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Magnetized Irrigation and its Potential in Sustainable Agriculture: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Magnetisation in agriculture is not a conventional method. It has tremendous implications in the crop production as well as mitigating the poor quality soil and water conditions. This reviews looks into the changes that occur in the properties of water on magnetization and the changes in the physico-chemical of soil that are affected by magnetic water. The practical application of magnetic irrigation in agriculture are reviewed based on recent researches. Magnetisaton positively influences the seed germination, seedling establishment, vegetative growth and yield of treated plants. Magnetic irrigation boosts the anti-oxidant and enzyme activity, enhances the plant metabolism and synthesis of plant pigments for coping up the adverse growth conditions. The remediation of poor quality irrigation water and waste water management are another fields where magnetization can be effectively utilized. Magnetic water can be used to alleviate abiotic stresses

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such as salinity and drought stresses. Magnetised irrigation is a suitable alternative for reduced water requirement and improved water use efficiency. Hence magnetised irrigation is a promising scientific method to boost crop production, while being sustainable and environmentally safe.

Keywords: Magnetic field; structural change; water use efficiency; saline soil.

1. INTRODUCTION

In India, the primary consumer of water is agriculture, which accounts for 81% of the total national water consumption [1]. The burgeoning population poses a never ending demand for water for domestic, agricultural and industrial purposes. The unforeseen and prolonged droughts along with climate changes add to the severity of the situation, placing an immense pressure on the existing water resources. The decline in both the quality and quantity of available water is also one of the major issues nowadays. The shortage of good quality irrigation water has led to the practice of utilizing poor quality water such as hard water, saline water, and wastewater for irrigation. In this context, the water scarcity in agriculture can be alleviated only by reducing the agricultural water input per unit area [2]. Therefore, developing a scientific methodology is crucial to withstand the impending water crisis and maximize crop productivity in agriculture.

Magnetic water treatment is one such approach, and the use of magnetic fields has been recognized for ages [3]. The concept of magnetic induction was first introduced by Michael Faraday in the early 1830s, and claimed that an electrical current is produced when a magnetic flux is crossed by ions or a conductor. This concept later got developed into application of magnetic field in various fields, including research and industries. The first commercial magnetic water treatment device was patented by Vermeiren in 1958 in Belgium [4].

Magnetic water, also referred to as magnetized water, magnetically treated water, or magnetic field-treated water, is water that has been exposed to a magnetic field with a specific flow rate and intensity. Pre-sowing seed treatment with a magnetic field (MF), known as "magnetopriming," is a non-destructive and dry seed priming method. This technique has been reported to improve germination and seedling vigour in many crops [5]. The “magnetic memory” of water refers to the long-term effects that persist for hours or days after the electromagnetic and/or magnetic field is removed [3].

Since water serves as the primary medium for various biological and non-biological reactions, exposure to magnetic fields could influence cellular metabolism, as water in the body acts as a key receptor for the magnetic field. When water is exposed to a magnetic field, its properties—including optical, electromagnetic, thermodynamic, and mechanical characteristics —change compared to pure water. These changes may include the formation of hydrogen bonds, alterations in conductivity, evaporation, surface tension, size of water molecules, activation energy, salt mobility, dissolved gases, and structural regularity. Consequently, magnetized water finds diverse applications in fields like industry, agriculture, and medicine [6-10].

Various studies suggest that using magnetized water for irrigation can improve seed germination, seedling growth, overall plant development, agricultural yield, and fruit mineral content. Research findings also advocate employing magnetic treatment on low-quality irrigation water to enhance crop production. Magnetized water has been found to significantly boost antioxidant activities in plants growing in soils contaminated with heavy metals [11]. It also helps address soil salinity problems through magnetic irrigation technology, facilitating the leaching of ions from the soil. Therefore, utilizing magnetized water for irrigation could be a highly promising and sustainable approach to enhancing agricultural production in the future. The growth characteristics that were considerably reduced by drought stress could be greatly increased when MW was used for irrigation. Furthermore, the concept of using magnetic irrigation treatment is not only environmentally safe but also cost-effective over the long run [4].

This paper emphasizes the effects of magnetized water on plant growth and development, highlighting its potential benefits for agriculture.

2. EFFECT OF MAGNETIC FIELDS ON PLANT GROWTH AND DEVELOPMENT

The Earth's magnetic field influences plants just as it does all other life forms [12]. Plant growth and development are impacted by electromagnetic fields under both in vitro and in vivo conditions. The biological effects of magnetic treatments depend on various factors, including magnetic strength, duration of exposure, quality and volume of water, temperature, and flow rate [13,14].

2.1 Germination and Early Growth

According to the literature, water exposed to a magnetic field becomes magnetized [8,15]. Studies suggest that the application of a magnetic field to seeds or irrigation water enhances seed germination [16,17], reduces the germination period [18], and promotes seedling growth and yield [9]. The proliferation of meristem cells induced by magnetic irrigation can explain the enhanced seedling characteristics observed in magnetically treated seeds compared to untreated seeds. Several studies have shown that exposure to a magnetic field activates seedling development, as seen in chilli [19], tomato and cotton [20,21], and sunflower [22].

However, Belyavskaya [23] and Turker et al. [15] suggested that weak magnetic fields might inhibit the development of primary roots during the initial growth phase. Exposure to weak magnetic fields can reduce cell reproduction in the root meristem and lower proliferative activity. Additionally, there may be a decline in genomic activity during the early pre-replicative stage in plant cells exposed to weak magnetic fields. The relative volume and size of mitochondria in cells may also increase as a result of weak magnetic field exposure [23]. Belyavskaya [24] reported that low magnetic field exposure could lead to calcium over-saturation and disruptions in metabolic processes involving Ca^{2+} homeostasis in cells.

2.2 Vegetative Growth and Yield

When tomato plants were alternately irrigated with fresh and agricultural drainage water, with or without magnetic treatment, the highest yield and economic efficiency were observed in plants irrigated with 100% freshwater exposed to a magnetic field [25]. In a study involving dry broad beans subjected to three different magnetic treatments—seeds magnetized for 2 minutes and 4 minutes, magnetized irrigation water, and no magnetic treatment—Altalib et al. [26] found that seeds magnetized for 2 minutes, combined with magnetized irrigation, significantly improved plant growth and yield. Early pod emergence occurred 6 days earlier for the 2-minute magnetized seeds and magnetized irrigation compared to control treatments.

In sunflower plants irrigated at three salinity levels (0.7, 4, and 8 dS/m) and exposed to two magnetic field strengths (1000 Gauss and 3000 Gauss), results showed that magnetized irrigation alleviated the negative effects of saline water, improving germination, root length, plant height, and shoot weight [27]. Similar effects of magnetic treatment on saline water irrigation were reported by Hozayn et al. [14], Alsuvaid et al. [28], El-Mugrbi et al. [29], and Okba et al. [30]. Furthermore, magnetization of saline water not only reduced its harmful effects but also increased levels of superoxide dismutase, peroxidase, and catalase enzymes, mitigating the salinity hazard [31].

Irrigation with magnetized water was found to produce significant improvements in root length and total root volume, leading to increased aboveground and belowground dry matter production [27, 32-35]. Conversely, adverse effects of weak magnetic fields on root development were also reported [15, 23,24]. The effect of magnetized water depends on the plant species, flow rate, and length of the magnetic pathway [36].

Several studies have reported enhancements in chlorophyll a + b and total phenol levels when using magnetized water in crops such as cotton [20], lettuce [37,38]), and rice [39]. Significantly higher chlorophyll content and reduced proline content, along with improved vegetative growth, were observed in pomegranate plants under magnetized irrigation treatment [30]. Reviews suggest that magnetic field application also improved nutrient content, including N, P, K, Ca, Mg, and enhanced levels of chlorophyll a and b, vitamin C, and carotenoids [33,38,40-44].

Researchers have also found that irrigation with magnetized water significantly improved growth indices, net photosynthetic rate, transpiration rate, SPAD value, stomatal conductance, and relative water content [45-47]. These variations could be attributed to increased photosynthetic pigment, secondary metabolites, and endogenous promoters (IAA), balanced enzyme activity, and high protein production due to the stimulatory effect of magnetization. Recently, Tombuloglu et al. [48] engineered a magnetic nanoparticle on barley, finding an increase in chlorophyll (a, b) and carotenoid pigments by 20% and 22%, respectively.

Magnetized water significantly enhanced antioxidant activity in plants grown in heavy metal-contaminated soils [11]. Mohrazi et al. [49] found that magnetization of irrigation water contaminated with copper sulphate significantly increased maize shoot dry matter compared to irrigation with distilled water. Conversely, maize yield was higher in plants irrigated with distilled water. Similarly, magnetically treated irrigation water led to more cadmium (Cd) removal from plants by accumulating Cd in dead and senescent leaves, indicating the phytoremediation efficiency of magnetized water [50-52].

In a hydroponic experiment with four treatments, distilled water, magnetized distilled water, tap water, and magnetized tap water, Alkhatib et al. [53] found that plant height and root length were significantly higher in plants irrigated with magnetized distilled water. The same trend was observed for protein content and photosynthetic rate. Zareei et al. [54] also reported that magnetic treatment positively stimulated the production of photosynthetic pigments in hydroponically grown grapes.

2.3 Physiological Responses to Abiotic Stress

Studies conducted by Ruzic and Jerman [55] suggested that exposure to very low-frequency magnetic fields could reduce the effects of heat stress in plants. They concluded that magnetic fields might act on similar metabolic pathways as temperature stress, indicating that magnetic fields serve as a protective factor against heat stress.

Magnetic treatments in in vitro systems, conducted in controlled environments, are easy, fast, and have consistent experiment reproducibility. These systems also require minimal space and resources [56]. Thus, they are ideal for analyzing biochemical, physiological, or molecular processes and changes induced by magnetic fields.

3. EFFECT OF MAGNETIC FIELDS ON THE PROPERTIES OF WATER

The magnetization of water is influenced by several variables, including the velocity of water flow through the magnetic field, the placement and arrangement of the magnets relative to the water flow, the strength of the magnetic field, temperature, and the duration of the magnetization process [46, 57, 58].

When water is exposed to a magnetic field, its atomic, molecular, and electronic structures undergo significant changes. These changes include shifts in the intracluster and intercluster structures, the formation of new clustering structures, and the development of magnetic interactions among them. Additionally, magnetic exposure can alter the boiling point, viscosity, dielectric constant, hydrogen-bond chains, and polarization effect of water molecules [59-61].

Magnetized water exhibits an optical shift in characteristics. The UV absorption intensity of magnetized water, which is higher than that of pure water, increases exponentially as the magnetization period lengthens and the wavelength of ultraviolet (UV) light decreases. These changes are directly related to atomic polarization, molecular clustering, and alterations in the transition dipole moment of electrons within molecules as a result of magnetization [62].

Compared to untreated water, magnetized water shows significant differences in UV absorption, X-ray and infrared diffraction, and Raman scattering. Research also indicates that the application of a magnetic field raises the pH of pure water and decreases its surface tension [59].

The key characteristics of magnetized water include the saturation effect, memory effect, temperature-dependent magnetization, and changes in surface tension. The saturation effect refers to the point at which no further changes in the properties of magnetized water can be achieved, even if the exposure period or field strength is increased beyond a certain threshold [62].

Temperature plays a crucial role in determining the degree of magnetization. As the temperature increases, the molecular strength within clustering structures decreases. Additionally, the "residual effect" or "memory effect" of magnetized water implies that changes in the properties of water are not immediately reversed when the magnetic field is removed. The duration of the memory effect is influenced by the magnetic field [63-65].

4. EFFECT OF MAGNETIC FIELDS ON SOIL PROPERTIES

Water scarcity and soil salinity are among the most significant challenges facing global agriculture. The primary cause of soil deterioration is the accumulation of salts in soil capillaries, leading to inadequate water availability and high salt concentrations that can ultimately cause plant death.

Numerous studies have shown that magnetized water enhances the availability of water-soluble nutrients in soil, thereby improving plant absorption. The growth improvements observed in plants treated with magnetic fields are attributed to beneficial effects on cell membrane permeability and soil characteristics. Magnetized water alters cell membrane permeability and facilitates ion transport across channels. Additionally, magnetized water influences the surface tension, viscosity, and evaporation rate of water [60]. Furthermore, magnetized water reduces soil hydrophobicity and promotes the coupling of water molecules to soil particles. As a result, soils irrigated with magnetized water exhibit higher moisture content than control plots [66].

Magnetization of irrigation water also alters several soil properties, including a decrease in soil pH [60], reduction in soil conductivity [13], stimulation of soil microbial activity [67], increased carbonate precipitation [68], and improved availability of phosphorus (P) and potassium (K) [8]. Using magnetized water enhances soil moisture retention, reduces deep percolation, and decreases irrigation intervals, thereby increasing water productivity and irrigation efficiency [69]. Moreover, magnetization can mitigate the harmful effects of saline soil or saline water on plant growth [8,69,70].

In a study conducted by Moussa et al. [71] on the pore changes due to the magnetization of water, they examined the soil structure of the surface layer by impregnating it with fluorescent glue and polishing horizontal sections. The results showed a significant effect on soil porosity, which enlarged both macroscopically and microscopically.

Cui et al. [72] reported that soil nutrient concentration, microorganism populations—especially the bacterial composition such as proteobacteria—and enzyme activity were higher in magnetized irrigated soil compared to the control, resulting in improved nutrient cycling.

Under conditions of low soil moisture, magnetic irrigation increased water use efficiency considerably compared to untreated water [28,30,32,47,73]. Magnetic water also improves the water use efficiency and water productivity by 7.5 and 88% depending on the plant species and the type of water that is magnetized [74].

5. CHALLENGES AND PROSPECTS FOR THE FUTURE

Magnetized water has demonstrated considerable potential in the agricultural sector, as discussed in this paper. However, there are significant challenges in fully integrating this technology into everyday agricultural practices. One of the primary challenges is the development of pumps that meet the technical and practical requirements of magnetic systems.

The scientific literature presents various magnetic mechanisms, many of which are contradictory. There is a lack of clarity regarding the extent of these effects and the underlying processes. Rigorous laboratory and field studies are needed to determine the precise mechanisms by which magnetization affects plants and to identify the standard magnetic strength suitable for irrigation and desalination of low-quality water.

While numerous studies on magnetic irrigation have been conducted, there has been limited research in India, particularly concerning the magnetization of low-quality irrigation water. As good quality water becomes increasingly scarce for agriculture worldwide, and as demand for water from other sectors continues to rise, magnetizing poor-quality water such as brackish, metal contaminated, or saline water, may offer a viable solution. High quality research and field trials are necessary to identify optimal magnetization methods suitable for the major crops in India.

6. CONCLUSION

Magnetized water has been shown to provide several benefits for farming and agriculture including improved germination, plant growth and development, increased crop yields, water savings, better soil quality, and improved irrigation water quantity and quality. Despite the fact that MW irrigation technology has been shown to have favourable benefits on crops for many years, its exact mechanism of action in biological systems is still unknown or only partially understood.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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