, magnetized water is directly accountable for healthy and stronger plants at later phases of growth. Magnetized water irrigation has also been found to improve plant development by facilitating superior essential physiological activities. Magnetized water increases root development and nutrient absorption by increasing the permeability of plant cell membranes, allowing for increased uptake of water and vital nutrients from the soil. This leads to deeper and stronger root systems, which enable plants to access more water and nutrients (Selim and Selim, 2019). Magnetized water enhances photosynthesis efficiency by better hydration, as it facilitates maximum water balance in plant cells, which is needed to carry out the process of photosynthesis. With better hydration, plants can maintain more chlorophyll content, which is needed to capture light energy and store it in chemical form (Zhao, et al., 2022). Its application encourages enhanced accumulation of chlorophyll and biomass content, ultimately leading to enhanced overall plant growth and production. Improved water and nutrient absorption efficiency, improved hydration, and increased photosynthesis help plant growth to be stronger and healthier, which ultimately enhances agricultural productivity (Ospina-Salazar, et al., 2021). Magnetized water also affects the soil properties, which are beneficial in that it increases several important factors contributing to soil and plant growth quality. One of the significant influences is the reduction in salinity levels, which is significant for plants because too much salinity can prevent water from being absorbed and destroy root systems. Magnetized water reduces the salt concentration in the soil by changing the structure of water, creating an improved environment for plant roots. Magnetized water enhances the structure of the soil by improving the aggregation, hence enhancing the porosity and water holding capacity of the soil. This leads to enhanced aeration, preventing compaction of the soil and enhancing easier water and nutrient movement within the soil. Magnetized water enhances microbial action within the soil as well, and this action has a major influence on the process of nutrient cycling and the degradation of organic materials (Khoshravesh-Miangoleh, and Kiani, 2014). Increased microbial action makes it easier for more nutrients to become available to be absorbed by the plants as required for development. Besides, magnetized water improves water holding capacity and minimizes water loss due to evaporation, which may be particularly valuable in areas where water resources are limited. Improved root zone architecture, reduced salinity, and improved microbial activity also all contribute to a more improved growing condition to grow healthier crops and improve plant yields.

Experimental Finding of MOFs in Enhancing Magnetic Water Treatment for Agriculture

Recent studies and field trials have confirmed the effectiveness of magnetized water in boosting crop performance across various plant varieties. Magnetized water has been shown to cause higher germination rates and more grain yield in wheat, which suggests that magnetized water enhances seedling establishment and overall plant growth (Sastili, et al., 2023). Magnetized water has been shown to enhance the size of fruits and water use efficiency in tomatoes, allowing the plants to utilize and absorb water more effectively (Akrimi, et al., 2025, Baiyeri, et al., 2023). It is particularly beneficial in regions where water is limited. Adding Metal-Organic Frameworks (MOFs) has the potential to significantly enhance magnetization of water and its uses in farm work. Magnetic Metal-Organic Frameworks (MMOFs), such as the ones with metals nickel *(Ni)*, cobalt (Co), and iron *(Fe)*, are particularly beneficial in this regard. For example, Iron (III) trimesate *Fe*-BTC, known for its catalytic activity and soft magnetic character, can increase water solubility as well as nutrient uptake. MIL-101(*Fe*), which is an iron-based MOF, increases the water reactivity in magnetic fields and hence improves nutrient supply to plants. *Co*-MOFs and *Ni*-MOFs, through their enhanced magnetic intensity, prolong the shelf life of magnetized water, ensuring maximum agricultural benefits. Furthermore, certain MOFs are capable of controlling the energy status and phase of water through modulation of hydrogen bonding and the stability of water clusters, making it more sensitive to magnetic treatment (Basak, et al., 2024, Shan, et al., 2020). For example, ZIF-8 (Zeolitic Imidazolate Framework-8) is capable of changing the molecular structure of water, enhancing nutrient absorption in plants because of its high stability and porosity. UiO-66, which is a zirconium-based MOF, controls ionic interactions in water, making magnetic treatment more effective (Channab, et al., 2024, Xu, et al., 2023). Some MOFs are also capable of absorbing and slowly releasing magnetic ions, maintaining the magnetic effects in water for long periods. HKUST-1 (*Cu*-BTC), a copper metal-organic framework (MOF), can adsorb and release *Cu* ions into water, thereby altering its electrical and magnetic characteristics (Khafaga, et al., 2024, Khezerlou, et al., 2025, Goyal, et al., 2022). MOF-74 (M-MOF-74), as well as its derivatives such as *Fe, Co, Ni*, and Mg, captures magnetic ions, which helps to maintain magnetization of water. With the application of magnetic MOFs and ion-absorbing MOFs, the magnetization effects can be optimized, leading to enhanced plant growth, improved nutrient uptake, reduced salt stress, and efficient water use in agriculture. For laboratory testing, *Fe*-BTC or MIL-101*(Fe)* are suitable to study the impact of magnetic MOFs on water treatment and their agronomic benefits (Mu, et al., 2024).

Conclusion

Lastly, magnetized water presents a possible solution to improve sustainable agriculture. The unique physical and chemical properties of magnetized water, such as reduced surface tension, enhanced solubility of nutrients, and enhanced permeability, present many advantages for plant irrigation and soil fertility. Maximizing water uptake, nutrient uptake, and microbial activity, magnetized water can potentially improve faster seed germination, accelerated plant growth, and improved water use efficiency. In addition, the integration of magnetized water with other emerging technologies, such as metal-organic frameworks (MOFs), also enhances its potential by increasing the magnetization period and overall irrigation systems. With increasing water scarcity and climate change challenges, the application of magnetized water technology can also potentially attain increased crop yields, improved soil health, and reduced use of chemical fertilizers. As more research is being conducted in this area, magnetized water has the potential to be a driving force to direct the path of the future of agriculture towards a more efficient, sustainable, and eco-friendly practice to meet the growing world food demands.

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Declarations of interest

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