EFFECT OF MAGNETIC FIELDS AND IRRIGATION LEVELS ON MAIZE YIELD AND APPLIED WATER PRODUCTIVITY

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Abstract
Water scarcity and low irrigation efficiency remain major constraints to maize production. Magnetized water is a promising technology for addressing these challenges. This study was conducted in 2024 at the Agricultural Scientific Research Center in Kafrayhmoul, northwestern Syria, to evaluate the effects of magnetic field treatments and irrigation levels on maize yield and applied water productivity. A split-plot experimental design was used, in which four magnetic treatments (NMT, MT1, MT2, MT3) were assigned to the main plots based on magnetization devices differing in the number of magnetic fields. The subplots received three irrigation levels corresponding to 85% (I1), 100% (I2), and 115% (I3) of field capacity. Statistically significant differences were observed across treatments for most traits. MT3/I3 recorded the highest leaf area 10883.9 cm², grain number per main ear 529.11, the number of ears per plant 2.28, grain yield 11676.75 kg ha⁻¹, and biological yield 29249.06 kg ha⁻¹. In contrast, MT3/I2 resulted in the highest plant height 231.5 cm, the 1000-grain weight 280.99 g and applied water productivity 2.146 kg/m³. No significant differences were found between MT3/I3 and MT3/I2 in any measured trait. using devices with a greater number of magnetic fields in combination with moderate irrigation enhances maize yield while reducing the amount of water used, offering a sustainable solution for water-limited environments.

Keywords: Magnetized water, Magnetic fields, Irrigation levels, Maize yield, Applied water productivity

Introduction

Maize (Zea mays L.), commonly known as American maize, is one of the most important food crops worldwide, playing a vital role in food security and the economy (5). However, given the increasing challenges in modern agriculture, particularly water scarcity and the impacts of climate change, the need for efficient water management strategies has become increasingly urgent. Consequently, research has focused on enhancing the utilization of available water resources to improve agricultural productivity. Among the recently proposed methods to improve plant growth is the use of magnetized water, which involves exposing irrigation water to a magnetic field that changes water properties, potentially enhancing its absorption efficiency by plants (34).

Magnetized water technology has been applied in agriculture both globally and within the Arab world to address soil and saline water challenges, while enhancing plant growth, and increasing the yield (11 and 15). Studies indicate that magnetizing irrigation water can be a promising tool for sustainable agriculture, particularly in regions facing challenges related to water and soil constraints (18). It has been found to affect various yield-related traits of maize, such as plant height and grain weight (3). Additionally, (23) reported that using magnetized water at a magnetic strength of 2500 Gauss significantly improved maize plant height, dry weight, and biomass yield.

(41) found that using magnetized water significantly increased maize seed germination rates from 42.86% to 85.71%, while also improved root and stem development compared to untreated water. Similarly, (16) reported that magnetized water enhances crop productivity by increasing photosynthetic pigments (chlorophyll) and stimulating sugar synthesis. Their findings indicated that maize seeds irrigated with magnetized water had higher germination rates compared to those receiving untreated water. Moreover, treatments with magnetized water resulted in greater ear length, weight, and grain count, ultimately leading to a 30% increase in yield.

(8) studying the effect of magnetized water compared to tap water (control) for irrigating maize plants in Palestine, found that the use of magnetized water significantly influenced the morphological and productive traits of maize plants. It increased plant height and stem diameter, as well as the number of leaves and leaf area. Furthermore, both grain yield and vegetative yield improved compared to the control treatment.

Irrigating maize with magnetized water resulted in an increase in plant height, leaf area, number of leaves, stems, roots, and both wet and dry weights. In addition, magnetized water treatment elevated levels of chlorophyll A and B, carotenoids, carbohydrates, proteins, total amino acids, proline content, total indole, total phenol, kinetin, RNA, and DNA. Furthermore, concentrations of inorganic minerals such as K^+, Na^+, Ca^{+2}, and P^{+3} increased in all plant parts (4). (10) demonstrated that magnetic treatment of irrigation water significantly influenced certain soil chemical properties and had a significant impact on increasing the dry yield. (2) observed that subjecting water to magnetization enhanced its physical and chemical properties, leading to improved plant water and nutrient absorption efficiency and accelerated growth across various crops. His findings revealed that water-saving rates reached 11% for eggplant, 13.5% for faba bean, and 14.2% for tomato. (33) found that magnetized water treatments were more effective than regular water treatments in providing water for maize grain formation. The efficiency of magnetized water was superior by 39% when a full water requirement of 100% evapotranspiration was provided, by 32% at 66.6%, and by 60% at 50% of evapotranspiration.

(30) identified a strong correlation between the use of magnetized water and the increase in dry weight of maize grains, indicating enhanced productivity. Their findings indicated that magnetized water remained in the soil for a longer duration, extending soil moisture retention, which contributed to improved plant growth and enhanced yield, while simultaneously reducing the amount of irrigation water needed. Magnetic treatment of irrigation water significantly enhanced popcorn germination, growth, and yield under deficit irrigation, with a yield increase of up to 48.73% compared to non-treated water. The highest efficiency was achieved at 80% irrigation level, highlighting its potential in optimizing water use without compromising productivity (40). Similarly, the effectiveness of magnetic treatment water (MTW) technology in optimizing water-use efficiency without negatively affecting crop productivity has been emphasized by several studies (43), (12) and (14).

Magnetizing water alters the arrangement of water molecules and modifies the structure of hydrogen bonds, enhancing water ability to interact with ions and nutrients.

This process weakens intermolecular hydrogen bonding, reduces surface tension, and improves the water's penetration into plant tissues and soil (14), (36) and (42). Additionally, magnetized water stimulates plant growth and increases productivity due to several improvements in water properties, such as density modification, surface tension adjustment, viscosity reduction, and enhanced solubility of minerals, vitamins, and salts (31) and (27). Furthermore, water magnetization induces both physical and chemical changes in water, which subsequently influence various plant traits, leading to improved plant characteristics, growth, and productivity (8), (12), (37) and (14).

The electrical conductivity and solubility capacity of magnetized water are influenced, while the viscosity of water molecules is decreased (26) and (14). Additionally, magnetized water shows increased electrical conductivity, higher pH levels, accompanied by an increase in dissolved oxygen content, which enhances chemical interactions in the soil and improves nutrient absorption by plants (28). Changes in the physical and chemical properties of magnetized water make water molecules more permeable and soluble as they move through the soil, enhancing mineral dissolution and improving the availability of dissolved nutrients (39), (12) and (14).

Findings from (28), (35) and (24) indicate that irrigation with magnetically treated saline water increased crop nutrient uptake. In contrast, deficit irrigation consistently reduced maize performance, leading to decreases in plant height, leaf area, wet weight, dry weight, and grain yield when water availability was limited (25), (29) and (19). Likewise, (6) found that the effect of moisture stress reduced the maize grain yield, kernel number per ear, and kernel weight whenever irrigation fell short of the crop's water requirement. In the study by (1), maize was cultivated under different irrigation regimes based on soil moisture depletion. Plant height ranged between 161.56 and 190.11 cm, the number of grains per main ear varied from 257.17 to 362.17, and the 1000-grain weight fluctuated between 273.2 and 382.2 g.

Research Objectives

This study aims to evaluate the impact of irrigation with magnetically treated water using four levels of magnetic field, in conjunction with three field capacity levels, on morphological and productive traits of maize plants, in addition to applied water productivity.

Materials and Methods

Experimental site: The experiment was conducted at the Agricultural Scientific Research Center in Kafrayhmoul, located at 36.051705° N and 36.704358° E, in northwestern Syria.

Plant material: Maize plant, hybrid (NK FAMOSO).

Magnetization devices: Three different magnetization devices were used to treat the irrigation water, each varying in the number of magnetic fields. Their specifications are presented in Table 1.

Table 1: Technical specifications of magnetization devices employed in the experiment

Weight (g)	Device Length (cm)	Number of Magnets	Number of Magnetic Fields	Diameter (inch)	Device Code
384	12.5	4	2	3/4	**MK24S**
630	21	8	4	3/4	**MK24G**
1222	37	16	8	3/4	**MK37S**

Type of magnet used: Neodymium N52 NdFeB, size 25 × 25 × 5 mm, 4800 gauss.

Moisture meter: Soil moisture was measured using a PMS710 digital moisture meter (the device length was adjusted locally), which provides accurate readings to support precise irrigation scheduling based on field capacity levels.

Experimental Design:

The experiment was conducted using a split-plot design. The main plots were assigned four magnetic field treatments based on the number of fields generated by different magnetization devices: NMT– No magnetization, MT1– Two magnetic fields, MT2– Four magnetic fields, MT3– Eight magnetic fields. The experimental subplots were subjected to three irrigation regimes, in which soil moisture was restored to 85%, 100%, and 115% of field capacity (FC), corresponding to volumetric water contents of 35.87%, 42.20%, and 48.53%, respectively, as measured by the PMS710 device (I1, I2, and I3). Soil moisture in each subplot was monitored daily using the PMS710 digital soil moisture meter, and irrigation was applied whenever the moisture content in any subplot declined to 70% of FC (29.54% volumetric water content). The total number of experimental plots was 4 × 3 × 3 = 36 plots. Each plot contained three rows, with a 70 cm spacing between rows. Each row had eight plants, with a 25 cm spacing between plants. The total number of plants per experimental plot was 24, and the plot area was 2.1 × 2 = 4.2 m².

Measured parameters:

1- Plant height (cm): Measured from the soil surface at the plant base to the base of the tassel at the end of the flowering stage.
2- Total leaf area (cm²): Calculated for all plant leaves using the formula: leaf length × maximum width × 0.75, at the end of the flowering stage (21).
3- Number of ears per plant.
4- kernel number per main ear.
5- Thousand-grain weight (g): After drying until weight stabilization.
6- Grain yield ($kg.ha^{-1}$): After drying until weight stabilization.
7- Biological yield ($kg.ha^{-1}$): after drying until weight stabilization.
8- Irrigation water applied: The depth of irrigation water applied was determined according to the following equation: (7).

$$D = ((x - m_d)\, z)/ 100$$

- D: the irrigation depth (mm) required to restore soil moisture to the designated FC level.
- x: the target soil moisture level (35.87%, 42.20%, or 48.53% volumetric water content for I1, I2, and I3, respectively).
- md: is the measured volumetric soil moisture content (%) in each subplot.
- z: the effective soil depth (mm), which increased by 10 mm daily with plant growth until reaching a maximum of 450 mm.

The amount of water applied per irrigation event was calculated as (38) and (9). Using the following equation:

$$V=D\times A$$

- V: volume of irrigation water per experimental plot (m³).
- A: experimental plot area (m²).

9- Applied water productivity: is calculated according to the following equation (17) and (20):

$$AWP=Y/I$$

Y: grain yield (kg/ha)
I=D: irrigation water applied (m³/ha)

Agronomic practices:

A chemical analysis of the soil was conducted, and appropriate fertilizers were applied according to the recommendations of the General Commission for Scientific Agricultural Research at a rate of 130.4 kg of urea (46%) and 217.3 kg of superphosphate (46%) per hectare before planting. An additional 130.4 $kg.ha^{-1}$ of urea (46%) was applied 30 days after planting.

On June 24, 2024, the experimental soil was plowed to a depth of 35 cm using a moldboard plow, followed by soil leveling at a depth of 15 cm using a chisel plow. On the following day, basins (plots) were established, and the irrigation networks were installed. Then the experiment was planted on June 26, 2024, with 48 seeds per experimental plot. After 15 days, thinning was performed, leaving 24 plants per plot.

The experimental field was irrigated for seed germination at a rate of 90.8 mm on June 27, 2024. Irrigation treatments were initiated on 17 July 2024, when soil moisture in one subplot reached 70% FC, and continued until 21 September 2024, with a total of 13 irrigation events. Agricultural maintenance operations, including weed removal and pest and disease control, were carried out periodically throughout the experiment. Harvesting took place from September 27, 2024, to October 3, 2024.

Statistical Analysis:

All recorded data were statistically analyzed using GenStat12. analysis of ANOVA was conducted following the split-plot design. Mean comparisons were performed using the Least Significant Difference (LSD) test at a probability level of 0.05 to determine the significance of individual and interaction effects among treatments.

Results and Discussion

Effect of magnetic fields and irrigation levels on morphological traits:

Figures (1A and 1B) illustrate a statistically significant effect of magnetic fields on maize plant height and leaf area. The MT3 treatment exhibited statistically significant superiority over the other treatments in both traits, followed by MT2, MT1 and NMT. No significant difference was observed between MT1 and NMT in plant height, and between MT1 and MT2 in leaf area. The average plant heights were 220.2, 209.7, 199.3, and 193.8 cm, respectively, while the recorded average leaf areas were 10349.7, 9804.8, 9359.7, and 8543.7 cm^2. In both cases, increasing the number of magnetic fields applied to irrigation water contributed to improved plant growth.

Figures (1C and 1D) illustrates a statistically significant effect of irrigation levels, based on field capacity, on maize plant height and total leaf area. The I3 treatment recorded the highest average plant height (222 cm), significantly surpassing I2 (212.8 cm) and I1 (182.5 cm), indicating a positive response of plant height to increased irrigation water levels. In terms of leaf area, I3 showed non-significant superiority over I2, while significantly outperforming I1, with recorded averages of 10185.9, 9865.9, and 8491.6 cm^2, respectively. These findings suggest that increasing irrigation levels enhances total leaf area, which may contribute to improved plant productivity.

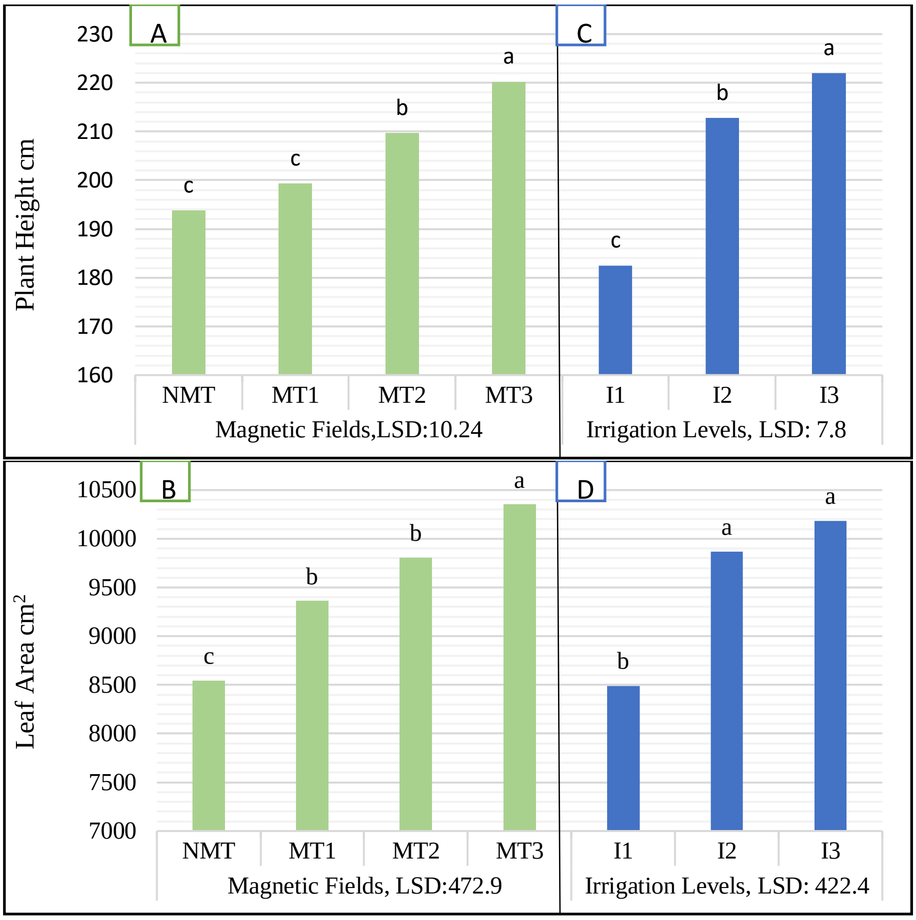

Figure 1: effect of magnetic fields on, plant height (A), leaf area (B) effect of irrigation levels on, plant height (C), leaf area (D)

Table (2) presents the combined effect of magnetic field number application and irrigation levels on maize plant height and leaf area. The highest plant height value (231.5 cm) was recorded under MT3/I2, with no statistically significant difference from MT3/I3, MT2/I3, MT2/I2, and MT1/I3, while significantly outperforming the other treatments. The lowest height (170.5 cm) appeared under NMT/I1. Increasing the number of magnetic fields applied to irrigation water enhanced its effectiveness in promoting plant height; for example, MT3/I1 (198.4 cm) was statistically comparable to NMT/I2, suggesting that greater magnetization may compensate for lower water input. Likewise, MT2/I2 produced similar results to NMT/I3, reinforcing the role of field number in vegetative growth. These findings are consistent with the studies of (3) and (23), which showed that magnetized water treatments outperformed other treatments in terms of plant height.

Similarly, the interaction between magnetic fields and irrigation levels significantly influenced leaf area. The MT3/I3 treatment recorded the highest value (10883.9 cm²), showing no statistically significant difference from MT3/I2, MT2/I3, MT2/I2, and MT1/I3, while significantly outperforming the remaining combinations. The lowest leaf area (7660.4 cm²) was observed under NMT/I1. The effectiveness of irrigation water increased with the number of magnetic fields applied, as seen in MT3/I1 (9407.5 cm²), which was statistically comparable to NMT/I3 and NMT/I2 despite reduced water input. Similarly, MT2/I2 and MT1/I2 produced results comparable to NMT/I3, reinforcing the role of magnetic fields in supporting vegetative growth under limited irrigation. These findings are consistent with those reported by (4), (41), and (8), who confirmed that magnetized water positively influences leaf development in maize.

Table 2: Interaction between Magnetic Fields and Irrigation Levels on Plant Height, Leaf Area, Number of Kernels per Main Ear, Thousand-Kernel Weight, and Number of Ears per Plant.

Magnetic Field	Irrigation Level	Plant Height cm	Leaf Area cm²	Number of Grains Per Main Ear	Thousand-Kernel Weight g	Number of Ears per Plant
NMT	I1	170.5 f	7660.4 e	367.84 f	234.75 d	1.75 d
	I2	197.1 de	8811.7 cd	423.83 e	254.3 c	1.94 bcd
	I3	213.7 bc	9159.0 cd	447.61 de	260.94 bc	2 bc
MT1	I1	177.8 f	8375.9 de	393 f	238.97 d	1.83 cd
	I2	202.5 cd	9531.3 bc	458.94 d	258.77 c	1.94 bcd
	I3	217.6 abc	10171.9 ab	486.78 c	270.1 ab	1.94 bcd
MT2	I1	183.1 ef	8522.6 d	425.83 e	242.75 d	1.89 cd
	I2	220.2 ab	10362.9 a	489.28 c	271.95 a	2 bc
	I3	225.9 ab	10528.8 a	499.72 bc	276.16 a	2.06 abc
MT3	I1	198.4 d	9407.5 bc	446.11 de	259.03 c	1.94 bcd
	I2	231.5 a	10757.8 a	518.83 ab	280.99 a	2.17 ab
	I3	230.6 a	10883.9 a	529.11 a	279.12 a	2.28 a
Average		205.7	9514.5	457.24	260.65	1.979
LSD (0.05)		15.19	784.8	25.24	10.94	0.2415
CV%		4.4%	5.1%	3.6%	2.9%	6.5%

Effect of magnetic fields and irrigation levels on yield components:

Figures (2A, 2B, and 2C) show that increasing the number of magnetic fields applied to irrigation water significantly enhanced maize yield components. Treatment MT3 consistently achieved the highest recorded averages across all traits: Kernel number per main ear 498.02 grains, 1,000-grain weight 273.048 g, number of ears per plant 2.129 ears. This confirms the effectiveness of increased magnetic field number in boosting productive performance in maize.

MT2 (471.61 grains) showed significant improvement in kernel number per main ear over MT1 (446.2 grains), which, in turn, significantly outperformed NMT (413.09 grains). This indicates a clear ascending pattern with increased field number. Similar trends were observed in 1,000-grain weight, with MT2 (263.62 g) significantly exceeding MT1 (255.95 g), and MT1 remaining superior to NMT (250 g). MT3 showed a non-significant advantage in number of ears per plant over MT2, while significantly outperforming MT1 and NMT. However, MT2 (1.981), MT1 (1.907), and NMT (1.898) did not differ significantly, suggesting a moderate influence of magnetic field number on ear formation.

Figures (2D, 2E, and 2F) illustrate the impact of irrigation levels, based on field capacity, on maize yield components. Treatment I3 recorded the highest averages across all traits: Kernel number per main ear 490.81 grains, 1,000-grain weight 271.58 g, Number of ears per plant: 2.069 ears.

In kernel number, I3 was significantly superior to both I2 (472.72 grains) and I1 (408.19 grains). I2 also significantly outperformed I1. For 1,000-grain weight, I3 was significantly superior to I1, but its advantage over I2 (266.51 g) was not statistically significant. I2 remained significantly better than I1 (243.87 g). In number of ears per plant: I3 showed statistically significant superiority over I1. Its advantage over I2 (2.014 ears) was not significant. I2, in turn, showed a significant improvement over I1 (1.854 ears). These findings demonstrate that increasing irrigation levels improves kernel number and grain weight with moderate but statistically supported gains in number of ears.

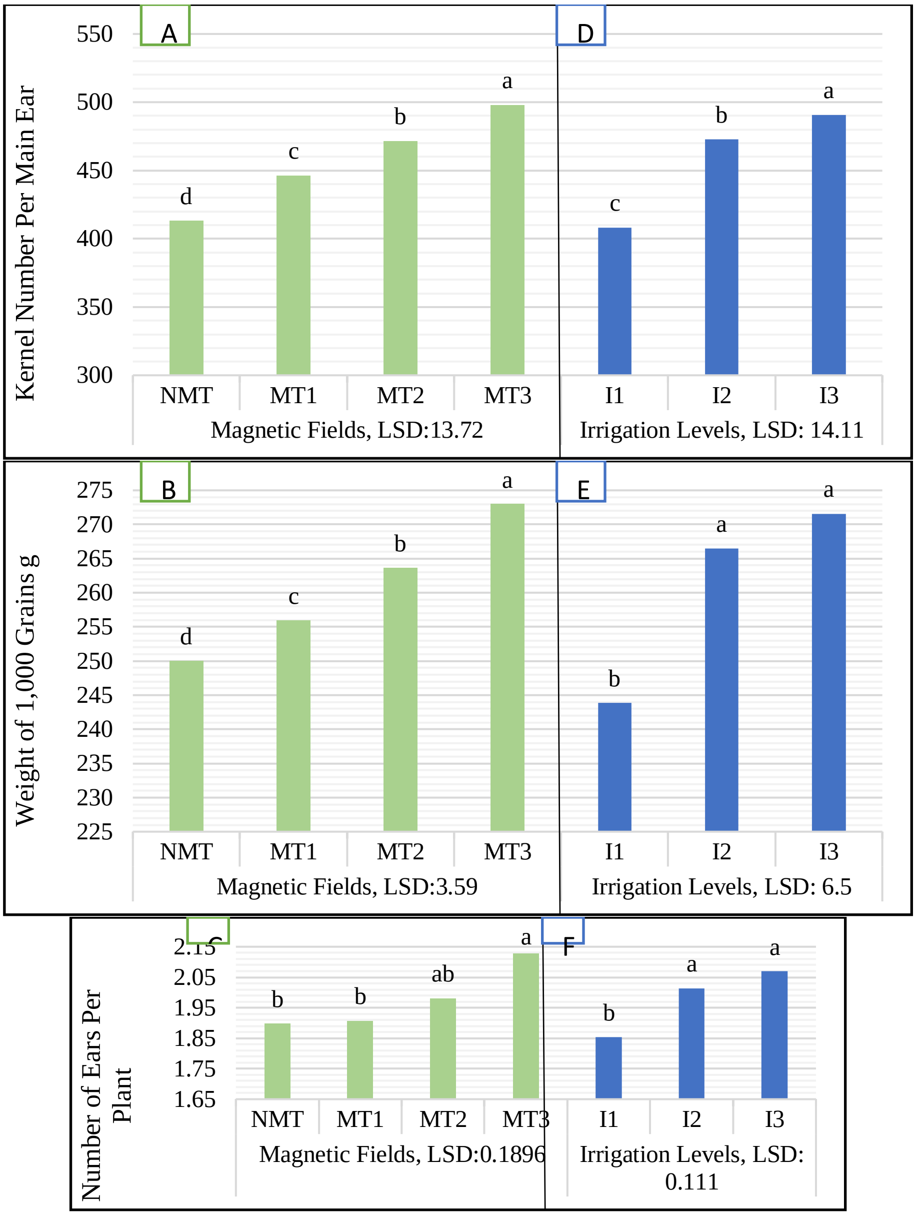

Figure 2: effect of magnetic fields on, kernel number per main ear (A), weight of 1,000 grains (B), number of ears per plant (C).

effect of irrigation levels on, kernel number per main ear (D), weight of 1,000 grains (E), number of ears per plant (F).

Table (2) illustrates the interaction between magnetic field number and irrigation levels on maize yield components. Treatment MT3/I3 recorded the highest averages in: kernel number per main ear 529.11 grains, ear number 2.28 ears, whereas treatment MT3/I2 recorded the highest average in 1,000-kernel weight 280.99 g.

In kernel number: MT3/I3 showed no statistically significant difference from MT3/I2, the lowest value (367.84 grains) was observed under NMT/I1. Notably, MT2/I2 achieved 489.28 grains significantly superior to NMT/I3 despite less water.

In 1,000-kernel weight: MT3/I2 showed no statistically significant difference from MT3/I3, MT2/I3, MT2/I2, and MT1/I3, while significantly outperforming the remaining treatments. Notably, MT3/I1 (259.03 g) was nearly identical to NMT/I3, suggesting that greater magnetization may compensate for reduced irrigation volume.

Regarding number of ears per plant: MT3/I3 showed no statistically significant difference from MT3/I2 and MT2/I3, yet was significantly superior to all other combinations. MT2/I2 achieved 2.17 ears, comparable to NMT/I3 (2.00 ears) despite lower water input, reinforcing the impact of magnetic treatment under limited irrigation.

These outcomes align with the findings of (16), who confirmed the superiority of magnetized irrigation treatments over non-magnetized ones in enhancing kernel formation, grain weight, and ear development.

Effect of magnetic fields and irrigation levels on yield trails:

Figures (3A) and (3B) demonstrate the statistically significant impact of increasing the number of magnetic fields applied to irrigation water on grain yield and biological yield of maize. The MT3 treatment consistently achieved the highest recorded averages in both traits. Statistical comparisons revealed a clear hierarchical pattern across treatments: MT3 significantly outperformed all other treatments, MT2 followed, showing a significant improvement over MT1, MT1 in turn, exhibited statistically significant superiority over NMT.

The recorded average yields across treatments were as follows: Grain yield MT3 (10756.64), MT2 (9686.48), MT1 (8765.19), NMT (8058.30) $kg \cdot ha^{-1}$. Biological yield: MT3 (25895.40), MT2 (22437.60), MT1 (19642.97), NMT (18058.83) $kg \cdot ha^{-1}$.

These results confirm that increasing magnetic field number enhances overall productivity.

Figures (3C) and (3D) illustrate the statistically significant impact of irrigation levels based on field capacity on grain yield and biological yield in maize. The I3 treatment consistently achieved the highest recorded averages in both traits: Grain yield: 10415.45 $kg \cdot ha^{-1}$, Biological yield: 24652.39 $kg \cdot ha^{-1}$.

Statistical comparisons revealed that: I3 was significantly superior to both I2 and I1 in grain and biological yield, I2 also showed statistically significant superiority over I1, with recorded values of: Grain yield: I2 (9865.62), I1 (7668.90) $kg \cdot ha^{-1}$. Biological yield: I2 (22987.94), I1 (16885.80) $kg \cdot ha^{-1}$. These findings confirm that increasing irrigation levels enhances both grain productivity and total biomass accumulation in maize.

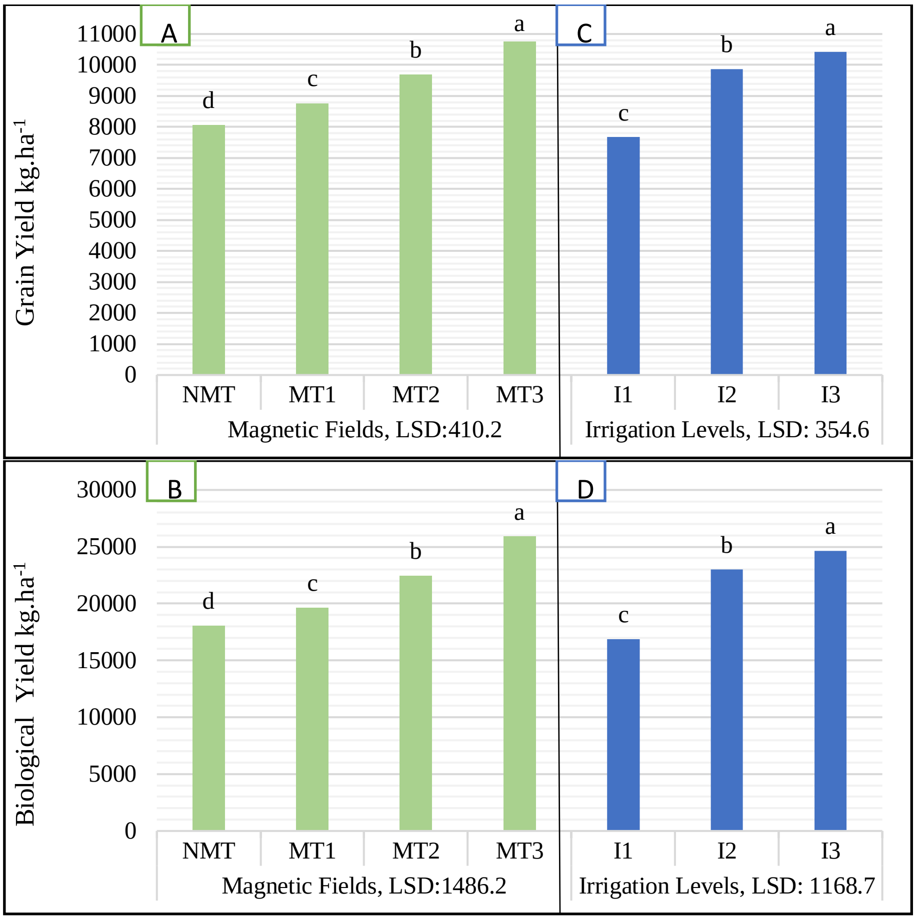

Figure 3: effect of magnetic fields on, grain yield (A), biological yield (B) effect of irrigation levels on, grain yield (C), biological yield (D)

Table (3) presents the interactive effect of magnetic field number and irrigation levels on grain yield and biological yield in maize. The highest recorded values across both traits were observed under the MT3/I3 treatment: Grain yield 11676.75 kg·ha^{-1}, Biological yield 29249.06 kg·ha^{-1}.

In grain yield, MT3/I3 showed no statistically significant difference from MT3/I2 (11541.79 kg·ha^{-1}), while significantly outperforming all other treatment combinations. Remarkably, MT3/I2 despite receiving less irrigation was statistically superior to the remaining treatments, indicating that increasing magnetic field number can enhance compensate for reduced irrigation volume. The lowest grain yield (6542.60 kg·ha^{-1}) was recorded under NMT/I1. Similar trends were observed in biological yield, with MT3/I3 and MT3/I2 (28133.93 kg·ha^{-1}) statistically indistinguishable, yet both significantly superior to other combinations. Again, MT3/I2 maintained high productivity under limited irrigation, highlighting the compensatory role of magnetization. The lowest biological yield (14466.27 kg·ha^{-1}) was also recorded under NMT/I1. These findings are consistent with prior studies, including those by (23), (10), (8), (40) and (4), which demonstrated that magnetized irrigation significantly improves both grain and biomass yields compared to non-magnetized water applications.

The observed increase in yield and studied traits can be attributed to the physicochemical changes induced by magnetization in irrigation water. Magnetized water enhances fluidity and facilitates the absorption of nutrients by plant roots (14). Additionally, magnetization improves crop productivity by increasing chlorophyll concentration, promoting sugar synthesis, and enhancing the transport of photoassimilates in maize plants (16).

During the magnetization process, the molecular structure of water is altered, resulting in weakened hydrogen bonds, reduced surface tension, and improved ionic interaction, which collectively enhance soil infiltration and nutrient availability (36). These changes positively affect key water properties such as density, viscosity, and solubility of essential minerals and salts (31) and (27), contributing to improved physiological function. Moreover, magnetized water contains higher dissolved oxygen levels (28), which may support root respiration and metabolic activity. Collectively, these effects translate into greater vegetative development and biomass accumulation, thereby improving biological yield and water-use efficiency in maize grown under semi-arid conditions.

Table 3: Interaction Between Magnetic Fields and Irrigation Levels in Grain Yield, Biological Yield, Irrigation Water Applied, and Applied Water Productivity

Magnetic Field	Irrigation Level	Grain Yield $kg.ha^{-1}$	Biological Yield $kg.ha^{-1}$	Irrigation Water Applied mm	Applied Water Productivity kg/m^3
NMT	I1	6542.6 g	14466.27 h	488 e	1.3403ef
	I2	8426.23 ef	18975.25 ef	601 c	1.4018e
	I3	9206.07 d	20734.96 de	716.1 a	1.2848f
MT1	I1	7163.64 g	15471.94 gh	466.8 ef	1.5349d
	I2	9115.65 d	20524.92 e	576.9 c	1.5806d
	I3	10016.29 c	22932.04 cd	710.9 a	1.4086e
MT2	I1	7917.95 f	17301.69 fg	442.8 fg	1.7887c
	I2	10378.8 bc	24317.64 bc	548.8 d	1.8929b
	I3	10762.68 b	25693.5 b	679.4 b	1.5844d
MT3	I1	9051.39 de	20303.31 e	436 g	2.075a
	I2	11541.79 a	28133.93 a	538 d	2.146a
	I3	11676.75 a	29249.06 a	668.2 b	1.7477c
Average		9316.65	21508.7	572.7	1.649
LSD (0.05)		664.6	2253.2	27.28	0.08561
CV%		4.4%	6.3%	3.0%	3.4%

Effect of magnetic fields and irrigation levels on irrigation water applied and applied water productivity:

Figure (4A) illustrates the statistically significant effect of magnetic fields applied to irrigation water on irrigation water applied. The highest value was recorded under the NMT treatment, followed by MT1, MT2, and MT3, with average water requirements of 601.7, 584.8, 557, and 547.4 mm, respectively. These findings suggest that increasing the number of magnetic fields contributes to reduced irrigation water consumption in maize.

Figure (4B) illustrates the impact of irrigation levels based on field capacity on irrigation water applied. The I3 treatment exhibited statistically significant superiority over I2 and I1, with average values of 693.6, 566.2, and 458.4 mm, respectively. Additionally, I2 showed statistically significant superiority over I1. This indicates that higher irrigation levels result in greater water usage.

Figure (4C) illustrates the statistically significant improvement in applied water productivity due to magnetic field treatment. The MT3 treatment recorded the highest value (1.99), followed by MT2 (1.755), MT1 (1.508), and NMT (1.342). These results demonstrate a gradual enhancement in water-use efficiency in maize under increasing magnetic field exposure. These findings suggest that increasing magnetic field exposure enhances water-use efficiency in maize, as reflected by improved productivity per unit of irrigation water.

Figure (4D) demonstrates the impact of irrigation levels based on field capacity on applied water productivity. The I2 treatment recorded the highest productivity (1.755), followed by I1 (1.685), whereas the I3 treatment showed the lowest value (1.506). Statistically significant differences were observed among all treatments. These results indicate that moderate irrigation levels are more effective in maximizing water productivity than excessive irrigation, emphasizing the role of strategic water management under magnetized conditions.

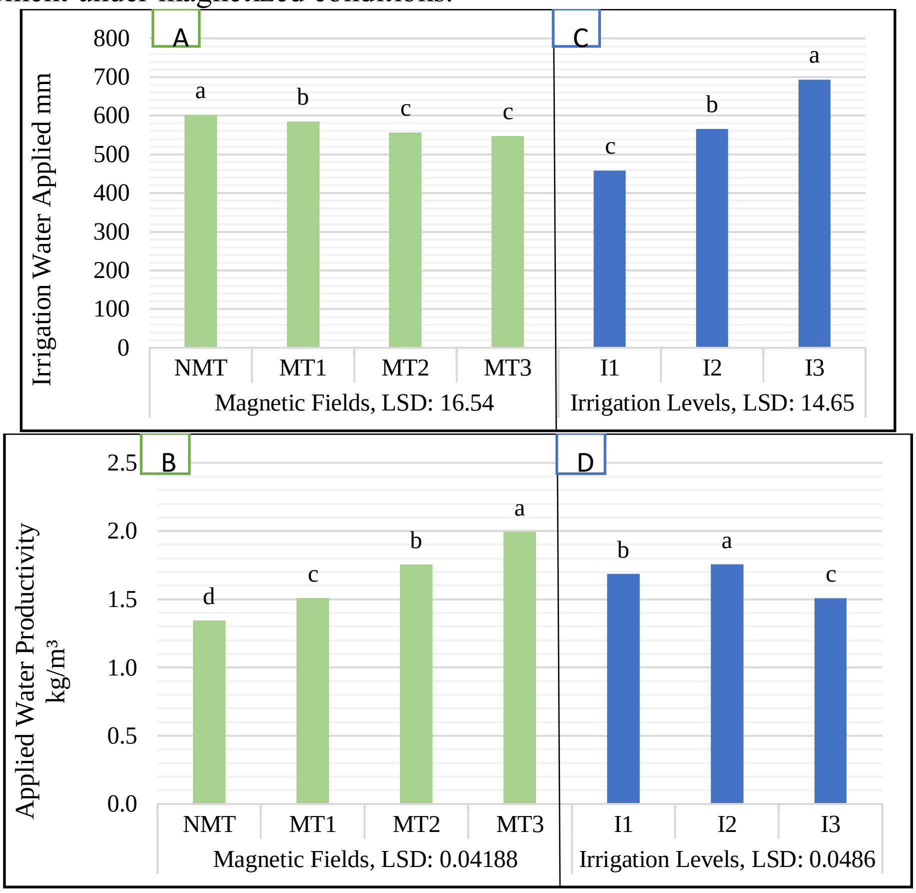

Figure 4: effect of magnetic fields on, irrigation water applied (A), applied water productivity (B) effect of irrigation levels on, irrigation water applied (C), applied water productivity (D)

The data presented in Table (3) revealed statistically significant interactions between magnetic field intensity and irrigation regimes on both the volume of irrigation water applied and water productivity in maize.

The maximum irrigation water applied was observed under treatment (NMT/I3), reaching 716.1 mm, whereas the minimum value was recorded under the MT3/I1 treatment (436 mm). This stark contrast underscores the efficacy of magnetic treatment in reducing irrigation requirements, particularly under deficit irrigation conditions.

As for applied water productivity, the highest value was achieved under MT3/I2 (2.146 kg/m³), while the lowest was associated with NMT/I3 (1.2848 kg/m³). These results clearly demonstrate that higher irrigation levels do not inherently lead to improved water-use efficiency, especially in the absence of magnetic stimulation. Conversely, magnetized water under moderate irrigation conditions significantly enhanced productivity per unit of water applied.

The optimal treatment combination was MT3 with I2, striking a productive balance between water input and yield efficiency, and reflecting a synergistic interaction between magnetic field application and field capacity-based irrigation. In contrast, NMT with I3 represented the least efficient scenario, combining excessive water input with minimal productivity gains.

These findings are consistent with previous studies by (33), (2), (22), (32), and (30), which collectively confirm the potential of magnetized irrigation water in reducing water consumption and improving crop performance across various agricultural contexts.

Conclusions

The application of magnetic fields to irrigation water demonstrated a significant positive impact on maize growth and yield-related parameters. Treatments involving Higher magnetic fields (particularly MT3) consistently outperformed the non-magnetized control (NMT) across all measured traits, underscoring the role of magnetized water in enhancing crop performance.

Moreover, magnetic field treatments markedly reduced the volume of irrigation water applied. The MT3/I1 combination registered the lowest irrigation input (436 mm), whereas the highest volume was recorded under the NMT/I3 treatment (716.1 mm). This reduction in water demand under magnetized conditions highlights the potential of magnetic stimulation in improving water infiltration and root absorption.

In terms of efficiency, the highest applied water productivity was achieved under the MT3/I2 treatment (2.146 kg/m³), reflecting optimal synergy between moderate irrigation and enhanced magnetic exposure. By contrast, the lowest water productivity (1.2848 kg/m³) occurred under the NMT/I3 combination, which combined excessive water input with minimal efficiency.

The interaction between magnetic fields and irrigation levels further revealed that elevated magnetization can partially offset reductions in water supply. Treatments such as MT3/I1 and MT2/I2 produced comparable growth and yield outcomes to high-volume, non-magnetized irrigation regimes thereby confirming improved water-use efficiency under constrained conditions.

In summary, magnetized irrigation water not only reduced the quantity of water required but also improved crop productivity per unit of water applied. These findings provide strong support for integrating magnetic field application with strategic irrigation management as a promising approach toward sustainable maize production, particularly in semi-arid regions facing acute water limitations.

Supplementary Materials:
No Supplementary Materials.

Author Contributions:
1: Project administration; Resources; Software; Supervision; Validation; Visualization; Writing - original draft; Writing.
2: Investigation; Methodology; Supervision; Project administration; Validation
3: Investigation; Methodology; Supervision; Project administration; Validation
4: Data curation; Validation; Investigation; Methodology; Project administration.

Funding:
This research received no external funding.

Institutional Review Board Statement:
The experimental protocol was approved by the Agricultural Research Department, Faculty of Agriculture, [idlib University], [syria].
Informed Consent Statement:
No Informed Consent Statement.

Data Availability Statement:
No Data Availability Statement.

Conflicts of Interest:
The authors declare no conflict of interest.

Acknowledgments:
The authors would like to extend their sincere appreciation to the Dean of the Faculty of Agriculture in Idlib for his continuous support and academic guidance. Deep gratitude is also due to the Director of the Agricultural Research Center in Kafriyehmoul for facilitating the fieldwork and providing essential resources throughout the experiment. Their contributions were instrumental to the successful completion of this study.

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