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Application of magnetic field improves growth, yield and fruit quality of tomato irrigated alternatively by fresh and agricultural drainage water

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ABSTRACT

Although the North Delta region in Egypt is one of the most densely populated areas in the world, it suffers from a severe shortage of fresh water needed to irrigate crops. So usually farmers resort to the use of low-quality water, such as agricultural drainage water, which could pose a threat to the quality of crops and then human health. Two field experiments were carried out during two consecutive summer seasons of 2014 and 2015 aimed at delivering more information about the pros and cons of alternative irrigation for tomato using fresh and agricultural drainage water with or without applying of magnetic field. The twelve surface irrigations, which tomato needs during its whole growing season, were applied alternatively between fresh and agricultural drainage water, respectively, at the following percentages (100 + 0), (75 + 25), (50 + 50), (25 + 75) and (0 + 100). Magnetic field was applied using iron fillings at a rate of 150 kg ha^{-1}. The results revealed that growth parameters, early, total and relative yield, marketable yield and total chlorophyll and NPK content of leaves were gradually decreased with increasing the irrigation using agricultural drainage water. However, irrigating tomato by 100% fresh water had the highest values, while using of 100% agricultural drainage water displayed the lowest values. Contrarily, vitamin C, total soluble solids (TSS) and fruit firmness where at their highest values when tomato irrigated by 100% of agricultural drainage water. Applying of magnetic field not only enhances the growth, yield and quality of tomato under irrigation using agricultural water but also under fresh water. These results are of importance in areas where the use of agricultural drainage water irrigating crops is inevitable for enhancing yield and its quality and consequently ensuring food safety.

1. Introduction

Tomato (*Solanum lycopersicon*) is one of the most important and widely distributed vegetable crops grown in Egypt for either local consumption or exportation. Almost 30% of the total area dedicated to vegetable crops in Egypt is cultivated by tomato (Ministry of Agriculture and Land Reclamation, Egypt, 2016). The water resources in Egypt are very limited, particularly in the North Delta region, and depend mainly on the stable historical right in River Nile water. The importance of using agricultural drainage water, as an untraditional source of water, comes from the fact that it forms a great portion of the strategy of water resources. Hence, adding this non-traditional source decreases the huge gap between the available and required water needs (Ministry of Agriculture and Land Reclamation, Egypt, 2016). In Egypt, nowadays, interesting in using agricultural drainage water, especially in the lands which suffer from water shortage, is growing fast due to rapid increase in population and changing climate. In this concern, Malash et al. (2008) stated that use of saline drainage water for irrigation has an environmental advantage. It reduces the fresh water requirements for salt tolerant crops and decreases the volume of drainage water requiring disposal and treatment. Younis et al. (2010) cited that irrigating of tomato plants with 80% fresh water and 20% drainage water caused a little change in the tomato yield compared to using 100% fresh water. In any case, there are many caveats to be considered before directing agricultural drainage water towards irrigation of crops, i.e., alkalinity, salinity and contamination with heavy metals as well as soil drainage and plant tolerance to such abiotic stresses (Abd El-Naim, 1995).

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Different chemical and non-chemical methods have been applied to improve crop yield and quality, one of which is magnetic field (Jinapang et al., 2010). The influence of magnetic field on plant development is studied rather intensively but still not enough deeply. Previous studies revealed that magnetic field improves the plant growth characteristics (Ahmed et al., 2013), affects soil nutrient availability (Maheshwari, 2009), plays an important role in cation uptake capacity and has a positive effect on immobile plant nutrients uptake, and leaching of soil salts (Estiken and Turan, 2004) as well as increases the yield of tomato (De Souza et al., 2005), pepper (Ahmed et al., 2013), cowpea and eggplant (Surendran et al., 2016). The use of magnetic field may overcome the deleterious effect of agricultural drainage water irrigation particularly on vegetable crops (Maheshwari, 2009; Selim et al., 2013; Surendran et al., 2016).

The present work aimed at delivering more information about the pros and cons of alternative irrigation for tomato using fresh and agricultural drainage water with or without applying of magnetic field. Also, growth dynamics and yield of tomato as well as economic efficiency were evaluated.

2. Materials and methods

2.1. Experimental location

Two field experiments were carried out during two consecutive summer seasons of 2014 and 2015 in Kafr El-Sheikh, Egypt (31° 5′ 47.7″ N and 30° 56′ 53.5″ E). Type of the experimental soil was clayey with the following chemical characteristics: pH 8.21; electrical conductivity (EC) 0.631 dS m^{-1}; and soluble cations and anions (meq L^{-1}) were Ca^{2+} 13.5, Mg^{2+} 12.1, K^{+} 0.13, Na^{+} 3.69, Cl^{-1} 4.17, CO_3^{2-} 1.42 and SO_4^{2-} 0.88. The seedlings were transplanted on 18th and 22nd March in both seasons, respectively. The experimental plot contained three ridges making 7 m in length and 1.2 m in width at spacing of 50 cm between rows making a total area of 25.2 m^2 per plot. Surface irrigation method was used. The recommended fertilizers of N (285 kg ha^{-1} N), P (119 kg ha^{-1} P_2O_5) and K (171 kg ha^{-1} K_2O) were added according to the recommendations of the Egyptian Ministry of Agriculture and Land Reclamation. The other agricultural practices were performed according to the usual local agricultural management. Meteorological data of experimental location during both growing seasons are presented in Table 1.

2.2. Experimental design and treatments

The experimental layout was a split-plot design with three replicates with a total of 30 plots. Irrigation treatments were randomly assigned as the main plots, each main plot was divided subsequently into subplots which randomly received the treatments of magnetic field (0 and 150 kg ha^{-1}). The irrigation treatments included 5 alternative irrigations of fresh and agricultural drainage water. Based on water requirements of tomato, which are 12 surface irrigations during the whole growing season, the treatments implied alternative supply of water as the first irrigation was done using fresh water then the second irrigation was applied from agricultural drainage water (Table 2). The average electrical conductivity (EC) for the used agricultural drainage water was 2.42 and 2.09 dS m^{-1}, while pH was 7.65 and 7.45 in 2014 and 2015, respectively. Values of EC of all 12 irrigations of fresh and agricultural drainage water as well chemical properties of agricultural drainage water during the growing seasons are in Tables 3 and 4. The magnetic field was applied using iron filings at the rate of 150 kg ha^{-1}. The applied amount of iron filings was according to the manufacturer (Al-Ahram for Mining Co., El-Maadi City, Egypt.)

Table 1
Meteorological data of experimental location during both growing seasons (2014 and 2015) as monthly average.

Date	Max Temp. (°C)	Min Temp. (°C)	Precipitation (mm)	Wind (km/h)	Relative Humidity (%)	Solar (MJ/m^2)
Mar-2014	22.94	11.71	9.09	3.45	71.46	20.05
Apr-2014	27.50	15.53	6.51	3.87	65.80	25.18
May-2014	30.47	19.57	6.05	4.12	62.90	26.16
Jun-2014	32.65	20.60	5.03	3.43	69.27	28.92
Jul-2014	33.15	23.64	4.08	4.08	69.15	30.25
Mar-2015	22.69	11.69	9.09	3.65	70.59	21.02
Apr-2015	25.64	13.70	8.51	3.99	63.40	24.71
May-2015	30.19	18.69	7.05	4.78	67.70	28.03
Jun-2015	30.85	21.40	6.09	4.39	65.00	29.30
Jul-2015	33.00	22.40	4.76	4.05	69.75	31.09

2.3. Vegetative parameters and yield

A representative sample of five plants was randomly taken per plot for measuring plant growth parameters, i.e., leaf area (dm^2 $plant^{-1}$) and shoots dry mass (g $plant^{-1}$) at 75 days after transplanting.

The following growth attributes were computed at two growth stages (45–60 and 60–75 days) after transplanting according to (Stange et al., 2002):

- Crop growth rate (CGR), it is defined as the increase in plant dry matter per unit of ground area per unit of time (g m^{-2} soil $week^{-1}$) and calculated using the following equation:

$$CGR = \frac{W_2 - W_1}{T_2 - T_1}$$

where: W_1 and W_2 refer to dry mass of two samples at time T_1 and T_2 in weeks, respectively.

- Net assimilation rate (NAR), it is defined as the increase in plant material per unit of leaf area per unit of time (g m^{-2} plant $week^{-1}$) and calculated using the following equation:

$$NAR = \frac{(W_2 - W_1)(Loge\ A_2 - Loge\ A_1)}{(A_2 - A_1)(T_2 - T_1)}$$

where: W_1, A_1 and W_2, $_{A2}$ refer to dry mass and leaf area at the time T1 and T2 in weeks, respectively.

The early fruit yield (Mg ha^{-1}) was measured from the first two pickings; while the total fruit yield (Mg ha^{-1}) was determined from the total weight of fruits collected during all the harvesting periods. Relative yield as percentage of the control yield was also calculated. Economic efficiency was calculated by dividing net profit (Egyptian Pound, L.E ha^{-1}) by total costs (L.E ha^{-1}).

2.4. Quality of yield

Five fruits per plot were randomly selected for measuring the following characteristics: i) marketable fruit yield (Mg ha^{-1}), it was estimated by subtracting non-marketable yield (diseased and malformed fruits) from total yield; ii) vitamin C content (mg 100 g^{-1} fruit), it was estimated by titration with 2, 6 dichlorophenol blue according to (A.O.A.C., 1980); iii) total soluble solids (TSS%), the percentage of TSS in juice of fruits was estimated by a hand refractometer according to (A.O.A.C., 1980); and iv) fruit firmness (kg cm^{-2}), it was determined by Magnus Pressure Tester.

2.5. Soil and water analysis

Soil samples were taken before the experiment at three different depths as (0–20), (20–40) and (40–60 cm) in triplicates. The samples were sealed in polyethylene bags and transported to the laboratory for analysis. The collected soil samples were air dried at room temperature (25 °C), pulverized, passed through a 2 mm sieve and stored until

Table 2
Description of alternative irrigation treatments.

Treatment ID	Description[a]
I_1	12 irrigations of fresh water and zero irrigations of agricultural drainage water (100 + 0%), respectively.
I_2	9 irrigations of fresh water and 3 irrigations of agricultural drainage water (75 + 25%), respectively.
I_3	6 irrigations of fresh water and 6 irrigations of agricultural drainage water (50 + 50%), respectively.
I_4	3 irrigations of fresh water and 9 irrigations of agricultural drainage water (25 + 75%), respectively.
I_5	Zero irrigations of fresh water and 12 irrigations of agricultural drainage water (0 + 100%), respectively.

[a] The number of applied irrigations is calculated based on the water requirements of tomato grown in this area as the farmers apply.

Table 3
Electrical conductivity (EC, dS m^{-1}) of fresh and agricultural drainage water during 2014 and 2015 seasons.

Number of irrigations	2014		2015	
	Fresh water	Drainage water	Fresh water	Drainage water
1	0.586	1.716	0.659	1.820
2	0.632	2.120	0.414	1.647
3	0.760	2.593	0.454	2.700
4	0.547	2.900	0.551	2.900
5	0.467	2.850	0.502	1.890
6	0.562	2.480	0.557	1.832
7	0.578	2.373	0.517	1.868
8	0.652	2.900	0.534	1.967
9	0.508	2.375	0.662	1.920
10	0.540	2.460	0.565	1.910
11	0.575	2.160	0.560	2.700
12	0.530	2.060	0.520	1.940
Mean	0.578	2.420	0.507	2.091

Table 4
Chemical properties of drainage water during 2014 and 2015 seasons.

Character	2014	2015
pH	7.65	7.45
Soluble cations (ppm)		
Na^+	144.9	152.7
K^+	9.98	9.72
Mg^{++}	48.0	47.0
Ca^{++}	20.0	21.0
Soluble anions (meq L^{-1})		
Cl^-	2.6	2.7
CO_3^{--}	0.00	0.00
HCO_3^-	6.40	6.50
Trace elements (ppm)		
Cu^{++}	0.053	0.067
Zn^{++}	0.267	0.285
Mn^{++}	0.337	0.346
Fe^{++}	0.331	0.340
Ni^{++}	0.602	0.580
Pb^{++}	0.430	0.420
Cd^{++}	0.032	0.038

analyzed. The physiochemical characterization of these soils was analyzed according to Sparks et al. (1996) as follows: soil pH was measured in a 1: 2.5 (soil: water suspension) using a pH-meter (JENWAY 3510, UK). Soil electrical conductivity (EC) was measured in a 1: 5 (soil: water extract) using an EC-meter (Mi170, Italy). Soluble cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) and anions (CO_3^{2-}, HCO_3^-, SO_4^{2-} and Cl^-) were determined in a 1:5 (soil: water extract). Water samples (about 2 L) were collected from both fresh and agricultural drainage water used for irrigating tomato plants in triplicate and then filtered. pH and EC were measured by pH- and EC-meters (JENWAY 3510, UK and Mi170, Italy, respectively). Water cations and trace metals (Cu, Zn, Fe, Mn, Ni, Pb and Cd) were measured by atomic absorption spectrometry (AAS) (GBC Avanta E, Victoria, Australia). All soil and water measurements were carried out at the Central Laboratory of Environmental Studies at Kafrelsheikh University according to ISO/IEC 17025 (2005).

2.6. Statistical analysis

Prior to the ANOVA test, Levene's Test for Equality of Variances was performed. The Levene test for different variables at ten treatments was negative, $p < 0.05$, and then the variances are homogeneity. The experimental design was established as a split-plot design with three replicates. Results of the experiments were subjected to two-way analysis of variance by 'CoStat' statistical software program according to Gomez and Gomez (1984) and the means were compared by Duncan's Multiple Range Test (Duncan, 1965).

3. Results and discussion

3.1. Development of tomato under agricultural drainage water and magnetic field

Data presented in Table (5) show that increasing the number of irrigations done using agricultural drainage water significantly and progressively decreased the studied growth parameters (i.e., leaf area, shoots dry mass and crop growth rate); whilst, the differences in net assimilation rate were not significant in the two seasons. The treatment (I_1) resulted in the highest values of leaf area, shoot dry mass, net assimilation rate and crop growth rate followed by treatments of (I_2), (I_3) and (I_4); while, treatment (I_5) recorded the lowest values as well in both seasons. Similar findings were reported in many literature (e.g., Malash et al., 2008; Whab-Allah and Al-Omran, 2012; You et al., 2016). They stated significant decreases in shoot dry mass, leaf area and crop growth rate with increasing EC of irrigating water applied to tomato plants. The harmful effect of irrigation with saline water on growth of tomato plants may be due to alerting leaf water relations and stomatal closure which influence CO_2 exchange and photosynthetic rate (Romero-Aranda et al., 2001). Also, increasing salt content in irrigating water may lead to direct toxic effect on plants, which in turn, diminishes carbohydrate accumulation in plants (Morales et al., 2008). Moreover, the negative effect of salinity on plant growth have been attributed to disturbance in protein assimilation, enzymes activity (Hussein and Oraby, 2008), activity of growth hormones (Kaya et al., 2009) and mineral and water uptake (Hussein et al., 2012).

Application of magnetic field not only affects the chemical properties of water but also, has significant influences on soil features, plant root architecture, and cell membrane permeability. Zúñiga et al. (2016) reported changes in surface tension, viscosity, and evaporation rate of magnetically treated water. Moreover, another effect on water properties was theorized by Khoshravesh et al. (2011), they cited that magnetically treated water had less hydrophobicity, due to its reaction with liberated ions in soil solution, increasing the linkage of water molecules to soil particles. Consequently, soil moisture content was higher in soil irrigated with magnetically treated water than control (water without magnetizing).

The effects of water exposed to magnetic field on soil features were reducing soil pH (Maheshwari and Grewal, 2009), precipitation of carbonate (Alimi et al., 2006), inducing soil microbial activity (Zúñiga et al., 2011), increasing phyto-availability of P and K in soil solution

Table 5
Effect of alternative irrigation with fresh and agricultural drainage water, magnetic field and their interaction on some vegetative growth parameters and growth dynamic of tomato plant during 2014 and 2015 seasons.

Irrigation[a]	2014 season				2015 season			
	Leaf area (dm^2 $plant^{-1}$)	Shoots dry mass (g $plant^{-1}$)	Net assimilation rate (g m^{-2} plant $week^{-1}$)	Crop growth rate (g m^{-2} soil $week^{-1}$)	Leaf area (dm^2 $plant^{-1}$)	Shoots dry mass (g $plant^{-1}$)	Net assimilation rate (g m^{-2} plant $week^{-1}$)	Crop growth rate (g m^{-2} soil $week^{-1}$)
I_1	230.5 a	366.5 a	5.87 a	78.50 a	226.7 a	361.3 a	5.87 a	74.40 a
I_2	221.9 b	353.8 b	5.86 a	75.70 b	220.3 b	350.2 b	5.74 a	73.80 b
I_3	216.6 c	340.4 c	5.79 a	73.35 c	213.3 c	335.2 c	5.65 a	70.85 c
I_4	211.2 d	329.8 d	5.83 a	71.80 d	208.6 d	321.5 d	5.65 a	69.95 d
I_5	204.3 e	319.1 e	5.83 a	70.05 e	207.5 e	313.9 e	5.70 a	69.30 e
Magnetic field[b]								
M_0	206.3 b	321.4 b	5.71 a	69.60 b	205.4 b	318.9 b	5.59 a	68.18 b
M	225.8 a	362.3 a	5.96 a	78.16 a	223.6 a	356.1 a	5.85 a	76.46 a
Interaction								
I_1Mo	220.7 d	343.1 e	5.71 a	73.50 e	218.8 d	340.2 d	5.70 a	73.00 d
I_1M	240.4 a	389.9 a	6.02 a	83.50 a	234.9 a	382.3 a	6.03 a	83.40 a
I_2Mo	210.6 f	334.2 g	5.82 a	71.90 f	213.3 f	326.8 f	5.59 a	69.80 e
I_2M	233.2 b	372.8 b	5.89 a	79.50 b	227.4 b	364.5 b	5.88 a	77.80 b
I_3Mo	207.3 g	319.0 h	5.65 a	68.80 g	205.4 g	312.5 g	5.56 a	67.20 f
I_3M	225.8 c	361.8 c	5.93 a	77.90 c	222.9 c	351.9 c	5.74 a	74.50 c
I_4Mo	201.5 h	309.2 i	5.68 a	87.40 h	203.4 h	303.2 h	5.55 a	66.50 g
I_4M	219.0 e	350.4 d	5.98 a	76.20 d	218.6 d	340.6 d	5.76 a	73.40 d
I_5Mo	197.9 i	301.4 j	5.68 a	66.40 i	199.6 i	297.1 i	5.56 a	65.40 h
I_5M	210.6 f	336.7 f	5.97 a	73.70 e	214.5 e	330.6 e	5.83 a	73.20 d

Means followed by the same letter in the same column are significantly different at the 5% level according to Duncan's multiple range test.
[a] (I_1 = 100% fresh water, I_2 = 75% fresh water + 25% drainage water, I_3 = 50% fresh water + 50% drainage water, I_4 = 25% fresh water + 75% drainage water, I_5 = 100% drainage water.
[b] M_0 = without magnetic field, M = with magnetic field (at the rate of 150 kg ha^{-1} iron filings).

(Maheshwari and Grewal, 2009), reducing electrical conductivity (Sadeghipour and Aghaei, 2013), and precipitation of salts (Zúñiga et al., 2016). On the other hand, the effect on structure and permeability of cell membrane and subsequently increasing ion transportation via channels, which later will lead to changes in metabolic activities in cells, were clearly reported by Balouchi and Sanavy (2009). Furthermore, treating irrigation water with magnetic field mitigated the detrimental impacts of saline water (1500 and 3000 ppm NaCl) on plant growth of celery and bean, respectively (Maheshwari and Grewal, 2009). These consequences for application of magnetic field during irrigation resulted in an increase in nutrient uptake by tomatoes (Duarte Diaz et al., 1997) and citrus (Hilal et al., 2002), and finally are expected to enhance the growth, development, and productivity of various crops.

The results indicated, also, that magnetic field treatment (M) significantly enhanced the tomato growth recording higher growth parameters than untreated tomato plants with magnetic field (M_0) in both seasons (Table 5). These results may be attributed to the generated impacts on the structure of cell membranes and increasing their permeability and ions transport, which consequently affects metabolic pathway activities (Stange et al., 2002). Moreover, Ratushnyak et al. (2008) showed that the magnetic treatment increased the amount of microbial community of the soils, which may expand the bioavailability of macro/microelements in the soil to be easily taken up by plants. Similar results were reported to tomato (Abou El-Yazied et al., 2012), pepper (Ahmed et al., 2013) and *Phaseolus vulgaris* (Najafi et al., 2013).

The combined interactions among alternative irrigation treatments and magnetic field significantly affected all the measured growth parameters, although the differences in net assimilation rate were not significant in both seasons. Therefore, the highest values of growth parameters were obtained from (I_1M) treatment, followed mostly by (I_2M), (I_3M) and (I_4M) treatment, while the lowest values resulted from (I_5M_0) treatment in both seasons. The other treatments manifested intermediate effect on this concern (Table 5). Some investigators suggested that magnetic field accompanied with irrigation water types may alter the characteristics of cell membranes and cell reproduction causing some changes in cell metabolism and various cellular functions including gene expression, proteins biosynthesis and enzyme activities in tomato (De Souza et al., 2005) and mung bean (Jinapang et al., 2010). Likewise, several researchers revealed that the combination between magnetic field and saline irrigating water increased one or more of the evaluated growth parameters compared with the sole saline water without magnetic field in tomato (Selim et al., 2013) and cowpea and eggplant (Surendran et al., 2016).

3.2. Tomato yield and its economic efficiency

Data presented in Table (6) show depending on agricultural drainage water as a main source for irrigating tomato led to progressive decrease in early and total yields, relative yield % and economic efficiency in both seasons. Moreover, treatment (I_1) resulted in the highest values of all the studied yield parameters followed by (I_2), (I_3) and (I_4) treatments; whereas, the lowest values corresponded to treatment (I_5). Our results were in the same line with those have been previously reported to tomato (Whab-Allah and Al-Omran, 2012), pepper (Semiz et al., 2014), cucumber (Abu-Zinada, 2015; Alsaeedi et al. 2018, 2019) and *Phaseolus vulgaris* (Alsaeedi et al., 2017). Their results clearly proved that saline water irrigation reflected negative significant effect on both early and total yields. The decline in both early and total yields with increasing sharing of agricultural drainage water in irrigating tomato may be due to some failure phenomena in fruit setting in tomato flowers as this refers to the reduction of pollen grains viability, flowering bud size, ovules and pistil length (Cuartero and Fernandez, 1999) as well as pollen number (Ghanem et al., 2009). Also, Zayton et al. (2009) revealed that increasing the EC reduced the fruit number per plant, and thus produced smaller fruit size and weight and consequently decreased the early and total yields. Magnetic field treatment significantly increased early and total yields, relative yield % and economic efficiency than control both seasons (Table 6). Similar conclusions were also cited for pepper (Ahmed et al., 2013), tomato (Yusuf and Ogunlela, 2015) and cowpea and eggplant (Surendran et al., 2016). The increment in fruit yield as a result of magnetic field treatment may

Table 6
Effect of alternative irrigation with fresh and agricultural drainage water, magnetic field and their interaction on early and total yields, relative yield and economic efficiency of tomato during 2014 and 2015 seasons.

Irrigation[a]	2014 season				2015 season			
	Early yield (Mg ha^{-1})	Total fruit yield (Mg ha^{-1})	Relative yield (as % of control)	Economic efficiency	Early yield (Mg ha^{-1})	Total fruit yield (Mg ha^{-1})	Relative yield (as % of control)	Economic efficiency
I_1	7.0 a	55.25 a	100.0	5.27	7.0 a	52.88 a	100.0	5.15
I_2	6.8 b	50.58 b	91.5	4.87	6.5 b	48.88 b	91.4	4.65
I_3	6.5 c	47.68 c	86.3	4.54	6.3 c	45.45 c	85.9	4.28
I_4	6.0 d	46.23 d	83.7	4.37	6.0 d	43.90 d	83.0	4.11
I_5	5.3 e	44.85 e	81.2	4.21	5.5 e	42.70 e	80.7	3.97
Magnetic field[b]								
M_0	6.5 b	46.90 b	84.9	4.42	5.8 b	45.03 b	85.2	4.21
M	6.8 a	50.93 a	92.2	4.96	7.0 a	48.50 a	91.7	4.82
Interaction								
I_1Mo	6.8 c	52.65 b	100.0	5.04	6.5 d	50.83 b	100.0	5.12
I_1M	7.5 a	57.83 a	100.1	5.49	7.3 a	54.93 a	100.1	5.17
I_2Mo	6.3 e	48.83 e	92.7	4.87	6.3 e	47.40 d	93.3	4.65
I_2M	7.0 b	52.33 c	99.4	4.88	7.0 b	50.35 c	99.1	4.66
I_3Mo	6.0 f	45.68 h	86.8	4.50	6.0 f	43.80 h	86.2	4.27
I_3M	6.8 c	49.70 d	94.4	4.58	6.8 c	47.13 e	92.7	4.27
I_4Mo	5.5 h	44.43 i	84.4	4.35	5.5 h	42.23 i	83.1	4.09
I_4M	6.5 d	48.00 f	91.2	4.39	6.3 e	45.65 f	89.8	4.13
I_5Mo	5.0 i	42.88 j	83.1	4.16	5.0 i	40.93 j	80.5	3.93
I_5M	5.8 g	46.83 g	88.9	4.26	5.8 g	44.45 g	87.5	4.00

Means followed by the same letter in the same column are significantly different at the 5% level according to Duncan's multiple range test.
[a] (I_1 = 100% fresh water, I_2 = 75% fresh water + 25% drainage water, I_3 = 50% fresh water + 50% drainage water, I_4 = 25% fresh water + 75% drainage water, I_5 = 100% drainage water.
[b] M_0 = without magnetic field, M = with magnetic field (at the rate of 150 kg ha^{-1} iron filings).

be attributed to improved capacity for nutrients and water uptake, better shoot and root growth (De Souza et al., 2005), which led to an increase in growth and consequently yield.

Results of interaction between irrigation and magnetic field indicated that treatment (I_1M) generated the heaviest weight of early yield followed by (I_2M) and (I_3M) treatments; while, the lowest yield was obtained from treatment (I_5M_0) in both seasons (Table 5). Regarding total fruit yield, relative yield % and economic efficiency, (I_1M) treatment produced the highest values of the three parameters followed by (I_1M_0) and (I_2M) interaction treatments; however, the lowest value was achieved at treatment (I_5M_0). The relative yield obtained was ranged from 100.1% for (I_1M) to 83.1 and 80.5% for (I_5M_0) in both seasons, respectively. Also, economic efficiency ranged from 5.49 to 5.17 for (I_1M) to 4.16 and 3.93 for (I_5M_0) in both seasons, respectively (Table 6).

The positive effect of the interaction between magnetic field and type of irrigating water on early and total yields as compared with the sole saline water may be due to that magnetic field assisting to reduce the Na toxicity at cell level by detoxification Na either by restricting the entry of Na at membrane level or by reduced absorption of Na by plant roots (Maheshwari, 2009). Our results were in agreement with those cited for tomato (Abou El-Yazied et al., 2012), potatoes (Hachicha et al., 2016) and cowpea and eggplant (Surendran et al., 2016). They stated that the combined interactions between magnetic field with saline water increased both early and total yields as compared with the saline water alone (control).

3.3. Quality of tomato's fruit irrigated with agricultural drainage water under magnetic field

Irrigation tomato plants with more agricultural drainage water than fresh water gradually decreased the marketable fruit yield in both seasons (Table 7). Furthermore, treatment (I_1) resulted in the largest marketable fruit yield followed by (I_2), (I_3) and (I_4) treatments; while, the lowest marketable yield was recorded at treatment of (I_5) in both seasons. This result is related to that obtained from total fruit yield (Table 6) and may be interpreted by the same way; since the marketable yield represents the main component of total yield. These results are in accordance with those reported for tomato (Zayton et al., 2009) and pepper (Navarro et al., 2010). They mentioned that increasing water salinity caused a decrease in marketable yield. In contrast, vitamin C, total soluble solids and fruit firmness were progressively increased with increasing the number of irrigation done with agricultural drainage water. Thus, treatment (I_5) enhanced the growth and consequently resulted in the highest values; whereas, the lowest values were obtained from (I_1) treatment (Table 7). The increment in vitamin C might be due to the accumulation of free amino acids and sugars in tomato fruits with saline water (Fathy et al., 2005). Also, the raise of TSS% in fruits of tomato plants irrigated with more agricultural drainage water than fresh water may be a result of the interaction between reduced fruit water content, increased ion content and maintained hexose accumulation as proposed by Zegbe-Dominguez et al. (2006). These results are in harmony with those of Bustan et al. (2005) reported on TSS and fruit firmness, Zhai et al. (2015) on vitamin C and You et al. (2016) on TSS in tomato fruits.

Magnetic field treatment significantly increased marketable fruits yield, vitamin C, TSS and fruit firmness as compared with the non-magnetic field treatments in both seasons (Table 7). Atak et al. (2003) outlined that magnetic field may alter the characteristics of cell membrane causing changes in the cell metabolism and help in pectin formation and Ca absorption causing an increase in fruit firmness. These results are encouraged by those of Peterson et al. (1998) on fruit firmness, De Souza et al. (2005) on TSS, and Ahmed et al. (2013) on vitamin C and marketable yield of tomato and sweet pepper fruits.

The treatment of (I_1M) provided the highest marketable yield followed by (I_1M_0) and (I_2M) treatments; and the lowest yield was obtained at treatment of (I_5M_0) in both seasons (Table 6). The other treatments manifested an intermediate effect. Otherwise, the highest values of vitamin C, TSS and fruit firmness were measured at (I_5M) treatment. The lowest values were achieved at (I_1M_0) treatment (Table 7). These results are in the same line with those obtained by Ahmed et al. (2013) for marketable yield, Selim et al. (2013) for vitamin C, Feizi et al. (2013) for TSS and Efihimiadou et al. (2019) for fruit firmness. They found that the combined interactions between

Table 7
Yield, vitamin C, total soluble solids and firmness of tomato fruits during 2014 and 2015 seasons.

Irrigation[a]	2014 season				2015 season			
	Marketable fruit yield (Mg ha^{-1})	Vitamin C (mg 100 g^{-1}) fresh fruit	Total soluble solids (%)	Firmness (kg cm^{-2})	Marketable fruit yield (Mg ha^{-1})	Vitamin C (mg 100 g^{-1}) fresh fruit	Total soluble solids (%)	Firmness (kg cm^{-2})
I_1	54.2 a	26.1 e	5.21 e	8.28 e	51.9 a	26.0 e	5.16 e	8.44 e
I_2	49.4 b	26.5 d	5.62 d	8.52 d	47.8 b	26.4 d	5.58 d	8.65 d
I_3	46.3 c	27.0 c	6.05 c	8.73 c	44.3 c	27.1 c	6.00 c	8.87 c
I_4	44.8 d	27.4 b	6.46 b	9.04 b	42.7d	27.5 b	6.40 b	9.13 b
I_5	43.2 e	27.9 a	6.65 a	9.35 a	41.3 e	27.8 a	6.62 a	9.42 a
Magnetic field[b]								
M_0	45.5 b	26.6 b	5.85 b	8.74 b	43.8 b	26.6 b	5.72 b	8.73 b
M	49.7 a	27.3 a	6.22 a	9.00 a	47.4 a	27.3 a	6.18 a	9.01 a
Interaction								
I_1Mo	51.5 b	25.7 g	5.02 f	8.09 g	49.8 b	25.5 g	4.90 g	8.34 e
I_1M	56.9 a	26.5 e	5.40 e	8.47 e	54.0 a	26.5 e	5.42 f	8.60 d
I_2Mo	47.6 e	26.1 f	5.39 e	8.31 f	46.3 d	25.8 f	5.36 f	8.48 e
I_2M	51.2 c	26.9 d	5.85 d	8.73 d	49.3 c	27.0 d	5.80 e	8.92 c
I_3Mo	44.2 h	26.7 e	5.80 d	8.51 e	42.6 h	26.8 d	5.76 e	8.69 d
I_3M	48.4 d	27.3 c	6.30 c	8.95 c	46.0 e	27.4 c	6.24 d	9.05 c
I_4Mo	42.9 i	27.0 d	6.42 c	8.83 c	41.0 i	27.3 c	6.18 d	8.94 c
I_4M	46.7 f	27.8 b	6.68 b	9.25 b	44.4 f	27.7 b	6.62 b	9.32 b
I_5Mo	41.1 j	27.7 b	6.45 c	9.13 b	39.5 j	27.6 b	6.41 c	9.24 b
I_5M	45.4 g	28.1 a	6.85 a	9.57 a	43.1 g	28.0 a	6.83 a	9.60 a

Means followed by the same letter in the same column are significantly different at the 5% level according to Duncan's multiple range test.
[a] (I_1 = 100% fresh water, I_2 = 75% fresh water + 25% drainage water, I_3 = 50% fresh water + 50% drainage water, I_4 = 25% fresh water + 75% drainage water, I_5 = 100% drainage water.
[b] M_0 = without magnetic field, M = with magnetic field (at the rate of 150 kg ha^{-1} iron filings).

magnetic field and saline water increased fruit quality of some vegetable crops compared with irrigation with saline water without magnetic field.

4. Conclusion

The present paper highlights the pros and cons of using agricultural drainage water as single or alternative with fresh water to irrigate tomato plants. Also, the role of magnetic field was assessed. It could be concluded that the highest yield, relative yield % and economic efficiency were obtained when plants were irrigated with 100% fresh water and exposed to magnetic field. If there is a slight shortage in fresh water, it is advisable to use alternative irrigation with 25% drainage and 75% fresh water besides magnetic field treatment; since the yield produced of this treatment was approximately equal to that obtained from irrigation with fresh water solely (control). When there is a severe shortage in fresh water, it is recommended to apply either alternative irrigation with 50% drainage and 50% fresh water or 75% drainage and 25% fresh water in addition to magnetic field treatment depending on the degree of severity in fresh water deficit. Since, the reduction in relative yields obtained from the latter two interaction treatments were mostly less than 10% in relation to the control as this relative yield is acceptable to tomato producers under these conditions.

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References

A.O.A.C., 1980. Official Methods of Analysis, thirteenth ed. Association of Official Chemists, Washington, DC.
Abd El-Naim, E.M., 1995. Re-use of treated waste water in agriculture. In: Proc. 2nd Conf. of "On Farm Irrigation and Agroclimatology" organized by Soil and Water Research Institute, Agricultural Research center, Ministry of Agriculture and Land Reclamation. Jan. 2-4, Egypt.
Abou El-Yazied, A., El-Gizawy, A.M., Khalf, S.M., El-Satar, A., Shalaby, O.A., 2012. Effects of magnetic field treatments for seeds and irrigation water as well as N, P and K levels on productivity of tomato plants. Appl. Sci. Res. 8 (4), 2088–2099.
Abu-Zinada, I.A., 2015. Effect of salinity levels and application stage on cucumber and soil under greenhouse conditions. Inter. J. Agric. Crop Sci. 8 (1), 73–80.
Ahmed, M.E.M., El-Zaawely, A.A., Bayoumi, Y.A., 2013. Effect of magnetic field on seed germination, growth and yield of sweet pepper (*Capsicum annuum* L.). Asian J. of Crop Sci. 5 (3), 286–294.
Alimi, F., Tlili, M., Gabrielli, C., Maurin, G., Ben-Amor, M., 2006. Effect of a magnetic water treatment on homogeneous and heterogeneous precipitation of calcium carbonate. Water Res. 40 (10), 1941–1950.
Alsaeedi, A., El-Ramady, H., Alshaal, T., El-Garawani, M., Elhawat, N., Al-Otaibi, A., 2018. Exogenous nanosilica improves germination and growth of cucumber by maintaining K^+/Na^+ ratio under elevated Na^+ stress. Plant Physiol. Biochem. 125, 164–171.
Alsaeedi, A., El-Ramady, H., Alshaal, T., El-Garawany, M., Elhawat, N., Almohsen, M., 2017. Engineered silica nanoparticles alleviate the detrimental effects of Na+ stress on germination and growth of common bean (*Phaseolus vulgaris*). Environ. Sci. Pollut. Res. 24 (27), 21917–21928.
Alsaeedi, A., El-Ramady, H., Alshaal, T., El-Garawany, M., Elhawat, N., Al-Otaibi, A., 2019. Silica nanoparticles boost growth and productivity of cucumber under water deficit and salinity stresses by balancing nutrients uptake. Plant Physiol. Biochem (in press).
Atak, C., Emiroglu, O., Alikamanoglu, S., Rzakouleva, A., 2003. Stimulation of regeneration by magnetic field in soybean (*Glycine max* L. Merrill) tissue cultures. J. Cell Mol. Biol. 2, 113–119.
Balouchi, H.R., Sanavy, S.A.M.M., 2009. Electromagnetic field impact on annual medics and dodder seed germination. Int. Agrophys. 23 (2), 111–115.
Bustan, A., Chhen, S., Pasternak, D., 2005. Effect of timing and duration of brackish irrigation water on fruit yield and quality of late summer muskmelon. Agric. Water Manag. 74 (2), 123–134.
Cuartero, J., Fernandez, R., 1999. Tomato and salinity. Sci. Hortic. (Amst.) 78 (1), 83–125.
De Souza, A., Garcia, D., Licea, L., Porras, E., 2005. Pre-sowing magnetic treatment of tomato seeds: effects on the growth and yield of plant cultivated late in the seasons. Spanish J. Agric. Res. 3 (1), 113–122.
Duarte Diaz, C.E., Riquenes, J.A., Sotolongo, B., Portuondo, M.A., Quintana, E.O., Perez, R., 1997. Effects of magnetic treatment of irrigation water on the tomato crop. Hortic. Abstr. 69, 494.
Duncan, D.B., 1965. Multiple range and multiple F. test. Biometrics 11, 1–42.
Efihimiadou, A., Katsenios, N., Karkanis, A., Papastlianou, P., Traiontafyllidis, V., Travlos, I., Bilalis, D.J., 2019. Effects of presowing pulsed electromagnetic treatment of tomato seed on growth yield and lycopene content. Sci. World J. 6, 260–272.
Estiken, A., Turan, M., 2004. Alternative magnetic field effects on yield and plant nutrient elements composition of strawberry (Fragaria x ananassa, cv. Camarosa). Soil Plant Sci. 54, 135–139.
Fathy, E.S.L., Khedr, Z.M.A., Abd El-Rahim, A.M.M., 2005. Salt tolerance in tomatoes (III): fruit yield and quality. Proc. Of the 6*th* Arab Conf., Hort., Ismailia, Egypt.
Feizi, H., Pour, S.J., Rad, K.H., 2013. Biological response of muskmelon (*Cucumis melo* L.)

by magnetic field and silver nano-particles. Annu. Rev. Res. Biol. 3 (4), 794–804.
Ghanem, M., Eleteren, J., Albacete, A., Quinet, M., Andujar, C., Kinet, J., Alfocea, F., Lutts, S., 2009. Impact of salinity on early reproductive physiology of tomato (*Solanum lycopersicon*) in relation to a heterogenous distribution of toxic ions in flower organs. Funct. Plant Biol. 36, 125–136.
Gomez, K.A., Gomez, A.A., 1984. Statistical Procedures for Agricultural Research. In: 2nd ed. John Wiley and Sons Inc., New York.
Hachicha, M., Kahlaou, B., Jouzdan, O., 2016. Effect of electromagnetic treatment of saline water on soil and crops. J. Saudi Soc. Agric. Jssa. 10, 1016–1023.
Hilal, M.H., Shata, S.M., Abdel-Dayem, A.A., Hilal, M.M., 2002. Application of magnetic technologies in desert agriculture. III. Effect of magnetized water on yield and uptake of certain elements by citrus in relation to nutrients mobilization in soil. Egypt. J. Soil Sci. 42, 43–55.
Hussein, M.M., El-Faham, S.Y., Alva, A.K., 2012. Pepper plants growth, yield, photosynthetic pigments and total phenols as affected by foliar application of potassium under different salinity irrigation water. Agric. Sci. 3 (2), 241–246.
Hussein, M.M., Oraby, S., 2008. Growth and antioxidant enzymes activity in onion plants as affected by benzyladenine and salinity from diluted sea water. J. Appl. Sci. 5, 655–658.
Jinapang, P., Prakob, P., Wongwattonanard, P., Islam, N.E., Kirawanich, P., 2010. Growth characteristics of mung beans and water convolvuluses exposed to 425-MHZ electromagnetic fields. Bioelectromagnetics 31, 519–528.
Kaya, C., Tuna, A.L., Yokas, I., 2009. The role of plants hormones in plant under salinity stress tasks for vegetation science. Salinity Water Stress 44, 45–50.
Khoshravesh, M., Mostafazadeh-Fard, B., Mousavi, S.F., Kiani, A.R., 2011. Effects of magnetized water on the distribution pattern of soil water with respect to time in trickle irrigation. Soil Use Manag. 27 (4), 515–522.
Maheshwari, B.L., Grewal, H.S., 2009. Magnetic treatment of irrigation water: its effects on vegetable crop yield and water productivity. Agric. Water Manag. 96 (8), 1229–1236.
Maheshwari, I.B., 2009. Magnetic treatment of irrigation water: evaluation of its effects on vegetable crop yield and water productivity. Ph.D. Thesis, Univ. of Western Sydney School of Environ. and Agric.
Malash, B.N.M., Aly, F.A., Fatahalla, M.A., Entsar, A., Khatab, A., Hatem, M.K., Tawfic, S., 2008. Response of tomato to irrigation with saline water applied by different irrigation methods and water management strategies. Int. J. Plant Prod. 2 (2), 101–116.
Morales, G., Stewart, A., Seguin, P., 2008. Effect of saline water on growth and physiology of bell pepper seedlings. Int. J. Veg. Sci. 14, 121–138.
Najafi, S., Heidari, R., Janei, R., 2013. Influence of the magnetic field stimulation on some biological characteristics of *Phaseolus vulgaris* in two different times. Global J. Sci., Eng. and Tech. 51–58 (ISSN: 2322-2441), Issue.
Navarro, J.M., Garrido, C., Flores, P., Martinez, V., 2010. The effect of salinity on yield and fruit quality of pepper grown in perlite. Plant Growth Regul. 8 (1), 142–150.
Peterson, K., Willusen, J., Kaack, K., 1998. Composition and taste of tomatoes as affected by increased salinity and different salinity sources. J. Hort. Sci. and Biol. 73 (2), 205–215.
Ratushnyak, A.A., Andreeva, M.G., Marozova, O.V., Morozov, G.A., Trushin, M.V., 2008. Effect of extremely high frequency electromagnetic fields on the microbiological community in rhizosphere of plants. Int. Agrophys. 22, 71–74.
Romero-Aranda, R., Sorai, T., Cvartero, J., 2001. Tomato plant-water uptake and plant-water relationships under saline growth conditions. Plant Sci. 160, 265–272.
Sadeghipour, O., Aghaei, P., 2013. Improving the growth of cowpea (Vigna unguiculata L. Walp.) by magnetized water. J. Biodivers. Environ. Sci. (JBES) 3 (1), 37–43.
Selim, A., Zayed, M., Zayed, M., 2013. Magnetic field treated water effects on germination, growth and physio-chemical aspects of some economic plants. Acta Bot. Hung. 55 (1–2), 99–116.
Semiz, G., Suarez, D., Unlukara, A., Yurtseven, E., 2014. Interactive effects of salinity and N on pepper (*Capsicum annuum*, L.) yield, water use efficiency and root zone and drainage salinity. J. Plant Nutr. 37 (4), 595–610.
Sparks, D.L., Page, A.L., Helmke, P.A., Loppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., Summner, M.E., 1996. Methods of Soil Analysis: Chemical Methods, Part 3. ASA and SSSA, Madison, WI.
Stange, B.C., Rowland, R.E., Rapley, B.I., Podd, J.V., 2002. ELF magnetic field increase amino acid uptake into (*Vicia faba* L.), roots and alter ion movement across the plasma membrane. Bioelectromagnetics 23, 247–354.
Surendran, Y., Sandeep, O., Joseph, E.J., 2016. The impacts of magnetic treatment of irrigation water on plant, water and soil characteristics. Agric. Water Manag. 178, 21–99.
Whab-Allah, M.A., Al-Omran, M.A., 2012. Effect of water quality and deficit irrigation on tomato growth, yield and water use efficiency at different developmental stages. J. Agric. Env. Dam. Univ., Egypt. 11 (2), 80–110.
You, Q., Xue, X., Wang, T., Liao, J., 2016. Growth, yield and fruit quality of cherry tomato irrigated with saline water of different developmental stages. J. Acta. Agric. Scandinvica, Section B-Soil and Plant Sci. 66 (4), 307–324.
Younis, S.M., Ahamed, S.F., Abou El-Kheir, A., Ibrahim, A.M., 2010. Effect of using mixture of drainage and fresh water on drip irrigation sysem. Misr. J. Agric. Eng. 27 (2), 530–540.
Yusuf, K.O., Ogunlela, O.A., 2015. Impact of magnetic treatment of irrigation water on the growth and yield of tomato. Not. Sci. Bio. 7 (3), 345–348.
Zayton, A., El-Shafei, A., Allam, K., Mourad, M., 2009. Effect of water salinity and potassium fertilizer levels on tomato productivity and water consumption in Siwa oasis. Misr. J. Agric. Eng. 26 (1), 107–131.
Zegbe-Dominguez, J.A., Behboudian, M.H., Clothier, B.E., 2006. Yield and fruit quality in processing tomato under partial root zone drying. Eur. J. Hortic. Sci. 71 (6), 252–285.
Zhai, Y., Yang, D., Hou, M., 2015. The effects of saline water drip irrigation on tomato yield, quality and blossom-end rot incidence. A3. A Case Study in the South China. Plos(11), e0142204doi. https://doi.org/10.1371/8.pone.0142204. One10.
Zúñiga, O., Benavides, J.A., Ospina-Salazar, D.I., Jiménez, C.O., Gutiérrez, M.A., 2016. Magnetic treatment of irrigation water and seeds in agriculture. Ingeniería y Competitividad 18 (2), 217–232.
Zúñiga, O., Osorio, J., Cuero, R., Peña, J., 2011. Evaluación de tecnologías para la recuperación de suelos degradados por salinidad. Rev. Fac. Nac. Agron. Medellín 64 (1), 5769–5779.