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The Impact of Irrigation Levels with Normal and Magnetic Water, Bio Fertilization on Garlic Growth, Yield and Storage

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ABSTRACT

An investigation was conducted in the field during the 2019/2020 and 2020/2021 seasons at the El Kanater Hort. Res. Station in the El Kaloubia Governorate, Egypt, to examine the impact of irrigation using normal water, magnetized water at 100%, 80%, and 60% of potential evapotranspiration, under biofertilizer with a combination of PGPR strains *(Pseudomonas aeruginosa* and *Burkholderia hytofirmonas*), and their collaborative interactions on the yield and water-use efficiency of garlic. variety Sides 40. Split plot design was used in the experiment, with three repetitions. The main plots were used for the watering treatments, and sub-plots were focused on biofertilizers. The best vegetative growth, total yield ton/fed, average clove weight, number of cloves per head, bulb ratio, and water productivity were observed in garlic plants that were irrigated with magnetic water at 100 and 80 percent ETc.. High growth, yield, and superior attributes were found in garlic bulbs treated with biofertilizers. Watering with either 100% or 80% ETc magnetized water plus biofertilizer provided excellent growth, yield, its constituent parts, and water utilization efficiency. Also, garlic bulbs that received both biofertilizer and 60% ETc magnetic water irrigation exhibited the least amount of weight loss after seven months. To optimize garlic bulb productivity and quality while reducing water usage by 20%, it is suggested to combine biofertilizers with 80% ETc magnetic water.

***Keywords*:** Garlic, magnetic water, bio fertilizer, yield, storage.

INTRODUCTION

Since garlic (*Allium sativum*) is used so extensively as a spice, export, and pharmaceutical ingredient, it is regarded as one of the most important and traditional crops produced in Egypt. Plants of garlic have both enzymatic and non-enzymatic antioxidants as defensive mechanisms against damaging oxidative processes carried on by a significant accumulation of reactive oxygen species. Nadeem *et al.* (2022) have been proven the anti-microbial, anti-cancer, and cardiovascular benefits of garlic, moreover allicin is a helpful natural chemical that lowers nervous system inflammation. In the twenty-first century, food security faces major local and global dangers from both biotic and abiotic factors. Vegetable production will be affected by climate change, which is bringing about more droughts, changing soil moisture and rainfall cycles and influencing plant uptake of water and nutrients.

These days, drought has become one of the main challenges facing crop producers. Water stress is an important abiotic stress that inhibits development, slows transpiration rates, creates a CO2 deficit due to stomatal closure, and lowers the water potential of plant tissues **(**Yordanov *et al.* 2000). Magnetized water can affect the growth and development of plants because it can alter the polarity, hydrogen bond structure, ionize and stimulate water molecules (Chang and Weng 2008). Applications of magnetic water treatment in agricultural irrigation systems show benefits including increased soil moisture content and decreased water application quantity **(**Zlotopolski, 2017). Water uses efficiency is associated with the ability of plants to absorb carbon amounts and to regulate stomatal closure to prevent water loss (Wang *et al.* 2020). Employing plant growth-promoting bacteria is one technique that may successfully fight environmental stress. It was also discovered that PGPR might be used as a substitute of chemical pesticides and fertilizers by altering the status of different plant hormones PGPR can mediate drought stress by influencing the uptake of water and nutrients this leads to an accumulation of osmolytes, which can include a range of organic solutes that are compatible, such as sugars, amino acids, polyamines, antioxidants, and an increase or decrease of genes that respond to stress (Chieb and Gachomo 2023**)**.

Burkholderia sp., endophytic bacteria, were able to increase vegetative biomass, weight of grains, and productivity while diminishing the detrimental effects of salt on quinoa as compared to uninoculated plants. The ability of *Burkholderia* sp inoculation to maintain an approximately higher rate of photosynthetic activity was accompanied by improvements in osmotic management, ion balance, and antioxidant defense Yang *et al.* (2020**)**. Endobacteria strains employed as a co-inoculant indicated favorable effects on development and antioxidant levels of wheat drought susceptible cultivar, that the maintenance of AsA and levels of GSH reduced cell damage from oxidation and enhanced growth in seedlings during drought (Maslennikova and Lastochkina 2021). When PGPB treatments were combined with varied levels of water stress, the dry and fresh weights of the seedling sections of *Secale Montanum* wild grass considerably increased in comparison to the control treatment (Rahnama *et al.* 2023**)**. This study aims to ascertain the effects

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of irrigation with natural water, magnetic water at 100, 80, and 60% of potential evapo-transpiration, and biofertilizer containing a mixture of *Pseudomonas aeruginosa* and *Burkholderia hytofirmonas* strains on the productivity and water use efficiency of garlic cv Sides40.

MATERIALS AND METHODS

The two consecutive seasons of the field experiment were conducted at El-Kanater Research Station, El-Kaluobia Governorate, Egypt of 2019/2020 and 2020/2021, to study the impact of magnetized irrigation water levels at 100%, 80% and 60% of potential evapotranspiration (ETc.) under bio fertilizer moreover their interactions on yield, quality, as well as water use efficiency and storage of garlic (*Allium sativum* L.) cv. Sids - 40. The soil type used for the investigation was clay loam. Table 1 displays bulk density and soil/water parameters, whereas Table 2 displays the major soil and irrigation water attributes. Table 3 displays the Agricultural Research Station's meteorological data.

Table 1. displays the soil's bulk density, wilting point, and field capacity at various depths.

Depths cm	Field capacity (F.C.)		Wilting point (WP)		Available water (AW)		Bulk density
	%	mm	%	mm	%	mm	(BD) g/cm^3
0-15	38.9	70.6	18.6	33.8	20.3	36.8	1.21
15-30	37.8	72.6	17.7	34.0	20.1	38.6	1.28
30-45	34.9	67.5	16.5	31.9	18.4	35.6	1.29
45-60	33.6	66.5	16.4	32.5	17.2	34.1	1.32

FC: moisture at 33 kPa moisture tension.
WP: moisture at 1.5 MPa moisture tension.
AW = FC – WP

Table 2. soil's physical characteristics and chemical evaluations.

Physiochemical of properties the soil				Chemical properties			Available macronutrients (mg kg 1)		
Sand	Silt	Clay	Texture (Class)	pH (1:2.5)	OM (g kg 1)	Total CaCO3 (g kg 1)	N	P	K
19.31%	25.21%	55.48%	Clay	7.67	9.6	40.9	53.62	5.72	439.5
				Soluble ions (mmolc L-1)					
ECe (dSm-1)	Ca2+	Mg2+	Na+	K+	Cl-	HCO3-	CO32-	SO42-	SAR
5.1	27.65	13.86	9.23	1.4	21.71	4.29	---	26.14	2.19

Irrigation water				Soluble ions (mmolc L-1)			
pH	ECe (dSm-1)	Ca2+	Mg2+	Na+	K+	Cl-	HCO3-
7.61	0.82	2.94	1.85	3.28	0.17	4.55	0.49
	CO32-		SO42-		SAR		
	---		3.2		2.19		

Table 3. Meteorological data in 2019/2020 and 2020/2021 seasons

Months	W.S	S.S	T.max	T.min	R.F	R.H.
			2019/2020			
October	2.7	11.2	32.3	18.6	16.8	53.8
November	2.4	10.6	28.4	14.8	0.11	52
December	2.9	10	20.9	9.5	25.9	63.6
January	2.9	12.4	19.5	8.4	20.6	65.5
February	2.7	11.8	19.8	8.3	18	65
March	2.8	11.1	21	8.7	82.1	63.1
April	2.8	10.3	22.2	9.4	103	61.2
			2020/2021			
October	3	11.3	33.3	19.1	0.7	57.3
November	2.4	10.5	24.6	13.6	10.9	63.4
December	2.3	10.1	22.6	10.5	0.6	60.6
January	2.6	10.4	21.5	8.3	1.9	59.1
February	2.4	11	21.8	8.3	20	61.5
March	2.7	11.5	23.3	9.2	95	62.4
April	3.2	11.8	29.4	11.7	4	50.2

Where: W.S = wind speed (m/ sec); S. S= actual sunshine (hour), T. max., T. min. = maximum and minimum temperatures °C; RF = rainfall and R.H. = relative humidity (%). Information was taken from SWERI, ARC's Agro Meteorological Unit.

The treatments used in the field experiment were: -

There were four different evapotranspiration (ETc.) levels: 100% of normal water served as the control, and the other three were 100%, 80%, and 60%. of magnetic water.

At the north and south poles, a magnetic device was f ixed by the main irrigation water line. The characteristics listed below provide more information about a magnetic device: The device had a flow rate of 12 m3 per hour, a density of 14500 Gauss, a diameter of 1 inch, and a weight of 6 kg. It operated at 7 bars of pressure.

Reference crop evapotranspiration (ET_oThe experimental site's local meteorological data (Table 2) and the Penman-Monteith equation from the FAO (1998) were used to obtain the ETo values. Utilizing the FAO's CROPWAT model, calculations were carried out (1992).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

Where:

ET_o: reference daily total precipitation (mm), net radiation (MJ m-2 day-1) at the crop surface (Rn), G: density of soil heat flow (MJ m-2 day-1), T: mean daily air temperature at a height of 2 m (°C), u_2: velocity of the wind at a height of two meters (m s-1), es: saturation vapor pressure (kPa), e_a: real vapor pressure (kP) es-ea: the difference in vapor pressure (kPa), Δ: The psychrometric constant (γ) represents the slope of the temperature-vapor pressure curve (kPa °C-1).

Crop evapotranspiration (ETc.)

The ETc. values were computed using the formula provided by FAO (1977).:

$$ETc. = ETo \times Kc$$

Where in Table 4 is the crop evapotranspiration (mm day 1) for ETc. and the reference crop evapotranspiration (mm day 1) for ETo.

Kc: coefficient of crop. For the garlic plants in the experimental locations, the ETc. was estimated using the Kc values proposed by Smith, (1992) in Table 4.

Table 4. Applying the Penman-Monteith equation, calculate the daily, monthly, ETo, and ETc. to garlic for the 2019–2020 and 2020–2021 growing seasons.

Season		ETo				ETc.			
		2019/2020		2020/2021		2019/2020		2020/2021	
Month	Kc	mm/ day	mm/month	mm/day	mm/month	mm/day	mm/month	mm/day	mm/month
October (10 -20 day)	0.45	5.2	83	5.69	113.8	2.34	37.4	2.56	51.2
November	0.60	4.07	122	3.33	99.9	2.442	73.3	2.00	59.9
December	0.75	2.84	88	2.74	84.9	2.13	66.0	2.06	63.7
January	1.0	2.75	85	2.99	92.7	2.75	85.3	2.99	92.7
February	0.90	3.17	89	3.28	91.8	2.853	79.9	2.95	82.7
March	0.75	3.82	118	4.16	129.0	2.865	88.8	3.12	96.7
April (10 day)	0.70	4.34	43	6.28	62.8	3.038	30.4	4.40	44.0
Seasonal (mm)			629.2		674.9		461.1		490.9

Amount of applied irrigation water (AIW):

The Vermeiren and Jopling (1984) equation was used to compute the amounts of applied irrigation water:

$$AIW = \frac{ETc \times Kr \times I}{Ea\,(1-LR)} - \text{Raineff}$$

Where:

AIW is for applied depth of irrigated water (mm), while ETc stands for crop evapotranspiration (mm day 1).

Kr: the reduction factor depends on ground cover. I: Days between irrigations

Ea: the drip irrigation system's irrigation application efficiency, which is 90% at the site.

LR: Leaching requirements: the extra water needed to leach salt, calculated using FAO (1985) formulas as follows:

$$LR = \frac{ECiw}{ECe}$$

Where

ECe is the average soil salinity that the crop can withstand, as measured by the soil saturation extract (dS m-1), and ECiw is the salinity (dS m-1) of irrigation water. To prevent any impact on stress treatments, no extra water was added for leaching under the current experimental circumstances.

Rain off = Rain × 0.65.

Water productivity (WP)

Applying irrigation water is a term used to explain the connection between productivity and water application quantity. It was established in accordance with Zhang (2003). The equation that follows is applied as follows:

$$WP = \frac{\text{Garlic yield (kg/fed.)}}{\text{Total seasonal applied water } (m^3/\text{fed.})}$$

2- Bio fertilization treatment: The biofertilization inoculated with mixture of biofertilizers (mixture of *Pseudomonas aeruginosa* and *Burkholderia hytofirmonas*) PGPR strains and uninoculated biofertilizer as control treatment. It was taken from the Microbial Inoculants center, Faculty of Agriculture, Ain Shams University, Cairo, Egypt. Bio fertilization was added 20 L/fed twice in season, 60 and 80 days after planting.

A split plot trail in randomized complete block design (RCBD) with three replications were employed in the experiment. Six treatments in all, consisting of four irrigation water treatments with and without biofertilizers, were included in each replication. The sub-plots dealt with bio fertilizers, while the major plots were devoted to irrigation water treatment. During soil preparation, organic manure was applied to each plot at a rate of 30 m^3/fed. Five row-bed systems, each measuring 100 cm in width and 30 cm in height, were used to organize the plants. Within each row, garlic clove seeds were sown in hills spaced 10 cm apart. Each hill's two sides were planted, and the experimental plot's 25 m^2 area consisted of five rows, each measuring five meters long and one meter wide. During both test seasons, all agricultural practices (fertilization, weeding, and pest control) were performed in accordance with guidelines provided by the Egyptian Ministry of Agriculture.

The storage experiment: -

To find out how magnetic water affects under bio fertilizer on the storability of garlic, after the treatment plots had cured, three-kilogram random samples were obtained from each one. All the heads with faults were discarded once the field trial treatments' heads were examined. For every treatment, three replicates were established, each containing one kilogram and being distributed according to a complete randomized design within perforated net bags with a thickness of fifteen micrometers. For the two test seasons of 2020 and 2021, all bags were kept for seven months at the store of Department of Potato and Vegetatively Propagated Crops, Dokki, Giza, Egypt, on June 1st, at the room temperature and 85–90% relative humidity.

Studied characters:

1.Vegatitive growth:

- Plant length (cm.)
-Number of leaves/plants
-Fresh weight of leaves (g)
-Dry weight of leaves (%)

2. Yield (ton/fed.): Yield per plot was estimated at harvest time on May 14 and yield per fed. (ton)was determined based on the yield \ plot after curing for 7 days was determined.

3. Bulbs quality: From each experimental plot, ten bulbs were chosen at random to determine the following character's bulb quality.

- Bulb weight (g).
- Cloves weight (g).
- Number of cloves/bulbs.
-Bulb ration (%).
- Dry matter of heads (%)
- **Total soluble solids percentage (TSS %):** It was determined in the juice of garlic bulbs by using Garlic 110 Refractometer according to AOAC (1990).

4. Storage of garlic:

Throughout the seven-month data storage period, which ran from June 1st to December 1st, the following data were recorded monthly:

Weight loss: It was calculated according to the following formula:

$$\text{Weight loss (\%)} = \frac{\text{initial weight} - \text{weight of tubers for sampling dates} \times 100}{\text{initial weight of tubers}}$$

Statistical analysis:

An IBM computer was used to analyze the data, and means were compared using Duncan's multi-range test according to Snedecor and Cochran (1982).

RESULTS AND DISCUSSION

1. plant growth parameters:

Plant length and leaves number /plant:

The results shown in Table 5 show that the irrigation by magnetized water at 100 and 80 % ETc. produced the highest plants in contrast to the other treatments in both tested seasons. Application of water that is magnetic results in increased plant resistance to water stress, indicating that its effectiveness is connected to enhancing the antioxidant system and lowering oxidative damage of globe artichoke leaves Bagherifard and Ghasemnezhad (2014). Also, result was in harmony with Ismail *et al.* (2022) where they showed that the highest vegetative growth of globe artichoke was achieved with irrigation using either 75% or 100% ETc. magnetic water. Bio-fertilizer treatment had the higher plant length of garlic compared to the non-biofertilizer. These bacterial strains' function in increasing endogenous plant hormones including GA_3, IAA, and cytokinin which in turn encouraged cell division and the development of more vascular tissues may be responsible for the increased growth (Nikou *et al.* 2018) on Origanum vulgare. The corresponding results were attained with Bhushan *et al.* (2020**),** on garlic. Furthermore, the results showed that the application of biofertilizer and magnetized water at 100 or 80 % ETc. and 100 % normal irrigation (control) resulted in increasing plant length during both growing seasons. This finding was consistent with those of Dawa (2019) on common bean. Also, the results revealed that the application of magnetic irrigation water at 100 and 80 % ETc. had the maximum number of leaves in both seasons. In addition, the number of leaves of garlic plants did not influence the addition of biofertilizer in both seasons. In both the first and second seasons, the combination of magnetized water at 100 ETc and non-bio fertilizer achieved the most leaves number, with no discernible variation when using magnetized water at 80 ETc with or without bio fertilizer. Similar results are consistent with Mazrou *et al.* (2021) on Majorana hortensis.

Table 5. Effect of magnetic water, bio-fertilizer, and interaction treatments on garlic plant length and no. leaf throughout the 2019–2020 and 2020–2021 growth seasons.

Treatments	Length of plant (cm)			Leaves number per plant		
	non biofertilizer	bio fertilizer	means	non biofertilizer	bio fertilizer	means
			2019/ 2020			
100% ETc. irrigation (control)	64.22 ab	63.22 abc	63.72 A	9.04 c	9.44 bc	9.24 B
100% ETc. magnetic irrigation	59.11 c	65.50 a	62.31 A	10.67 a	9.67 bc	10.17 A
80% ETc. magnetic irrigation	60.22 bc	61.56 abc	60.89 A	10.11 ab	10.34 ab	10.22 A
60% ETc. magnetic irrigation	50.67 d	52.00 d	51.33 B	10.00 ab	9.89 abc	9.95 AB
means	58.55 B	60.57 A		9.95 A	9.83 A	
			2020/ 2021			
100% ETc. irrigation (control)	82.67 b	88.66 a	85.67 B	8.33 b	10.00 a	9.17 B
100% ETc. magnetic irrigation	90.00 a	88.67 a	89.33 A	9.67 a	9.67 a	9.67 A
80% ETc. magnetic irrigation	88.00 a	87.00 a	87.50 AB	9.33 a	9.37 a	9.35 AB
60% ETc. magnetic irrigation	72.67 d	78.00 c	75.33 C	7.67 b	7.69 b	7.68 C
means	83.33 B	85.58 A		8.75 A	9.18 A	

A multiple range test at the 5% level indicates that values in a column or row that are followed by the same capital or small letter(s) do not significantly differ from one another.

weight of fresh and dried leaves

The findings illustrated by Table 6 show when irrigation with 100 and 80% of ETc. for magnetized water treatments were employed, the fresh and dry weight of garlic leaves increased in both tested seasons. The same results were also reported in Hassan *et al*. (2019), where stated that after receiving magnetic water treatment, the fresh weight and dry weight of moringa plants greatly improved, suggesting that this increase may have been achieved by an improved rate of photosynthesis. Additionally, it was observed by Faridvand *et al.* (2021**)** revealed the fennel plants' fresh and dried weight increased when they were treated with magnetic water. The use of biofertilizer treatment produced a higher value fresh weight of leaves compared to non-biofertilizer in the first season. Moreover, the presence of bio fertilizer that was applied significantly affects the dry leaves weights in both seasons. These findings coincide with the result of Yang *et al*. (2020), who revealed that Quinoa grain weight enhanced in plants treated with *Burkholderia phytofirmans*. Applying biofertilizer combined with magnetic irrigation treatment at 100 or 80 % of ETc. produced the optimum interaction for fresh and dry leaf weight values in both seasons. Similar results were obtained by Dawa (2019), who observed that the maximum plant dry weight values were attained when common bean plants received magnetized water and had biofertilizer incorporated into their soil.

Table 6. Effect of magnetic water, bio-fertilizer, and combined treatments on fresh and dry weight of garlic leaves throughout the 2019–2020 and 2020–2021 growth seasons.

Treatments	Weight of fresh leaves per plant (g)			Leaf dry weight percentage		
	Non-bio fertilizer	Bio fertilizer	Means	Non- bio fertilizer	Bio fertilizer	Means
			2019/2020			
100% ETc. irrigation (control)	58.67 cd	67.67 ab	63.17 AB	14.07 e	17.67 b	15.83 B
100% ETc. magnetic irrigation	65.00 b	69.67 a	67.33 A	16.67 bc	19.33 a	18.00 A
80% ETc. magnetic irrigation	63.00 bc	67.33 ab	65.17 A	16.05 cd	18.08 ab	17.00 A
60% ETc. magnetic irrigation	57.33 d	59.33 cd	58.33 B	15.03 de	15.07 de	15.00 B
Means	61.00 B	66.00 A		15.42 B	17.50 A	
			2020/ 2021			
100% ETc. irrigation (control)	45.70 bc	53.40 ab	49.55 B	12.17 bc	14.46 ab	13.28 AB
100% ETc. magnetic irrigation	58.47 a	58.00 a	58.24 A	13.60 abc	15.31 a	14.54 A
80% ETc. magnetic irrigation	55.20 a	53.38 ab	54.29 A	12.47 bc	14.37 ab	12.93 AB
60% ETc. magnetic irrigation	43.46 c	47.34 bc	45.40 B	11.59 c	12.71 bc	12.15 B
Means	50.71 A	53.03 A		12.46 AB	14.21 A	

A multiple range test at the 5% level indicates that values in a column or row that are followed by the same capital or small letter(s) do not significantly differ from one another.

Production per Fadden:

As indicated in Table 7, in the first season, irrigation of 100% ETc. of magnetic water produced the highest yield/fed/ton values with no significant differences from 80% ETc. of magnetized water; in the second season, irrigation of both 100% and 80% ETc. of magnetic water produced the highest yield/fed/ton values. The pH of the soil can be changed by adding magnetic water, which will increase the solubility of the micronutrients around the plant. Additionally, magnetic water might stimulate the production of proteins, rates of photosynthesis, and pigments considerably which could contribute to an increase in garlic yield (Mostafa 2020**)**. Similar results were obtained by Ismail *et al*. (2022), that noticed a significant increase in artichoke yield ton/fed when they used magnetic water to irrigate the plants at either 75 or 100% ETc. Moreover, As stated by Faridvand *et al.* (2021), applying magnetic water treatment substantially improved the yield of fennel seeds. The results in Table 7 demonstrate the bio-fertilizer produced the maximum yield per fed./ton compared to the non-bio-fertilizer in both tested seasons Similarly, Bhushan *et al.* (2020) found that adding biofertilizer resulted in the best optimal garlic yield Also, Yang *et al.* (2020**)** indicated that plants inoculated with *Burkholderia phytofirmans* increased grain yield of Quinoa over un-inoculated control. Also, results show the highest values of yield/fed/ton were obtained in both tested seasons by irrigation with 100 and 80 percent ETc. of magnet water when combined with the biofertilizer treatment. Similar results were observed by Abdel Nabi (2019), who claimed that irrigating garlic crops with magnetic water may improve garlic productivity. As stated by Dawa (2019), the results further shown that the combination of biofertilizers with magnetic irrigation water achieved the highest yield of common bean plants.

Table 7. Effect of magnetic water, bio-fertilizer, and combined treatments on yield per Fadden and water productivity of garlic throughout the 2019–2020 and 2020–2021 growth seasons.

Treatments	Yield (ton /fed.)			Water productivity (WP) kgm^{-3}		
	non biofertilizer	bio fertilizer	means	non biofertilizer	bio fertilizer	means
2019/ 2020						
100% irrigation (control)	7.54 d	13.05 a	10.29 B	3.53 d	6.06 b	4.88 C
100% magnetic irrigation	8.34 c	12.95 a	10.65 A	3.86 d	6.06 b	4.96 BC
80% magnetic irrigation	8.86 b	12.82 ab	10.52 AB	5.16 c	7.45 a	6.31 A
60% magnetic irrigation	6.75 e	6.68 e	6.71 C	5.24 c	5.19 c	5.22 B
means	7.87 B	11.22 A		4.45 B	6.19 A	
2020/ 2021						
100% irrigation (control)	6.47 d	7.66 b	7.07 B	2.84 e	3.33 d	3.08 C
100% magnetic irrigation	7.15 c	10.36 a	8.76 A	3.18 d	4.54 b	3.86 B
80% magnetic irrigation	7.26 c	10.24 a	8.75 A	3.97 c	5.36 a	4.66 A
60% magnetic irrigation	6.26 d	6.04 e	6.15 C	4.57 b	4.46 b	4.51 A
means	6.79 B	8.58 A		3.64 B	4.42 A	

A multiple range test at the 5% level indicates that values in a column or row that are followed by the same capital or small letter(s) do not significantly differ from one another.

Water productivity (WP) kgm^{-3}:

The results in Table 7 show that in the first season, irrigation with 80% ETc. magnetic water provided the highest water productivity, followed by irrigation with 80% ETc. Furthermore, in the second season, irrigation with 80% and 60% ETc. magnetic water revealed the highest levels of water productivity in comparison to the other treatments. These findings are consistent with those of Ismail *et al.* (2022), where showed that globe artichokes irrigated with 75 or 100% ETc. magnetic water during drought stress generated the highest efficiency of water use. Plants of celery and snow peas showed statistically significant increases in water productivity because of magnetic irrigation water (Maheshwari and Grewal 2009). Also, the biofertilizer treatment recorded the maximum water productivity compared to non-biofertilizer in both seasons. In this respect Naveed *et al.*, (2014) indicate that the bacterial endophytes that are carried by maize plants may provide some protection against the suppressive consequences of dryness and endophyte inoculation enhanced maize plants growth under drought stress, leading to superior root/shoot biomass, water content, and survival when compared to the non-inoculated control. Additionally, irrigation with magnetic water at 80% ETc. while receiving biofertilizer treatment gave the best interaction value of water productivity in both tested seasons. Various investigations have demonstrated that PGPR can act as biofertilizers during droughts, directly boosting plant growth by increasing the intake of particular minerals through a variety of methods, such as iron, phosphate and potassium absorption, nitrogen fixation, siderophore employment, and mineral solubilization (Hardoim *et al.* 2015**)**. To preserve the water potential in the tissues, and mitigate drought-stressed plants by PGPR inoculated exhibited a variety of adaptive responses, including osmotic adjustment, the synthesis of osmo protectants (sucrose, proline and beta glycine) and growth regulators, in addition to increasing activity of antioxidants(APX, CAT, GPX, POD Aand DOD) (Chieb and Gachomo 2023).

Average of the head and clove weights:

Data in Table 8 indicates the average weight of garlic head achieved its highest level when the plant was irrigated with normal or magnetically applied water at 100%ETc. in two tested seasons besides irrigation with magnetic water at 80 % ETc. in the first year. The data presented in Table 8 indicates that the maximum average weight of cloves was generated in both seasons when irrigation was done with magnetic water at 100% and 80% ETc. However, in the first season, 100% ETc conventional water had the maximum clove weight with no discernible changes when compared to 100 or 80% ETc. The higher nutrient availability and hormone production brought on by applying magnetic water may be the cause of the rise in garlic head superiority. These factors may also stimulate the creation of beneficial chemical substances. Moussa and Hozayn (2018) found that magnetizing irrigation water had numerous positive effects on potato plant output and its components (the quantity of tubers and potato tuber weight/plant). These findings agree with those of Abdel Nabi (2019) who showed that using water with magnets to irrigate garlic plants improves metrics for quality.

As shown by the data in Table 8 using biofertilizer led to increased average weight heads and clove weights of garlic bulbs in the two investigated seasons when compared to non-biofertilizer, Bhushan *et al*. (2020) reported similar results, stating that the bio fertilizer produced the best average bulb weight. For average head and clove weight of garlic bulbs in both tested seasons, combined applications of 100% ETc. irrigation (either normal or 100% ETc. magnetic water) with biofertilizer treatments produced the maximum levels of interaction. In addition, biofertilizer in conjunction with irrigation using magnetic water at 80% ETc. showed the greatest values for every character in the first season.

Table 8. Effect of magnetic water, bio-fertilizer, and combined treatments on weight of head and clove of garlic throughout the 2019–2020 and 2020–2021 growth seasons.

Treatments	Average of weight of head (g)			Average of weight of clove (g)		
	Non- bio fertilizer	Bio fertilizer	Means	Non- bio fertilizer	Bio fertilizer	Means
				2019/2020		
100% ETc. irrigation (control)	49.23 bc	63.99 a	56.61 A	1.52 ab	1.85 a	1.69 A
100% ETc. magnetic irrigation	46.65 cd	61.90 a	54.27 A	1.52 ab	1.75 a	1.64 A
80% ETc. magnetic irrigation	53.30 b	60.62 a	56.96 A	1.46 abc	1.73 a	1.60 A
60% ETc. magnetic irrigation	42.14 d	42.68 d	42.41 B	1.10 bc	1.00 c	1.05 B
Means	47.83 B	57.30 A		1.40 B	1.59 A	
				2020/2021		
100% ETc. irrigation (control)	60.30 bcd	73.26 a	66.78 A	2.33 e	3.60 a	2.97 C
100% ETc. magnetic irrigation	65.72 b	74.68 a	70.20 A	2.87 d	3.40 ab	3.13 AB
80% ETc. magnetic irrigation	56.34 cd	63.61 b	59.98 B	3.20 bc	3.14 bc	3.17 A
60% ETc. magnetic irrigation	55.46 d	62.79 bc	59.12 B	3.02 cd	3.00 cd	3.01 BC
Means	59.46 B	68.59 A		2.86 B	3.29 A	

A multiple range test at the 5% level indicates that values in a column or row that are followed by the same capital or small letter(s) do not significantly differ from one another.

Number of cloves per head and bulb ratio:

The data shown in Table 9 indicates that throughout the two tested seasons, irrigation using 100% ETc. magnetic water produced the most numbers of cloves per head. Using magnetic water irrigation at 80% ETc during the first season achieved the greatest number of cloves per head. However, during the 2019–2020 and 2020–2021 growth seasons, the 80% ETc. irrigation with magnetic water achieved the highest bulb ratio. In contrast to non-magnetic water irrigation, Helaly (2018) revealed that the average total number of clusters /plants, average fruit weight and total number of fruits/plants were improved substantially while using magnetic water. This is likely because the use of magnetic water mitigated the negative effects of low moisture Hassan *et al.* (2019) on the moringa plant. The bio fertilizers treatment significantly had no effects on number of cloves per head in the two tested seasons. Moreover, In the first season, the bulb ratio was not significantly impacted by the bio fertilizer. In contrast to non-bio-fertilizers, bio-fertilizers exhibited a greater bulb ratio % in the second growing season.

Table 9. Magnetic water, bio-fertilizer, and combined effect on number of clove and bulb ratio of garlic throughout the 2019–2020 and 2020–2021 growth seasons.

Treatments	No. clove of head			Bulb ratio %		
	Non- bio fertilizer	Bio fertilizer	Means	Non- bio fertilizer	Bio fertilizer	Means
			2019/2020			
100% ETc. irrigation (control)	9.04 c	9.44 bc	9.24 B	0.17 d	0.22 c	0.19 C
100% ETc. magnetic irrigation	10.67 a	10.29 ab	10.48 A	0.24 b	0.29 a	0.27 A
80% ETc. magnetic irrigation	10.11 ab	10.34 ab	10.22 A	0.30 a	0.24 b	0.27 A
60% ETc. magnetic irrigation	10.00 ab	9.89 abc	9.95 AB	0.20 c	0.21 c	0.21 B
Means	9.95 A	9.99 A		0.23 A	0.25 A	
			2020/2021			
100% ETc. irrigation (control)	8.33 c	10.00 a	9.17 A	0.16 cd	0.17 c	0.17 BC
100% ETc. magnetic irrigation	9.67 ab	9.67 ab	9.67 A	0.14 d	0.22 a	0.18 B
80% ETc. magnetic irrigation	8.00 c	8.67 bc	8.33 B	0.20 b	0.22 a	0.21 A
60% ETc. magnetic irrigation	7.67 c	7.67 c	7.67 C	0.15 cd	0.15 cd	0.16 C
Means	8.42 A	9.00 A		0.16 B	0.19 A	

A multiple range test at the 5% level indicates that values in a column or row that are followed by the same capital or small letter(s) do not significantly differ from one another.

The best results were obtained when 100% magnetized water and biofertilizer were combined, since this resulted in the maximum numbers of cloves per head in both seasons. In addition, no significant difference with 80% ETc. magnetized water under the bio or non-biofertilizer in the first season. Further, in comparison to the other treatments in both seasons, the bulb ratio percentage was higher with a combined application of 100% ETc. irrigation of magnetized water and biofertilizers. Furthermore, the highest bulb ratio value in the second season is obtained from the interaction of 80% ETc. magnetized water with the bio biofertilizer.

Dry matter:

When compared to the other treatments in the two tested years, the results in Fig. 1 show that applying 60% ETc. magnetic water produced the highest dry matter percentage. In this respect, Ismail *et al*. (2022), globe artichokes exhibited the highest dry matter when irrigated with either 75% or 100% ETc. magnetic water. Adding bio fertilizer increased most dry matter (Fig 1). In general, bio fertilizer gave a higher dry matter percentage compared with control treatment in the two growing seasons. These findings are consistent with those of Rahnama *et al.* (2023), that are reported that seed priming with PGPB strains increased the dry weight of Secale montanum seedlings.

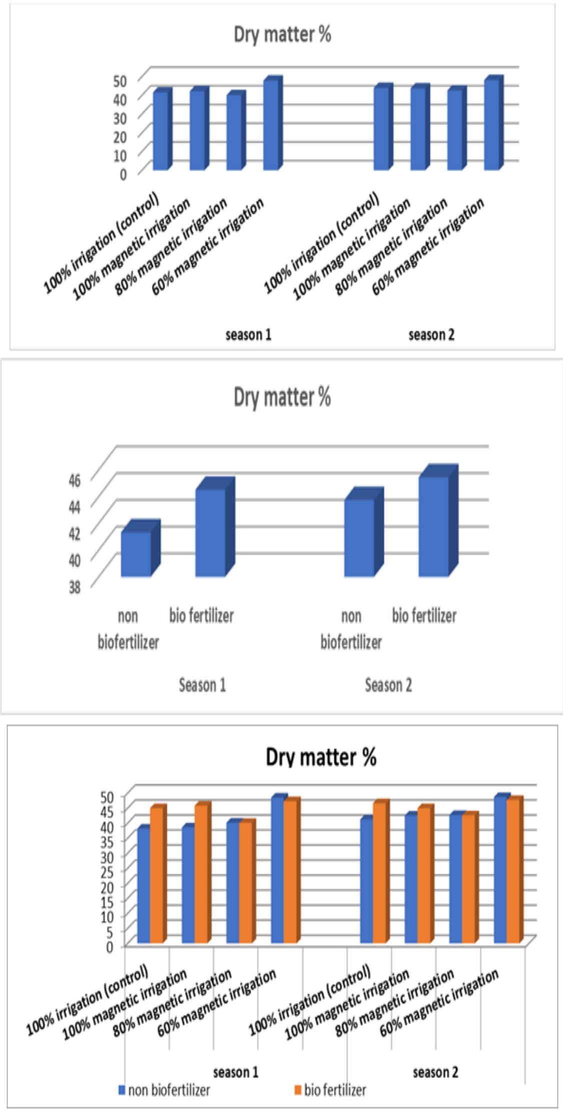

Fig. 1. The impact of magnetic water, bio-fertilizer, and combined treatments on Dry matter % of bulb of garlic throughout the 2019–2020 and 2020–2021 growth seasons.

In comparison to the other treatments in both tested seasons, Fig. 1 demonstrates that applying 60% of magnetic water irrigation with bio or non-bio fertilizers greatly increased the dry matter percentage.

Total soluble solids % of garlic bulb:

Fig. 2 shows that during the two growing seasons, irrigation using magnetic water at 100% ETc. provided the maximum TSS bulb content. The result was consistent with El-Merghany *et al.* (2021) who found that Hyany date palm cultivar with magnetic water irrigation exhibited the maximum concentration of soluble solids. TSS % bulb content was not affected by the addition of bio fertilizers in the first season. On the other hand, the bio fertilizer revealed a higher value of TSS % bulb content in contrast to the control during the second season Fig 2. During the two growth seasons, the combination of both biofertilizers and non-biofertilizers under irrigation with magnetic water at 100% ETc provided the best interaction of the TSS (Fig, 2). Our results agree with the findings of Ali *et al*. (2019), who observed magnetized water with chemical or bio fertilizers produced the highest rate of total soluble solids in melon (*Cucumis melo* L.) after three days of storage.

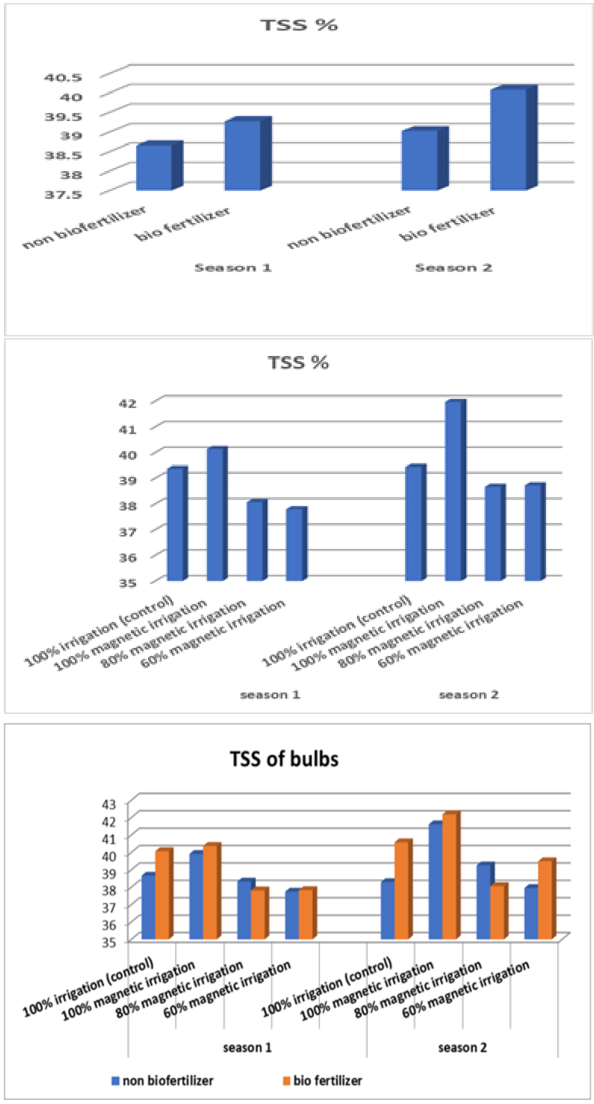

Fig. 2. Impact of magnetic water, biofertilizer, and combination treatments on garlic bulb TSS throughout the growing seasons of 2019–2020 and 2020–2021.

Weight loss of bulb of garlic:

Data in Fig. 3 indicates that after three months of storage, the irrigation 100% or 60% ETc. magnetic water treatments significantly decreased the garlic weight loss of bulb in both growing seasons. These results are in line with those of Moussa and Hozayn (2018), who observed that the application of magnetic water significantly decreased the percentage of infected potato tubers after 60 days of storage. However, bio fertilizer had no significant effect on weight loss of bulb in the two tested seasons. Moreover, the interaction between irrigation of 100% or 60% magnetic water with bio fertilizer significantly decreases this weight loss of garlic bulb in the two growing seasons.

Concerning the irrigation of garlic with magnetized water, the results after five months of storage are listed in Fig. 3 showed that there was a significant effect on bulb weight loss % in both growing seasons. The bulbs with the lowest percentage of weight loss were those treated with 60% irrigation with magnetic water. The highest loss in weight of garlic bulbs was found when 100% normal irrigation. By suppressing respiration rate and ethylene, magnetic water may enhance the quality of fruits and increase fruit and vegetable shelf life during storage (Saletnik *et al.*2022).

On the other hand, bio fertilizer treatment had insignificant effect on bulb weight loss of garlic in both tested seasons. However, when compared to the other treatments in both seasons, the interaction of 60% magnetized water treated with biofertilizer showed the smallest percentage of weight loss.

Fig. 3. Impact of magnetic water, biofertilizer, and combination treatments on weight loss of bulb of garlic after 3, 5 and 7 months throughout the 2019–2020 and 2020–2021 growth seasons.

On the contrary, the significant lowest bulb weight loss after seven months of storage was detected with the irrigation of 60% magnetized water in two tested seasons.

However, application of bio fertilizer had a significant effect on bulb percentage of weight lost in the 1st season. While the application of biofertilizer in the second season showed no discernible impact on bulb weight reduction (Fig. 3). In addition to, the lowest loss of weight of bulbs was found when garlic bulbs were treated with 100 or 80 % magnetized water with non-bio fertilizer and 60% magnetized water with bio fertilizer in first season, while the lowest value was obtained in weight of garlic bulb treated with60 % magnetized water with bio fertilizer in the second season. In contrast to plants watered with regular water, Abdel Nabi (2019) suggested irrigating garlic plants with magnetic water to maximize the quality parameters of storage.

Relations between crops and water:

The amount of water utilized for irrigation (IWA, m^3/fed):

Table 10 shows the seasonal rates of irrigation water application (IWA, m3/fed) by garlic plants under various treatments for soil moisture stress. For the tested amounts of applied irrigation water (AIW) 100, 80 and 60 % ETc., results indicated that recorded the highest figures of seasonal applied water, which amounted at 2152 and 2291 m^3 fed-1 for 100 % ETc. treatment, followed 1721 and 1833 m^3 fed-1 for 80% ETc. treatment, then 1291 and 1374 m^3 fed-1 for 60% ETc. treatment in 2019/20 and 2020/21 seasons, respectively. According to the findings, garlic plants require more water during the second growing season than they need during the first. These results are primarily caused by of variations in meteorological conditions, such as rising air temperatures. In this regard, Hafiz and Ewis (2015) reported that evaporation as well as transpiration for crops of onions were substantially boosted by increasing the quantity of irrigation water. Additionally, El-Akram (2012) revealed that when onions were irrigated more frequently—that is, when 40% of the available soil moisture was depleted—their actual evapotranspiration (ETc.) was higher than when they were irrigated at 60 and 80% depletion rates. The results that were achieved are in line with the findings of Sankara *et al.* (2008).

Table 10. Impact of irrigation treatments on the total amount of water employed throughout the 2019–2020 and 2020–2021 growing seasons.

Month	ETc. 100 %		ETc. 80 %		ETc. 60 %	
	m^3/fed./day	m^3/fed./month	m^3/fed./day	m^3/fed./month	m^3/ fed./day	m^3/fed./month
2019/2020						
October	10.9	174.7	8.7	139.8	6.6	104.8
November	11.4	341.9	9.1	273.5	6.8	205.1
December	9.9	308.1	8.0	246.5	6.0	184.9
January	12.8	397.8	10.3	318.3	7.7	238.7
February	13.3	372.8	10.7	298.2	8.0	223.7
March	13.4	414.5	10.7	331.6	8.0	248.7
April	14.2	141.8	11.3	113.4	8.5	85.1
Total		2152		1721		1291
2020/2021						
October	11.9	239.0	9.56	191.2	7.17	143
November	9.3	279.7	7.46	223.8	5.59	168
December	9.6	297.3	7.67	237.8	5.75	178
January	14.0	432.6	11.16	346.0	8.37	260
February	13.8	385.7	11.02	308.6	8.27	231
March	14.6	451.4	11.65	361.1	8.74	271
April	20.5	205.1	16.41	164.1	12.31	123
Total		2291		1833		1374

On the other hand, the results of Table (10) show that the applied irrigation water began low (in October) when plants were small and in their early stages of growth and gradually increased over time, peaking in March when plant growth reached its maximum, reflecting the highest water demand.

CONCLUSION

It is recommended to use 80% ETc. magnetized water from evapotranspiration with biofertilizers to give the highest productivity and quality of garlic bulbs. Thus, we save 20% of the water consumption of garlic through magnetized water and increase the storage period to seven months by adding 60% ETc. magnetized water of irrigating garlic crops with biofertilizer.

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تأثير مستويات الري بالماءالعادى و الممغنط والتسميد الحيوي علي نمو وتخزين محصول الثوم

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الملخص

أجريت تجربة حقلية خلال موسمي الزراعة 2020/2019 و 2021/2020 بمحطة بحوث القناطر بمحافظة القليوبية لدراسة تأثير الري بالمياه العادية والمياه الممغنطة بنسبة 60 و 80 و 100% من البخر النتح مع الأسمدة الحيوية PGPR خليط من سلالات (*Pseudomonas aeruginosa*) و *Burkholderia hytofirmonas*) والتفاعل بينهم وتاثيره على الإنتاجية وكفاءة استخدام الماء للثوم الصنف سدس 40 و استخدمت للتجربة تصميم قطع منشقة مرة واحدة بثلاثة مكرارات، حيث خصصت القطع الرئيسية لمعاملات الماء الممغنط بينما القطع الفرعية للأسمدة الحيوية. أظهرت النتائج أن أفضل نمو خضري و إنتاجية الطن/فدان ومتوسط وزن الفص وعدد الفصوص لكل رأس، ومعدل التبصيل وكفاءة أستخدام المياه قد تم تحقيقها عند ري نباتات الثوم بـ % 80 و100% من البخر نتح من الماء الممغنط. أدى استخدام الأسمدة الحيوية إلى إنتاج أعلى نمو خضري للثوم، وأنتاجية وجودة أبصال الثوم بالمقارنة مع الكنترول. وأعطي أعلي نمو وانتاج و مكونات الأنتاج وكفاءة استخدام المياه عند المعاملة بكلا من الري بالماء الممغنط مع 80 و100% من البخر نتح والأسمدة الحيوية وعلاوة على ذلك أدى استخدام الأسمدة الحيوية و60% من الماء الممغنط إلى أقل فقد في الوزن للابصال بعد سبعة أشهرمن تخزين رؤس الثوم. وتوصي الدراسه باستخدام الري بالماء الممغنط 80% من البخر نتح مع الأسمدة الحيوية لأعطاء أعلي انتاجية وجودة لأبصال الثوم وكما تم نوفير 20% من الاستهلاك المائي للثوم وزيادة فترة التخزين لسبعه أشهر عن طريق ري محصول الثوم بالماء الممغنط عند 60 %من البخر نتح.