**COVER PAGE**

1. **Growth characteristics of chili pepper (*Capsicum annuum*) under the effect of magnetizing water with neodymium magnets (NdFeB)**

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**Requirements for the candidates:**

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**Growth characteristics of chili pepper (Capsicum annuum) under the effect of magnetizing water with neodymium magnets (NdFeB)**

**ABSTRACT**

This study aims to identify the impact of magnetized water on growth characteristics of chili pepper (*Capsicum annuum*) plants. A total of 80 chili seeds were divided into four groups: the first group was watered with normal tap water, while the three groups were watered with water magnetized using 3, 6 and 9 neodymium magnets (NdFeB) respectively. The findings revealed that magnetized water caused changes in the study parameters. Despite the plants watered with magnetized water were taller than those watered with normal tap water, there were no significant differences between the four groups (p=0.224). The results revealed that stem thickness of chili peppers is fairly affected by the magnetized water. There was no significant difference between the four treatments (p=0.218). The current study found that the number of leaves is significantly influenced by watering with magnetized water (p=0.015). The leaves of chili peppers watered with water treated with 6 magnets (74.50±13.57) were the highest and those watered with non-magnetized were the lowest in number (60.00±6.09) among four groups. The effect of magnetized water relies on the number of magnets utilized for magnetizing water.

**KEYWORDS:** Magnetized water, magnetic fields, chili pepper (*Capsicum annuum*) plants, neodymium magnets.

**INTRODUCTION**

During the current years, the agricultural efforts are shifting to an effective and environmentally clean technology based on physical treatment of the plants or their seeds to increase the seedling vigour and crop production. The previous studies showed that exposure to suitable magnetic fields is one of the affordable physical treatments to enhance the growth of plants (Khade & Avinash, 2018; Vashisth & Joshi, 2017; Radhakrishnan, 2019). The impacts of the magnetic field on biological systems, especially on the growth of plants and germination of seeds and, have been attracted to the attention of scientists in this field. Magnetic fields were found to affect germination rate, seed vigour, seedling growth and yield (Maheshwari & Grewal, 2009; Nyakane et al., 2019; Mroczek-Zdyrska et al., 2020).

There are many factors affecting plant growth and development such as exposed to electromagnetic radiation (Alattar et al. 2017 & 2020b) and magnetic fields (Podleśna et al., 2019). Directly exposed to plants or their seeds to magnetic fields have been extensively studied in the last years. However, little interest has been paid to the impact of water magnetized water on the growth characteristics of plants. Passing water through magnetic field resulted in producing magnetic, magnetically treated water, magnetized or magnetic water (Higashitani et al., 1993). The previous studies revealed that a low magnetic field can change the water to be magnetized (Ji et al., 2007). As a result of magnetization, water properties including physical, chemical, physicochemical and biophysical properties change such as salt solution capacity, density, viscosity, freezing and boiling points, surface tension, electrical conductivity, hydrogen bond formation, pH, water molecule size, and dielectric constant (Chang & Weng, 2006; Amiri & Dadkhah, 2006; Ji et al., 2007).

Most of the previous studies have widely discussed the response of living systems to low, moderate as well as strong magnetic fields (Saunders, 2005; Pazur et al., 2007; Zablotskii et al., 2016). Despite many studies have been carried out concerning the influence of directly or indirectly exposed to magnetic fields on biological materials, the exact effect of magnetic fields is still under examination (Chibowski, 2018). According to the literature review, the impact of exposure to magnetic fields is not identical. Some papers show an inhibitory effect by the magnetic fields, whereas, others show activation and still others no significant effects on the biological materials. The different effects of the magnetic field on exposed plants produce from several factors such as the intensity of the magnetic field, polarity, type of magnets, flowing water, exposure time, type of water sample, the pathway length in the magnetic field (Podsiadło & Skorupa, 2017). Moreover, plant species is considered one of the main factors affected by a magnetic field, so the magnetic field should be tested individually on desired plants before going on a larger scale (Zaidi et al., 2014; Surendran et al., 2016).

Magnetized water has a beneficial impacts on germination rates of seeds (Matwijczuk et al., 2012; Patile, 2014); percentages of emergence (Podleoeny et al., 2004), root growth (Turker et al., 2007), seed yield (Selim & El-Nady, 2011), moving of nutrients from fertilizers to soil (Hozayn and Abdul Qados, 2010), plant yield (Maheshwari & Grewal, 2009; Patile, 2014), as well as water-holding capacity of the soil (Al-Khazan et al., 2011). In addition, Mousa et al. (2013) observed enhanced absorption of nutrient, increased in production of endophyto-hormones and higher osmotic pressure for plants watered with magnetized water. It was found that magnetized water helps plants to overcome the bad effect of water deficit (Selim & El-Nady, 2011). Moreover, using magnetized water helps to increase the soil moisture and reduce the deep percolation, and thus decrease the irrigation intervals (Khoshravesh et al., 2011; Mostafazadeh-Frad et al., 2012; Surendran et al., 2016).

To date, studies on using magnetized water in the watering of plants, especially chili pepper, are still rare. So, the current study aimed to identify the eﬀect of magnetized water on plant growth of chili plants cultivated in the Gaza Strip, Palestine.

**MATERIALS AND METHODS**

**STUDY SITE**

It should mention the time and place of research in the first part. The study area is located in Shuja'iyya, which is a neighbourhood district of Gaza. It is located east of Gaza, which lies between North latitudes 31◦25 and East longitudes 34◦20. The district has a hot semi-arid climate with dry hot summers and mild rainy winters. Spring season extending from March to April and the hottest months are July and August, with the average high being 33°C. The coldest month is January with temperatures usually at 18°C. The average annual rainfall is 390 mm and falls between November and March. The study started in Jun 2019 for 43 days at a field in East Gaza.

**MAGNETIC TREATMENT**

In this study, we preferred to design our magnetic equipment in laboratory conditions. Normal water was taken and then separated into four parts. The first part of the water was not magnetized and given control group, while the remaining parts were magnetized and given to treated groups. The block diagram of this study illustrates in the flow chart as shown in Figure 1. The system prepared for the preparation of magnetized water composed of pipelines that hold the water and provide a surface that magnets can touch it. We used 4 pipes and 18 Nickel-plated neodymium magnets for this system. We selected a polyvinyl chloride (PVC) pipes with a length of 270 mm and a diameter of 15 mm. The magnets used in this study had an ellipse shape (30 mm length x 15 mm diameter) with a magnetic flux density of 70 mT. All magnets were identical and have the same size, shape, and strength. Neodymium magnets are preferable due to their remarkable strength and easy accessibility.

**Tap water**

**Part 1**

Was not magnetized

Was given to group I

**Part 2**

Magnetized using 3 magnets

Was given to group II

**Part 3**

Magnetized using 6 magnets

Was given to group III

**Part 4**

Magnetized using 9 magnets

Was given to group IV

Figure1 Block diagram of the experimental setup.

For the first pipe, which corresponds to the control group of the experiment, no magnets are used. For all of the other groups that have magnets, the pipes with magnets were built up correctly. The second pipe was fitted with 3 magnets. The third and fourth pipes were fitted with 6 and 9 magnets respectively. The magnets are stuck on the inner sides of the pipes. Bi-Polar water was prepared by placing high powered magnets side-by-side at a distance of at least (5-10 mm) apart. The polarity of the magnets was taken into consideration, where the south and north poles of the magnets on the treatment pipe seat were alternated. This procedure is necessary to ensure that opposite poles face each other and produce the required magnetic field between the two poles and thus, effectively treat water by the magnetic field (Pazur et al., 2007). The magnets were placed at the end which is nearest to the plant at distance was 100 mm. The installation of the magnets inside the pipelines system was shown in Figure 2. After all, the pipe was ready, they were placed in the field with the same containers to watering the plants.

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Figure 2 Magnetizing water system. (A) non-magnetized water. (B), (C) and (D) Magnetized water with 3, 6 and 9 magnets respectively.

**FIELD EXPERIMENT**

A total of 80 chili pepper seeds were purchased from a local farm in East Gaza. Corn seeds having viability of 45%, healthy and uniform-sized without insect damage, visible defect and malformation were chosen and divided into four groups in a randomized complete block design. The chili pepper seeds were sterilized with a 1% sodium hypochlorite and then washed with sterile distilled water. According to agricultural specialist guidelines, the chili pepper seeds were then correctly placed in the soil field. The tested seeds were chosen due to the lack of papers that study the response of chili pepper to magnetized water with a different magnetic flux density. Furthermore, they grow during the study experiment. Also, it is easy to transfer chili pepper plants from the field to the laboratory and conduct the desired analysis.

All of the remaining variables were maintain constant. Also, a constant watering time was maintained to reduce unexpected variables that affect the growth of chili pepper plants, therefore the treatment and watering times were correctly scheduled. During the study, the tested plants were fertilized with 13-13-13 NPK fertilizer, which added as recommended by Haifa NutriNet™ company (Nutritional recommendations for pepper, 2019). Table 1 illustrated the nutrient content of fertilizer. Throughout the present study, the plants were also treated with Roger pesticides, where all chili peppers got the same amount at the same time.

At the end of the study, shoot length, stem thickness, and the number of leaves/plant were recorded. Thickness and length of plants were measured using a capillary and ruler, respectively. These variables were selected because they show the status of growth of chili pepper plants under the tested condition. The investigated variables are good criteria to interpret the changes induced by magnetically treated water whether indirectly or directly method.

Table 1 The nutrient content of 13-13-13 NPK fertilizer used in this study

|  |  |  |  |
| --- | --- | --- | --- |
| **Item** | **Nutrient** | **Quantity** | **Unit** |
| Main components | Nitrogen (N) | 13 | % |
| Phosphorus oxide (P2O5) | 13 | % |
| Potassium oxide (K2O) | 13 | % |
| Trace element | Iron (Fe) | 500 | ppm |
| Manganese (Mn) | 250 | ppm |
| Zinc (Zn) | 75 | ppm |
| Copper (Cu) | 55 | ppm |
| Molybdenum (Mo) | 35 | ppm |

**STATISTICAL ANALYSIS**

The Statistical Package for the Social Sciences (SPSS) software, version 22 was used to analyze the obtained data. The data were presented as mean ± standard deviation. The comparisons of means between four treatments were carried out by one-way analysis of variance (ANOVA) followed by Tukey test for pairwise comparisons. A p-value <0.05 was considered a statistically significant difference for all the statistical tests.

**RESULTS AND DISCUSSION**

The influence of magnetized water was investigated by the growth characteristics of chili pepper plants. The findings showed that magnetized water changed the growth of treated plants during the whole time of research duration. The overall results are presented in Table 2.

**Effect of magnetized water on shoot length**

The results showed that the length of treated plants was found different depend on the type of irrigation water. Every seven days, the shoot length of chili peppers was measured in all groups until the last day of the study. Figure 3 compares the mean shoot length of plants grown in the fourth group.

Figure 3 Mean shoot length of chili pepper plants through the present study.

On day 43, it was noticed that the magnetized water had a similar trend respecting plant lengths. The results revealed that the shoot length of chili peppers is fairly influenced by the magnetized water. Among four treatments, plants in the M6 group recorded the higher plant length (73.83 ± 11.30 cm) and the lowest was found in the control group (59.80 ± 5.93 cm). Although the plants watered with magnetized water were taller than the plants watered with non-magnetized water, there were no significant differences between the four groups (p = 0.224).

Table 2: Effect of magnetized water on the growth of chili pepper plants

|  |  |
| --- | --- |
| Irrigation Treatment | **Parameters (Mean ± SD)** |
| **Shoot Length (cm)** | **Stem Thickness (cm)** | **Number of leaves** |
| ANOVA | NS | NS | \* |
| Multiple range test Tukey |
| Control | 63.00±5.93 a | 1.82±0.22 a | 60.00±6.09 c |
| M3 | 69.83±8.58 a | 1.90±0.25 a | 74.16±3.85 a |
| M6 | 73.83±11.30 a | 1.78±0.22 a | 74.50±13.57 a |
| M9 | 71.00±3.39 a | 2.10±0.31 a | 73.00±3.39 ac |
| NS= Not significant, \* significant at p < 0.05. Means followed by the same letter within the same column were not significantly different (p < 0.05), according to Tukey’s least significant difference test. Control: non-magnetized tap water; MW3, MW6 and MW9, water treated with three, six and nine magnets, respectively.  |

This finding was in accordance with the finding reported in the study of Alattar et al. (2020a), they carried out a study to identify the impact of magnetized water on the growth of pepper (Capsicum annuum). They selected one-week-old pepper plants and separated them into four groups. The first group was given non-magnetized water and the rest groups were given magnetized water (magnetized with at 3, 6, and 9 magnets). They found that magnetized water has no effect on the length of treated plants.

On the contrary, these results disagree with that reported in the previous studies, which found either inhibition or a stimulatory effect of magnetized water on shoot length of treated plants. For example, Ahamed et al. (2013) conducted a study to investigate the effect of the magnetic field on the growth of sweet pepper (Capsicum annuum). Pepper seeds or irrigated water (separately or together) were passed through a magnetic funnel. They found that the growth parameters were increased in the treated plants when comparison to plants in the control group. They revealed that the magnetic field is a good way for the pre-sowing treatment of the seeds that enhance their growth. In addition, the similar stimulatory effect of magnetized water on shoot length was obtained on different crops such as barley (Martinez et al., 2000), cowpea (Tahir et al., 2010), soybean (Shine et al., 2011; Radhakrishnan & Kumari, 2012), garden pea (Iqbal et al., 2012), Tomato (Feizi et al., 2012), brinjal (Sadeghipour & Aghaei, 2013), cucumber (Shahin et al., 2016), chickpea (El-Zawily et al., 2019), Corn (Alattar et al., 2019) and pepper (Ahamed et al., 2013). They found that magnetized water increased shoot length of treated plants. On contrast, different results have been reported in wheat (Triticum aestivum) cultivars: Sakha 93, Masr 1 (Almaghrabi et al., 2012) and NR-234 (Ijaz et al., 2012). They showed that the plants watered with magnetically treated water had lower shoot length than that of control.

Moreover, some studies found a negative impact of magnetized water on plant length such as Ijaz et al. (2012), they carried out a study to assess the influence of magnetized seed and magnetized water on wheat seeds. They showed that the length of treated plants (watered with magnetized water in different passing times) were lower than the length of those watered with non-magnetized water.

The stimulatory or inhibitory impact of magnetized water on the length of pepper plants may be due to the impact of treated water on protein formation, biochemical process, and activities of enzymes. It was proposed that the magnetic field stimulates root development and plant growth. These modifications may be due to the fact that the magnetic field interacts with ionic fluxes through the cell membrane which induces changes in the mechanism of osmotic pressure, ionic concentrations, and water uptake (Aladjadjiyan, 2002; Atak et al., 2007). The magnetic field also influences on soil/water interface and lead to destabilization of gas bubbles, therefore upsetting the balance of ions between the shell of absorbed negative ions and counter ions (Hilal & Hilal, 2000).

**Effect of magnetized water on stem diameter**

The results of this study showed that stem thickness (diameter) changed when watering chili peppers with magnetized water when compare with plants in the control group. An increase in the stem diameter of plants which watered with magnetized water when compared to other counterparts in the control (Figure 4).

At the end of the experiment, using 9 magnets for magnetizing water obtained the highest increase in stem diameter (2.10 ± 0.31cm), while using 6 magnets obtained the lowest (1.78 ± 0.22 cm) when compared with plants in the rest groups. Analysis of the obtained results revealed that there was no significant difference among the four treatments (p = 0.218).

The similar result was obtained on different plants such as pear plants (Osman et al., 2014). The study found that the stem diameter didn’t change when watering pear plants with magnetized water. On the contrast, different results were obtained on different crops such as corn (Alattar et al., 2019), mustard plants (Jogi et al., 2015), tomato (Yusuf & Ogunlela, 2015 & 2017). They showed that watering plants with magnetized water positively affected on stem diameter, where plants in magnetized water showed significantly increased in their diameter as compared to plants which watered with non-magnetized water.

Figure 4 Mean stem diameter of chili pepper plants through the study

**Effect of magnetized water on the number of leaves/plant**

The results which are presented in Figure 5 showed the impact of magnetized water on the number of leaves for each group during the current study. The current study revealed that the number of leaves is significantly affected by watered with magnetized water (p = 0.015). The leaves of chili peppers plants watered with magnetized water were more in number when compared to plants watered with non-magnetized water. At the end of the study, the leaves of chili peppers watered with water treated with 6 magnets (74.50 ± 13.57) were the highest and those watered with non-magnetized were the lowest in number (60.00 ± 6.09) among four groups (Table 2).

These results are in accordance with that obtained in other plants such as strawberry (Eşİtken, 2003), pear (Osman et al., 2014), and corn (Alattar et al., 2019). They found that the number of leaves/plant was significantly influenced by irrigation with magnetically treated water, where plants in magnetized water showed an increase in the number of leaves per plant as compared to plants watered with non-magnetized water. El-Gizawy et al. (2016) found that the treated potato plants with magnetic field resulted in a higher number of leaves/plant. The findings are also in agrrement with that obtained results in the study of Marks & Szecowka (2010) on potato and Ahamed et al. (2013) on sweet pepper. They found that magnetizing seeds produced plants with a higher number of leaves when compared to plants derived from non-magnetizing seeds. Also, Surendran et al. (2016) found that magnetized water increased the number of leaves when compared to plants in the control group.

Figure 5. Mean of number of chili pepper leaves during the study period

The changes of chemical and physical characteristics of water after magnetizing it may result in accelerated the biological activity of treated plants and therefore affected the growth of plants including the number of leaves per plant. The improvement of vegetative variables including the number of leaves in plants watered with magnetized water may be due to an increase in the concentration of photosynthetic pigments (i.e. chlorophylls and carotenoids) and protein biosynthesis, activations of hormones and enzymes, and enhancement in the transportation and mobilization of nutrients. It was reported that the magnetic field caused various modifications in the transport properties of cellular membranes, which play a key role in regulating the assimilation of the nutrients required for its functioning. The previous changes provided a significant amount of assimilates required for vegetative growth and thus increase the total number of leaves in treated plants (Leelapriya et al., 2003; Dhawi & Al Khayri, 2009; Maheshwari & Grewal, 2009; Radhakrishnan & Kumari, 2012; Surendran et al., 2016).

**CONCLUSIONS AND SUGGESTION**

The present study was carried out to identify the impact of magnetized water on the growth of chili pepper plants. The results showed that the magnetized water caused changes in some growth characteristics of chili pepper plants. Watering chili peppers with magnetized water significantly affect the growth parameters such as the number of leaves, where the leaves of plants watered with magnetized water were more in number when comparison to plants watered with non-magnetized water. Although the plants watered with magnetized water were taller and thicker than those watered with normal tap water, there were no significant differences between the four groups. The impact of magnetized water depends on the number of magnets used to magnetizing water. Therefore watering with magnetized water can be used as a safe method to improve some growth characteristics of the exposed plant. We highly recommend to conduct more studies on other commercial crops and investigate the impact of magnetized water in their growth.

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