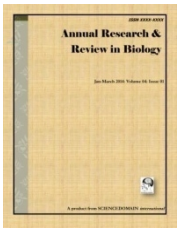

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Why Magnetic Fields are Used to Enhance a Plant's Growth and Productivity?

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Review Article

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ABSTRACT

Studies have accumulated over the years to emphasize the importance of the magnetic fields, MF, used as a safe alternative choice to improve agricultural crops. The most important applications of a magnetic field are the treatments of irrigation water, dry seeds, wet seeds and seedlings. The studies also included the application of magnetic fields at different periods of times (minutes, hours and days) and different doses. The effect of different magnetic fields varies depending on the plant species and age during exposure, as well as the intensity of magnetic field and period of exposure. The variation of MF exposure intensities may transform the effect on the plants from a positive to stressful factor. In this review article we highlighted the influence of a magnetic field, and why it is one of the best methods to enhance a plant's growth and productivity.

Keywords: Magnetic field-growth-plants.

1. INTRODUCTION

The Geodynamo of Earth created a magnetic field layer, which shields us from sun omitted charged particles. The Earth magnetic field (geomagnetic field) is ranged from 25-65μT (0.25 to 0.65 G). This magnetic field is important to maintain the Earth's immunity toward solar radiation. In recent years, the geomagnetic field has decreased 10% than before [1].

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This fact might explain the positive effect of magnetic field exposure on plants improvement and productivity which compensate the reduction in geomagnetic field.

In addition, the geomagnetic field affect charged particles in a phenomenon called geotaxis or electrotropism [2]. The geotaxis induced by MF attracted starch grains within plant cells, which influence the direction of plant growth [2]. This phenomenon, evident clearly in seedlings, at early stage when MF applied during germination; where shoots leaned towards the MF centre [3].

Similarly, the geotaxis effects of MF also include the cryptochromes proteins, which involved in blue light reception, growth, development and circadian cycle. Thus MF intensity variation has no effect when applied on cryptochrome mutant *Arabidopsis thaliana* [4].

Although MF has become implanted in our daily life activities, it did not compensate the Earth decreased MF. The MF is an energy change factor with non-ionization effect on a molecular level. The MF energy also can induce heat via current, electron excitation and redirect charged ions toward an applied field [5]. Using MF has become a cost effective and a safe method to enhance plant growth and productivity. However, all the metabolic activities are energy exchange independent; the nature of the interaction of biological material varies, according to MF source, exposure duration, filed intensities and plant species [6-8].

2. MAGNETIC FIELDS' EFFECT ON WATER MOLECULES

The magnetic field changes water properties due to displacement and polarization of water atoms. Therefore magnetic fields magnetize the water's ability to soak solid matter will be increased [9]. Analogues results found by Cai et al. [10], who reported that MF (at 500 mT) caused changes in physicochemical properties of water; these changes include decreasing water surface tension and increase viscosity. More that their results suggested an increase of activation energy and water molecule size due to extra hydrogen bond formation; this effect is linear with exposure period.

In another study, MF (at 15mT for 5min) affects not only the hydrating intensity of water molecules around ions in electrolyte solutions but, also evaporation and conductivity. The changes of electrolyte solutions, when exposed to MF, depended on ions nature and thermodynamic function of hydration [11]. These finding were confirmed later by Szczes et al. [12] who reported that MF decreased the water conductivity and increased evaporation by affecting the hydrogen bond network and disturbing gas/liquid interface from the air nanobubbles in the water. Fujimura and Iino [13], reported that MF increased water surface tension and strengthen hydrophobic bounds.

The effect of MF on water and electrolyte solutions in previous studies is theoretically applicable on many activities and reactions in the biological system. A study conducted by Maheshwari and Grewal [14] has shown that magnetized water increased yield and fresh weight of celery and snow peas but, there is no effect on pea plants. In the same study, soil was also affected by magnetize water treatment with decreased in soil PH and increase in soil EC and some elements (Ca, Mg, P and Na) availability. The optimal MF does become more effective when applied on humid tissues to ensure ions mobility [15]. In Ijaz et al. [16] study the magnetized wheat seeds with low viability, showed insignificant effects, when exposed to MF unlike seeds treated with magnetized water due to seeds lack of humidity.

It seems that the effect of MF application on irrigation water alone or soaked seeds has the same beneficial effects on plants productivity. Soaking seeds is a crucial factor to enable MF effect because of the water's role as MF mediator. This was confirmed later by Grewal and Maheshwari, [17] study, who reported that exposing seeds to MF or using magnetized irrigation water has similar positive effects. The MF treatment in both cases, accelerates growth and nutrient uptake of snow pea (*Pisum sativum* L var. macrocarpon) and Kabuli chickpea (*Cicer arietinum* L) seeds. Similar results found in Sadeghipour and Aghaei, [18] study who reported that magnetized water induced significant increase in cowpea (*Vigna unguiculata* L. Walp.) biomass, stomatal conductance and water use efficiency.

3. MAGNETIC FIELDS INDUCED MODIFICATION ON A MOLECULAR LEVEL

The negative charges around the DNA molecule, as any charged entity, increase the potential of MF impact. Several studies reported that MF has affected the molecular level leading to plant growth enhancement [19-23]. The nature of MF effect has reached protein synthesis activation leading to further development of root system [24-26]. The MF induced changes in cellular level leading to increase in cell viability, organization and differentiation [27,28]. In addition, MF affects cell reproduction and cellular metabolism [19,29] gene expression [30] and enzyme activity [31].

The theoretical concept of how MF affects the DNA is that MF prolongs free radical ions' lifetime, by inducing the singlet-triplet transition of unpaired electrons leading to oxidative stress [32]. The oxidative stress is a major factor that enhances mutation [33-35] and increase general biological stress [36]. The level of DNA content increase or decrease accordingly with MF exposure level.

Several studies reported a decrease in DNA level following low level exposure of MF Racuciu et al. [37,38] in arbour seedlings (*Robinia pseudoacacia*) and date palm (*Phoenix dactylifera L.*) [21]. The genotoxic effect of MF has been encountered in several studies, Koana, et al. in 1997 [39] reported that magnetic fields induced excitation in cell radical ions which affect DNA integrity and cause spontaneous mutation. The mutagenic effect of MF is indirect because of the limited physical ability of non-ionizing radiation to induce double brake in DNA. The only reasonable explanation is that MF is a co-factor to environmental mutagenic. This fact was confirmed by Pingping et al. [35] study who suggested that MF increase cell membrane permeability, which may increase uptake of any mutagenic compounds existed in the environment. The ability of MF to interacts with any moving charges, even at low level [40,41] attract charged molecules from the surrounding environment which may interfere with DNA charges. A study showed that static magnetic field SMF caused mutation when used at high level (20T) in *Arabidopsis thaliana* [30] and low level on *Helianthus annus* at 200mT [33]. The fact that MF is species specific and the biological system vary between different plants and species; make the mutagenic dose of MF vary accordingly. The common positive effect of MF was identified in several studies where the MF at lower dose stimulated seed germination and its further development [42,43]. Regardless of potential mutagenic effect of MF many plants recover and proceeded to have normal growth in later stages. Dhawi and Alkhayri, [21] reported the date palm (*Phoenix dactylifera* L.) seedling treated with MF preceded normal growth after reduction of DNA content at 1500 mT. In addition, albino plants of magnetically treated wheat (*Triticum aestivum*) turned green partly in later periods of their lifetime following 200 mT MF exposure [35].

4. STRESS REACTIONS IN RESPONSE TO MAGNETIC FIELDS

The MF treatment at a higher dose (dose>500mT) consider abiotic stress factor that induces stress response in plant system. The physiological plants system know to accumulate cellular solutes in response to abiotic stress [44-46] including quaternary amino acid derivatives such as proline, glycine betaine, alanine betaine and proline betaine [47]. Proline is the most well known stress indicator that accumulates following stress. The proline level accumulate in cells vary depending on the species and the extent of stress [48-50]. The role of proline in stress conditions is to enhance plants cellular recovery and relief stress by providing cells with carbon and nitrogen as source of energy [51]. Cellular proline accumulation in different plants species under abiotic stress has reached 80% in compare with 5% under normal conditions [52-54]. Stress response caused by MF on plants has been reported in different studies [6,36,55,56]. The release of free radical ions increased following MF exposure which disturb cellular macromolecules and their activities [56-58] and reported to damage antioxidant enzymes function in tobacco (*Nicotiana tabacum* L.) [32]. The proline involved in stabilizing macromolecules and reduce the damage of free radicals [59-62] which resulted from MF prolonged exposure. A study done by Dhawi and Alkhayri, [36] indicated that MF decreased proline accumulation in 45days old seedling date palm at 1500mT intensity. The affect of MF involved some antioxidant compounds as phenolic compounds which showed significant decrease following MF exposure. Ghanati et al. [56] reported that MF decreased phenylalanine- ammonialyase activity and phenolic compound concentration in *Ocimum basilicum.* The decrease of proline concentration or any antioxidant compounds may result of accumulation of its own by products which lead to redirection of synthesis pathway.

The 'caged reaction' theory explained the reduction of proline by oxidizing the free radicals that are enhanced during exposure to MF [57,58]. Proline consumption in 'caged reaction' oxidizes proline to various compounds [63] and this process can protect plant tissue from potential damage [62]. In addition, the proline pathway could be shifted by MF exposure, through oxidation of proline to glutamate or forming glutamic acid *g*-semialdehyde [62]. The shift of cellular metabolic pathways following exposure to MF was noted by Ghanati et al. [56] who reported that under stress of MF, plants shifted their metabolism from biosynthesis of phenolics to the production of essential oils.

5. THE EFFECT OF MF ON PLANT'S ELEMENTAL COMPOSITION

The diffusion of charged biological particles in a solution can be oriented toward MF current under the effect of Lorentz force or Maxwell stress [64]. The interaction between the external MF and the internal MF resulted from free radicals' non-paired electrons has a significant impact on the biological system [7,41]. The impact of MF energy excitation can be directed positively by distributing energy that accelerate metabolism and consequently lead to better germination [65]. MF treatment induces molecular transformation to provide cells with better condition for growth and further development. Flux and intensity and exposure period affect different plants system positively or negatively [66].

The MF effect on water molecules and electrolyte solutions approve that MF will enhance ions uptake. The cytoplasm is full of charged ions that may orient toward MF direction. Any changes of ions organization along the membrane change the cell electric potential. The MF may increase electric potential which increase the elements uptake. The adsorption and

uptake of elements affected by MF segregated electrophoretic charges [67] which stimulate elements accumulation differently.

This approved by Belyavskaya [6], study who reported that MF caused Ca over-saturation in pea [*Pisum sativum* L.] cytoplasm and organelles. The MF ability to increase Ca uptake is one of the factors that enhance plants growth and development due to Ca involvement in many growth processes and stress response [68]. Several studies [6,69,70] showed that MF increased calcium ions uptake by changing electrical conductivity, this effect increased with prolonged MF exposure. The increase of calcium ions accumulation can be also explained by its role in stress reactions to avoid further cellular damage induced by MF affect on free radicals release [68]. The accumulation of macro elements such as calcium which involved in major regulation reactions enhances plants growth and development. The MF dose ranged 10-100mT (50-60 Hz) was enough to change the plasma membrane permeability of *Vicia faba* L. tip cells and alter ion movement across the membrane [71].

This increase of membrane permeability by MF increased the content of N, K, Ca, Mg, Cu, Fe, Mn, Na and Zn but reduced P in strawberry leaves (*Fragaria* x *ananassa*) [72] and date palm seedlings (*Phoenix dactylifera* L.) [23].

Although MF has been reported to affect macromolecules uptake, the accumulation of the elements differ significantly in each plant and in the same plant different parts. In buckwheat (*Fagopyrum esculentum*) an increased was noticed in content of Mg, Fe and Cu in grain and the P, Ca, K and Zn content of straw.

The influence of MF on free radicals and elements uptake involved in many biochemical process that enhance plants seed vigor and stimulate proteins and enzyme activities [71,73]. MF increased ions content significantly with prolonged exposure treatment on date palm seedlings [23] which indicate that prolong or high dose MF exposure may irreversibly affect cell membrane permeability leading to increase elements uptake.

6. MAGNETIC FIELDS INDUCE CHANGES IN PHOTOSYNTHETIC PIGMENTS CONTENT

The energy exchange and transformation is the core of biochemical activities in biological system. The assimilatory pigment involved directly in the conversion of solar energy into chemical energy can be affected by MF. It has been found that an increase occurs in chemical reactions of plants under MF, which has a positive effect on photochemical activity, respiration ratio and enzyme activity [20,24,25,74]. Chlorophyll and carotenoids are essential photosynthetic pigments, plant health indicator and considered as stress defence mechanism. The stress induced by MF caused increasing reactive oxygen species [32,57,75] may lead to increase in carotenoids level due to its role in protecting plant system [76]. As any organic chemical structure chloroplasts have paramagnetic properties which can be affected by MF and may be oriented toward MF direction as suggested by Campbell, [77] which increase the inner energy. The MF increment of the inner energy that involved in metabolism and chemical reactions enhance growth further development. The MF has the ability to increase the assimilatory pigments level weather it used in magnetized water which increased rice chlorophyll content [78] or directly when exposing seeds or seedlings which was reported in several studies [36,38]. The MF has increased total chlorophyll content in sugar beet (*Beta vulgaris* L.) leaves [79] and content of chlorophyll a, b and carotenoids in potato (*Solanum tuberosum* L.) [80], soybean (*Glycine max* L.) [19] and chlorophyll a,b and

carotenoids in date palm seedlings [81]. In contrast longer MF exposure reported to decrease the level of photosynthetic pigments in *Zea mays* L. [37] and *Robinia pseudoacacia* L. seedlings [38]. This could be explained by MF stressful effect when prolong exposure which disturb biological system stability.

7. MAGNETIC FIELD'S INCREASE WEIGHT AND WATER CONTENT IN PLANTS

The subsequent effect of MFs on ions accumulation, photosynthetic pigments and stress reaction represented in proline accumulation will increase and accelerate plants growth. MF has a very high stimulating effect on cell multiplication, growing and development [82]. Several studies have indicated that productivity of some plants, increased in response to MF effect [65,83-85]. MF treatment increased *Triticum aestivum* seeds germination, root length, length of radicle, dry weight of root and dry weight of radicle [86]. The positive effect of the magnetic field treatment was expressed in increased germination, increased height and weight of shoots [87]. Moreover, date palm seedlings leaf fresh, dry weight and water content, increased significantly in response to MF treatment [22]. Germination, fresh and dry weight of onion, (*Allium cepa* L.) and rice, (*Oryza. sativa* L.) was increased following MF treatment [83]. In addition, MF caused acceleration of pea (*Pisum sativum*) maturation [42] and acceleration of fruits ripening was noticed in tomatoes [88]. Moreover, MF increased wheat (*Triticum aestivum* L.) and sunflower (*Helianthus annuus* L.), length and mass of growing seeds[43], fresh weights of soybean (*Glycine max* L.) seedlings [19], germination of oak (*Quercus robur* L.) seeds and their subsequent growth [84], tomato growth (*Lycopersicun esculentum* L.) [89] and corn (*Zea mays*) fresh weight and shoot length [65]. MF may act as a plant hormone and proposed to mimic auxin in plant system leading to fruit ripening and increased growth [88,90] or could activate or accelerate enzymes related to auxin reactions. The increase of plant water uptake, after MF exposure due to increase in water absorption, retention and ionization [91] The MF also reported to decrease the energy of water hydrogen bonds among its molecules [92] leading to increase in water uptake. Another explanation of increase in water uptake following MF treatment is increase in ions uptake [23] and free radical [56-58] leading to increase stress and proline accumulation [36] which changes the osmotic [93] and electric potential, as well as enhance water absorption.

8. CONCLUSION

The cellular composition, which includes electrolyte liquids, make the cell more susceptible to the magnetic field effect, due to the ability of the magnetic field to change the water's physical properties. The increase of hydrogen bonds' number in water molecules caused by MF exposure affects all biochemical reactions, including enzymatic activity. Additionally, MF increased the cells permeability and uptake ability due to increased number of active energy in cellular electrolyte solutions. This increase of active energy may contribute to some physiological activities and accelerates plant germination. However, MF is considered abiotic stress which contributes in free radicals induction. As a defense mechanism the MF stress impact is usually stabilized by an increase in photosynthetic pigments and amino acids as proline. The increase of these compounds affects the osmotic pressure and induce water uptake leading to increase in plant's biomass. Although MF effect on plant physiological system has been studied extensively, there is a gap in our knowledge to understand of how plant's proteins and DNA may modify after MF exposure. Is the increase in plants biomass related to increase in cell reproduction or cells size? All these questions are crucial to better understand the MF molecular and cellular effect.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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