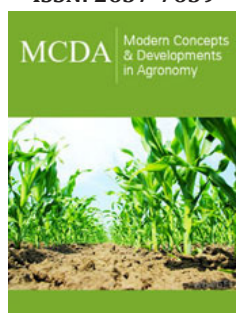


Effects of Magnetic Fields on the Vegetative Growth of Garlic (*Allium Sativum* L.) Cloves

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ISSN: 2637-7659



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Submission: 📅 November 20, 2024

Published: 📅 December 05, 2024

Volume 14 - Issue 5

How to cite this article: Yiyuan Zhang and Nguyen Hue*. Effects of Magnetic Fields on the Vegetative Growth of Garlic (*Allium Sativum* L.) Cloves. Mod Concep Dev Agrono. 14(5). MCDA. 000848. 2024. DOI: [10.31031/MCDA.2024.14.000848](https://doi.org/10.31031/MCDA.2024.14.000848)

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Abstract

This study investigates the effects of Magnetic Fields (MF) on the vegetative propagation of garlic cloves (*Allium sativum* L.) with focus on sprouting rates, root mass, and lodging incidents. The effects of constant exposure to different magnetic poles (magnetic field direction) were also examined. The magnetic field strength was 174mT for the north-seeking pole and 177mT for the south-seeking pole. There were four treatments with 3 replications per treatment: non-magnetized water (control), magnetized water, north-seeking pole of the magnet exposed, and south-seeking pole exposed. The results show that the magnetized water treatment had a 15.9% increase in root mass, higher sprouting rate (16% vs. 4.5%), and lower lodging rates (0% vs. 9%) as compared to the control. The north-seeking pole (upward direction) significantly enhanced both sprouting speed and shoot growth compared to the south-seeking pole (downward direction) and the control. While the south-seeking pole also outperformed the control in sprouting speed and shoot growth, it promoted more robust root development relative to the north-seeking pole and the control. It is speculated that magnetic fields could affect unpaired electrons and thus reactive oxygen and nitrogen species resulting in increased nitric oxide levels, which in turn help root and seedling growth. Magnetic fields may also influence DNA replication and gene expression.

Introduction

All living organisms are naturally exposed to Electromagnetic Fields (EMF), and such fields appear to interfere with biological processes at various scales. In fact, the Earth's surface and ionosphere act as spherical-layer concentric conductors connected electrically by air, which act as a weakly conducting capacitor as shown in Figure 1. Utilizing this natural electromagnetic background energy to improve agricultural production can date back to the 18th century, when the influence of atmospheric electricity on plants' organisms was first discovered Bertholon [1] & Elektrokultur [2]. Using Magnetic Fields (MF) or Electro-Magnetic Fields (EMF) has been proposed as a non-chemical alternative for agricultural improvements [3,4]. More recently, instead of applying EMFs to living organisms, the direct application of EMFs to water for agricultural production [5], especially with the magnetic fields on irrigation water, showed promising results [6]. MF-treated water enhanced germination and plant growth [7-9]. In this experiment, we examined the effects of the magnetized water and different magnetic poles on sprouting rate, root weight, and lodging incident of garlic cloves (*Allium sativum* L.).

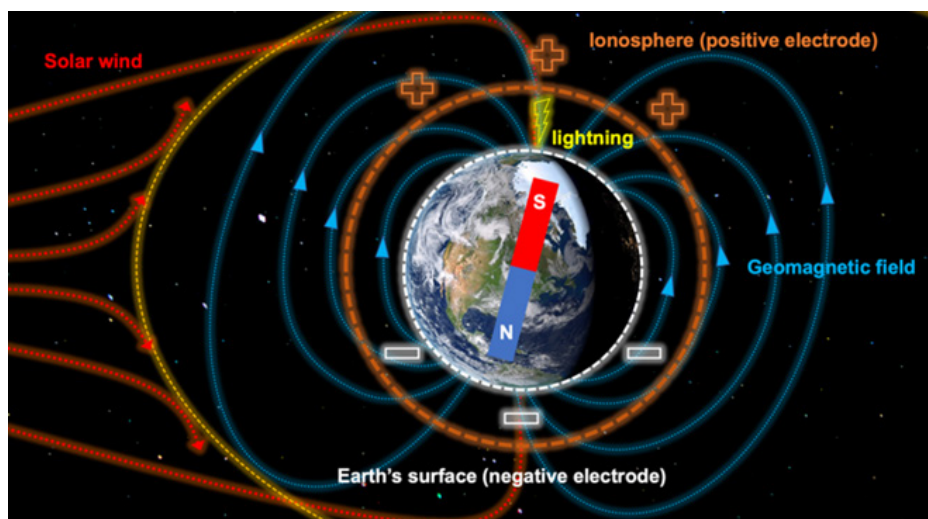


Figure 1: Solar activity, geomagnetic field and Ionosphere.

Experimental Design

The experiment consisted of 4 treatments (1) Non-magnetized water (control), (2) Magnetized water, (3) North-seeking pole of the magnet exposed, and (4) South-seeking pole of the magnet

exposed (Figure 2). Each treatment was replicated 3 times, in a completely randomized design. Statistics and figures in this study were generated using R statistics (statistical plots) and PowerPoint (schematic diagrams).

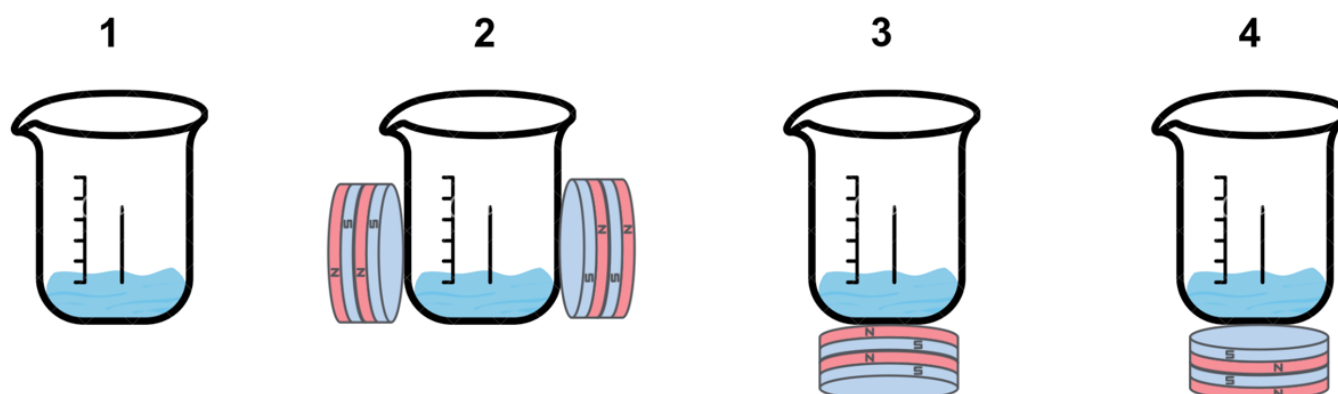


Figure 2: The set-up of the four treatments showing magnet positions..

Experimental Procedures

α. Water magnetization

- A. 600ml of tap water was poured into a 1000ml glass container with a bottom radius of 4.5cm and a height of 17cm, and the container was then sealed with its metal cover.
- B. The container was then placed between four N52 grade neodymium magnets (40x40x20mm for each) with two magnets adhered in an attracting configuration on each side. On one side, the north-seeking pole of the magnet faced the container, and the south-seeking pole faced the container on the other side.
- C. The container was then left in place to let the magnetic field interact with the water inside, and after 2 hours at room temperature of 27 °C, the magnetized water was added into

the plastic container, which has garlic cloves inside.

β. Magnetic polarity

- A. Two N52 grade neodymium magnets adhered in an attracting configuration (40x40x20mm for each) were placed under the bottom of the plastic bottle after cutting, which was filled with tap water. The plastic bottle has a bottom radius of 3cm, and the vertical distance between the garlic and the surface of the magnets is 4cm. The north-seeking pole was facing up to the bottom of the plastic bottle. The magnetic pole facing up was different for the other group.
- B. The magnetic field exposure was constant for 7 days, which means the magnets were under the bottom of the plastic bottle through the experiment.

γ. Magnetic field strength and magnetic flux

The magnetic field strength and the resulting magnetic flux were analyzed due to the non-uniform magnetic field generated by the magnets. The magnetic field strength of two adhered neodymium magnets was measured with a handheld Gauss meter. The field strength was measured when the probe was positioned directly at the geometric center of the magnet's north/south pole surface. The sensor was parallel to the surface of the magnet; therefore, the sensor was perpendicular to the magnetic field lines. The field strength was 174.22mT (N) and 177.35mT (S) (Tables 1 & 2).

Table 1: Data collection for calculating the magnetic flux for water magnetization.

Grid #	Layer	Coordinates	$A_i(m^2)$	$B_i(T)$	$\Phi_{B,i}(Wb)$
1	1	(x1, y1)	0.000472	0.01547	$7.29411e^{-6}$
2	1	(x2, y1)	0.000472	0.03039	$1.43289e^{-6}$
3	1	(x3, y1)	0.000472	0.01455	$6.86033e^{-6}$
4	2	(x1, y2)	0.000472	0.02022	$9.53373e^{-6}$
5	2	(x2, y2)	0.000472	0.03005	$1.41686e^{-6}$
6	2	(x3, y2)	0.000472	0.02126	$1.00241e^{-6}$
7	3	(x1, y3)	0.000472	0.00834	$3.93231e^{-6}$
8	3	(x2, y3)	0.000472	0.01422	$6.70473e^{-6}$
9	3	(x2, y3)	0.000472	0.0082	$3.8663e^{-6}$

Table 2: Data collection for calculating the magnetic flux for direct magnetic polarity.

Ring #	$r_{inner}(m)$	$r_{outer}(m)$	$A_i(m^2)$	$B_r(T)$	$\Phi_{B,i}(Wb)$
1	0	0.005	0.00007854	0.02025	$1.59044e^{-6}$
2	0.005	0.01	0.000235619	0.01939	$4.56865e^{-6}$
3	0.01	0.015	0.000392699	0.01844	$7.24137e^{-6}$
4	0.015	0.02	0.000549779	0.01667	$9.16482e^{-6}$
5	0.02	0.025	0.000706858	0.01436	$1.01505e^{-6}$
6	0.025	0.03	0.000863938	0.01164	$1.00562e^{-6}$

The magnetic flux was calculated by the equation below. To account for the non-uniform magnetic field, the magnetic flux surface was divided into smaller sections to account for variations in field strength (B_i). The total magnetic flux (Φ_B) was calculated by summing the contributions from smaller sections of the surface. The magnetic field lines were considered as perpendicular to the surface ($\cos(\theta_i) = 1$). For water magnetization, the magnetic flux surface (side surface of the water body) was divided into nine grids arranged in three horizontal layers from top to bottom, with three grids per layer. For direct magnetic field exposure with different polarities, the magnetic flux surface (the circular base of the container) was divided into six concentric rings where r_{inner} represents the inner radius and r_{outer} represents the outer radius. The detailed calculation process for magnetic flux with the collected data is provided in the appendix for reference. As a result, the magnetic flux for water magnetization is $7.6713e^{-5}$ (Wb), and the magnetic flux for direct magnetic exposure is $4.2772e^{-5}$ (Wb).

$$\Phi B = \sum \Phi_{B,i} = \sum (B_i \cdot A_i \cdot \cos(\theta_i))$$

Result

α. Water magnetization

After five days, the number of distinctive sprouted garlic cloves were different for the two treatments with 16% sprouting for magnetized water treatment and 4.5% for the control (Figure 3). After five days, the fresh root weight (clove weight excluded) of each sample was collected. Since the size of the garlic cloves varied, the number of cloves required to fill the same container differed between samples. To account for this variation, the fresh root weight of each sample was adjusted by multiplying it by the ratio of the target number of plants to the actual number of plants. Figure 4 shows the fresh root weights of the two treatments. Compared with the control, magnetized treatment has visible improvement in the development of root mass. The magnetized water treatment had average fresh weight of 2.92g (3.08g, 2.71g, 2.97g) with some variability among the samples, and the control had a lower average outcome of 2.52g (2.24g, 2.64g, 2.68g).

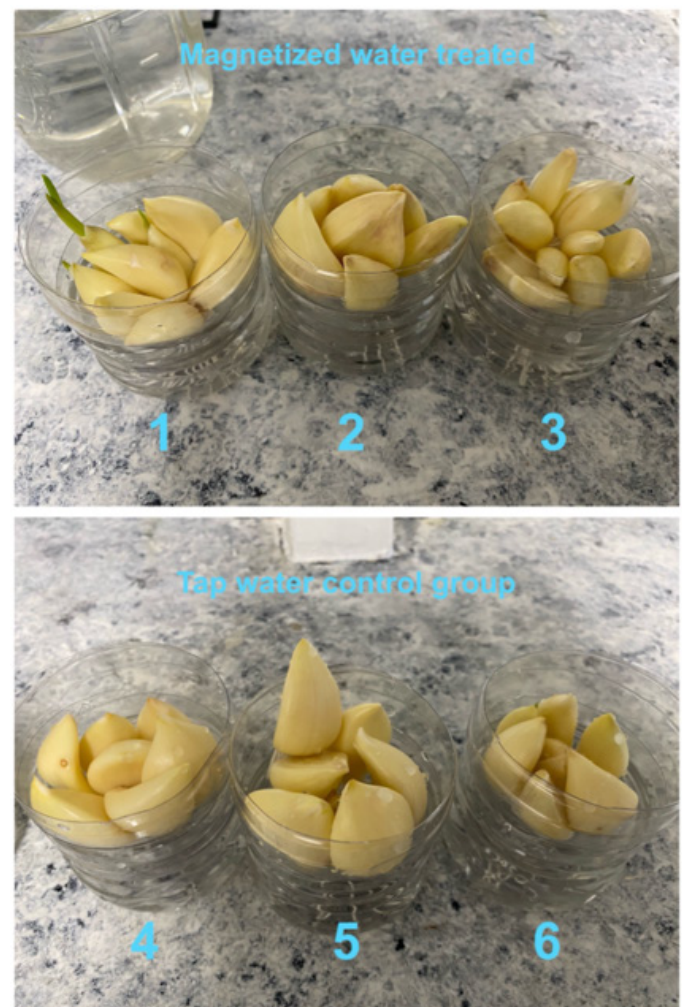


Figure 3a: Sprouting of garlic cloves treated with magnetized and non-magnetized water.

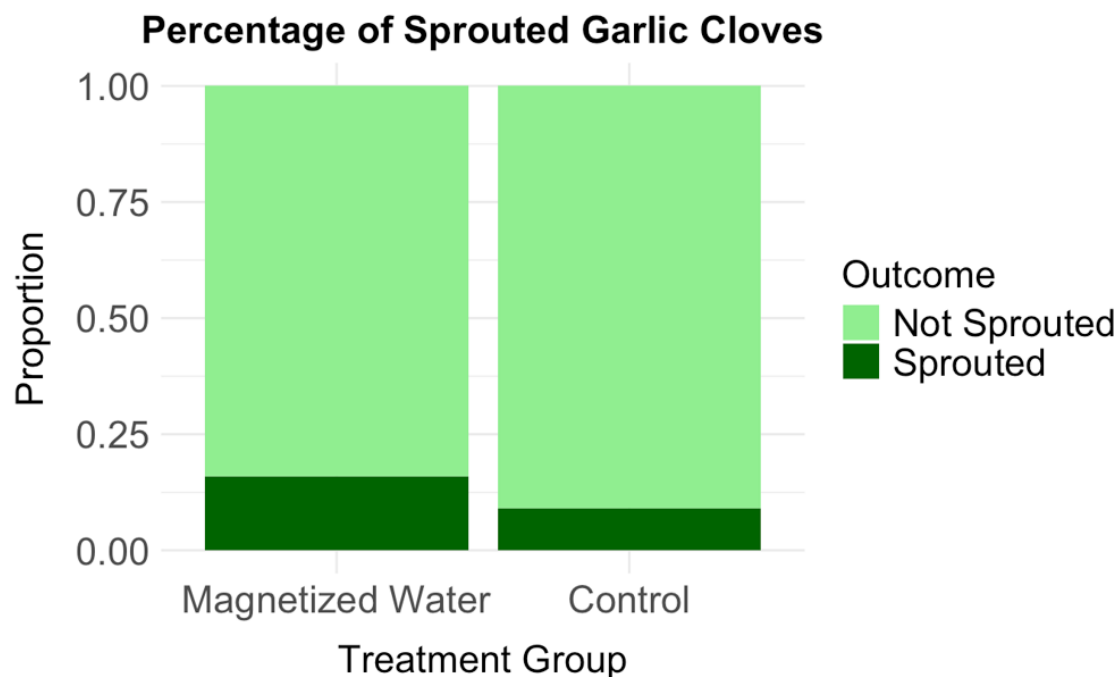


Figure 3b: Sprouting of garlic cloves treated with magnetized and non-magnetized water.

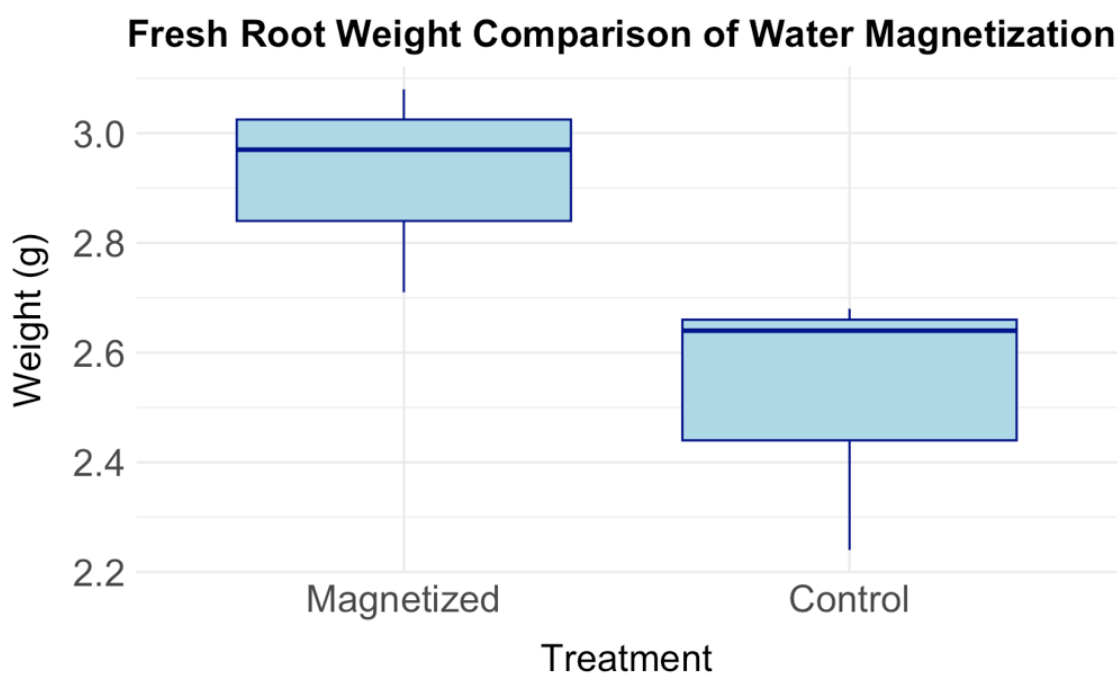


Figure 4: Fresh root weight comparison between magnetized and non-magnetized water treatments.

After 15 days, the magnetized water treatment exhibited robust upward growth and showed no sign of lodging. In the control, 9% of plants are severely lodged (Figure 5).



Lodging Comparison of Garlic Sprouts

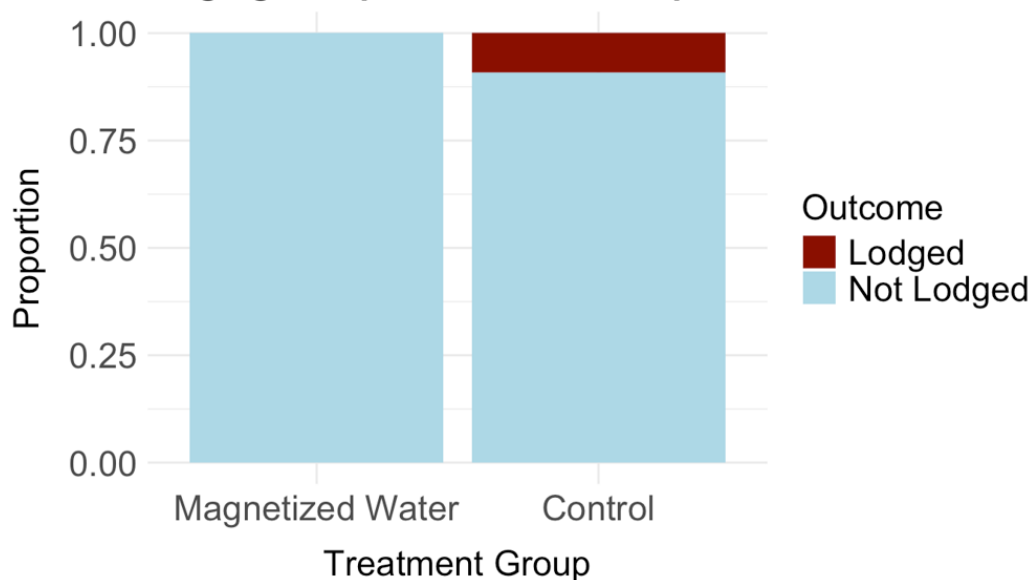


Figure 5: Lodging comparison between two treatments: Samples 1, 2, 3 were treated with magnetized water and samples 4, 5, 6 treated with non-magnetized water.

β. Magnetic polarity

Though not well studied in the agricultural field, the magnetic poles do have different effects on living organisms [10]. For example, the north-seeking pole significantly reduced cell numbers

in human solid tumor cells and inhibited tumor growth in mice; the south-seeking pole showed little to no effects, while both the north- and south-seeking poles inhibited leukemia cells [11]. Therefore, the long exposure to different magnetic poles was also

investigated in this study. Our results showed that the exposure to the north-seeking pole significantly increased sprouting speed and shoot growth, while the south-seeking pole also outperformed the control in sprouting speed and shoot growth (Figure 6). Although the south-seeking pole's enhancing effects on sprouting speed

and shoot growth were less than the north-seeking pole, the enhancement on the root formation is more obvious: Roots under south-seeking pole exposure were denser and more robust (Figure 7).

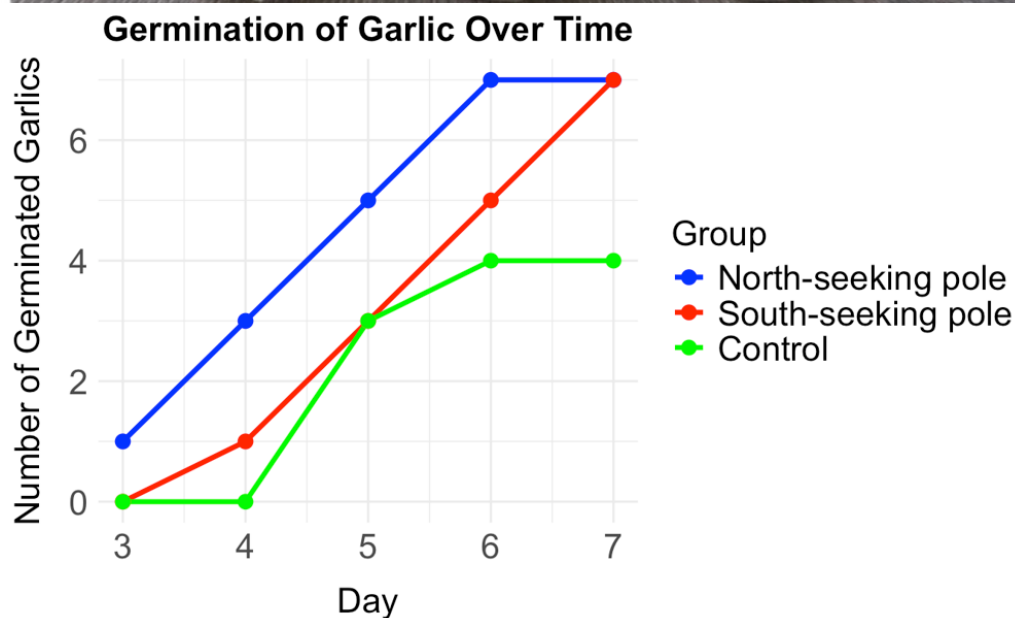
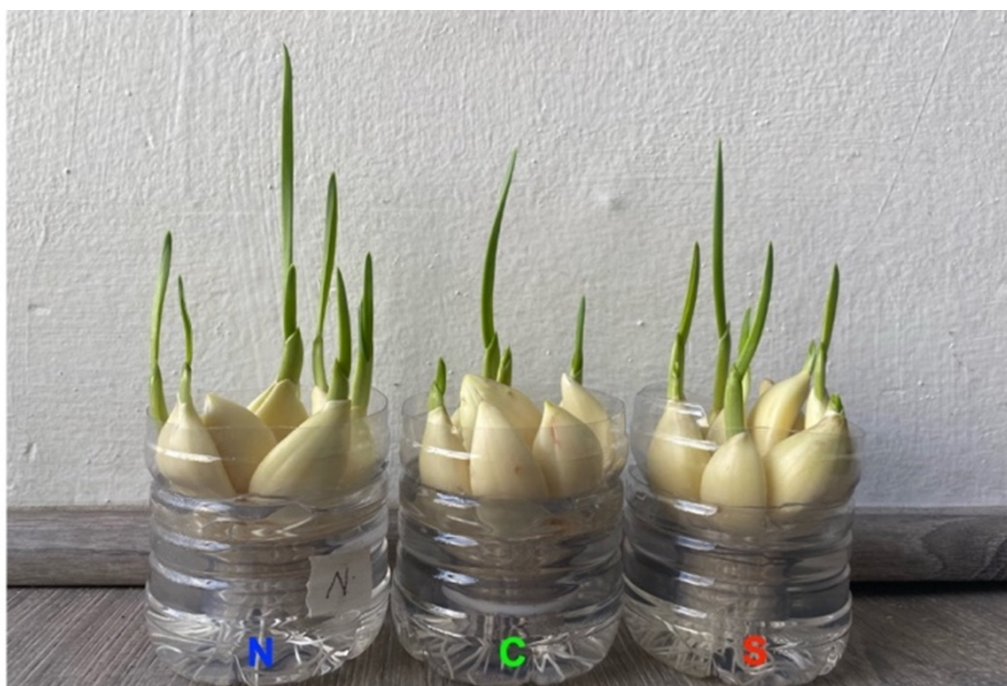


Figure 6: Germination counts over time under north seeking, control, and south seeking treatments.



Figure 7: Root formation under long exposure to south-seeking and north-seeking poles.

Discussion

Recently a few studies have shown that Static Magnetic Fields (SMF) can induce considerable effects on biological systems [12]. More specifically, the effects of SMF on seed germination, seedling development, and plant yield have been reported (Chadapust et al. [13]; Nyakane et al. [14] and Rifna et al. [15]). Factors such as polarity (magnetic field direction), intensity, exposure time, device magnet type, and genotype-dependent effect can influence plant development positively or negatively [12,16]. In an elaborate study, Sestili et al. [17] reported that the use of magnetized water led to higher root elongation in both durum wheat (*Triticum durum*) and lentil (*Lens esculenta*). Using gas chromatography coupled with mass spectrometry analysis, the authors further showed that SMF treatments affected several metabolites in both seeds and roots, including organic acids (oxalic, citric, malic, maleic, succinic, fumaric), amino acids (valine, proline, serine), sugars (glucose,

sucrose, fructose, maltose), fatty acids (decanoic, octadecanoic, docosanoic).

On the molecular and cellular levels, it has been speculated that SMF can control the state of electrons, manipulate the unpaired electrons in free radicals, thus potentially modulating Reactive Oxygen Species (ROS) and Reactive Nitrogen Species (RNS) in cells [18,19]. SMF influence on cellular Nitric Oxide (NO) levels has been implicated in increased growths of roots and seedlings [19]. Additionally, DNA synthesis has been shown to be differentially regulated by SMF and their N-S directions [20]. Since DNA is negatively charged and undergoes fast rotation to get winding and unwinding during replication, the externally applied SMF would affect the DNA openness through Lorentz force, resulting in differential effects on DNA synthesis and perhaps gene expressions (Figure 8).

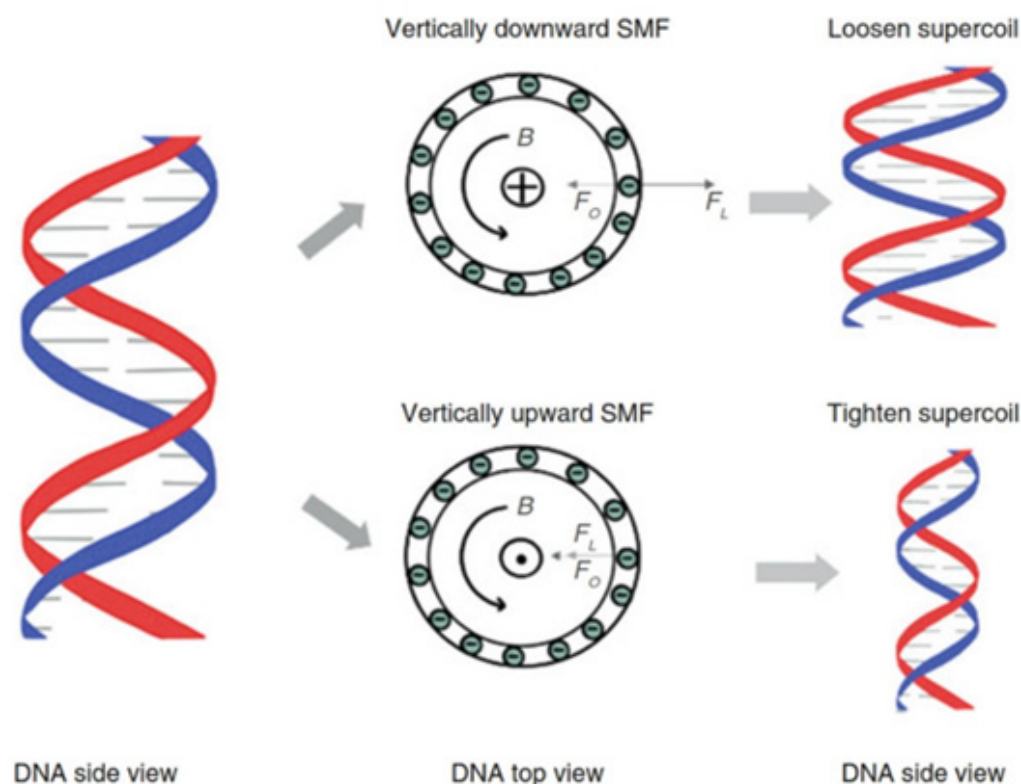


Figure 8: DNA openness as affected by Static Magnetic Fields (SMF). (Left and right) side view of DNA, (middle) top view of DNA cross section. For downward and upward SMFs, the Lorentz force (F_L) of negatively charged DNA has different directions. F_o is an endogenous centripetal force determining DNA rotation. Arrows indicate rotation directions. (Adapted from Yu and Zhang [20]).

Conclusion

The magnetized water treatment can significantly increase root mass, sprouting rate (16% vs. 4.5%), and lower lodging rates (0% vs. 9%) relative to the non-magnetized water control. The north-seeking pole notably enhances both sprouting speed and shoot growth while the south-seeking pole exposure has more obvious effect on root development compared with the north-seeking pole and control. The magnetic field has the potential as a low-cost, easy-to-practice method for cleaner production. However, for large scale magnetization of irrigation water, more effective methods need further investigation. The north-seeking pole and south-seeking pole exposure may have varied effects on different plants, but if the enhancement on root formation effect is consistent across plants, the south-seeking pole can be used as valuable practice for plant propagation in agricultural production. In a recent literature review, Bernard et al. [21] called for establishing magnetic exposure protocols for different plant species, that would enhance beneficial bioactive compounds as reported by Lockett [22]. In our study, it was observed that different magnetic poles had different effects on the growth of garlic cloves, suggesting the important role of magnetic field directions in plant developments.

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