Review Article

Magnetized Irrigation And Its Potential In Sustainable Agriculture- A Review

ABSTRACT

Magnetized water is water that has been subjected to a magnetic field or passed through a magnetic device, where the water molecules become ionized, forming hexagonal structures. This review emphasizes the use of magnetized irrigation in the agricultural sector and its impact on plant growth and development. Magnetized irrigation, or magnetically treated seeds, enhances seed germination, seedling establishment, vegetative growth, early flowering, and fruit formation, all of which ultimately boost crop productivity. Magnetic treatment of irrigation water activates plant metabolism, improves antioxidant and enzyme activity, and promotes the synthesis of plant pigments such as chlorophyll a, chlorophyll b, and carotenoids. The magnetic field alters various characteristics of water, including conductivity, dissolved gases, salt mobility, surface tension, activation energy, and evaporation. It also affects the molecular structure of water, such as hydrogen bonds, structural regularity, and the size of water molecules. Researchers have suggested that magnetic irrigation positively influences root depth, root volume, and nutrient mobility and uptake from the soil. The magnetization of irrigation water improves water use efficiency and reduces the risk of soil salinity. Magnetizing poor-quality water (e.g., saline, brackish, or heavy metal-contaminated water) can be considered an alternative method to address the problem of water scarcity. Therefore, magnetic treatment of irrigation water can be regarded as a promising scientific technology to boost agricultural production while remaining sustainable and environmentally safe for future use.

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Keywords: Magnetic field, structural change, water use efficiency, saline soil

1. INTRODUCTION

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In India, agriculture is the primary consumer of water, accounting for 81% of the total national water consumption [1]. Unforeseen and prolonged droughts, combined with increasing water demands, have placed immense pressure on the nation's existing water resources. Currently, the foremost issue is the decline in both the quality and quantity of available water. The shortage of good quality irrigation water has led to the growing practice of utilizing poor quality water for irrigation, such as hard water, saline water, and wastewater. Water scarcity in agriculture can be alleviated only by reducing the agricultural water input per unit area [2].

Modern agricultural technologies focus on efficient, sustainable, and eco-friendly approaches to enhance crop yields using available resources. Implementing sufficient measures to conserve water quality and quantity is essential to prevent future water supply hazards. Therefore, developing a scientific methodology is crucial to withstand the impending water crisis and maximize crop productivity in agriculture.

Comment [UB3]: Source ?

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

Comment [UB4]: Context ?

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. The magnetic memory of water may last for up to 72 hours after the magnetic field is withdrawn.

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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, 7, 8, 9, 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. 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].

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 (2004) [23] and Turker *et al.* (2007) [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 (2001) [24] reported that low magnetic field exposure could lead to calcium over-saturation and disruptions in metabolic processes involving Ca^{2+} homeostasis in cells.

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*. (2022) [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.* (2021) [14], Alsuvaid*et al.* (2022) [28], El-Mugrbi*et al*. (2022) [29], and Okba*et al.* (2022) [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, 3334,35]. 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, 41, 42, 43, 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, 46, 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.* (2020) [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*. (2021) [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, 51, 52].

In a hydroponic experiment with four treatments, distilled water, magnetized distilled water, tap water, and magnetized tap water, Alkhatib *et al*. (2020) [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*. (2021) [54] also reported that magnetic treatment positively stimulated the production of photosynthetic pigments in hydroponically grown grapes.

Studies conducted by Ruzic and Jerman (2002) [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, 60, 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 [63,64,65].

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*. (2020) [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*. (2020) [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].

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.

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