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Applications of magnetic technology in agriculture: A novel tool for improving crop productivity (1): Canola

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Two field trials using canola (var. Serw-6) were conducted to study and evaluate the effects of magnetizing irrigation water on Canola vegetative growth, photosynthetic pigments, seed, yield and water use efficiency as well as seed biochemical constituents and fatty acids composition of the yielded oils. Application of magnetizing irrigation water led to marked increases in growth parameters (plant height (cm), fresh weight and dry weight (g plant^{-1}) and water contents (%); photosynthetic pigments (chlorophyll a, chlorophyll b, chlorophyll (a+b), carotenoids and consequently total pigments). Treating plants with magnetized water increased also, seed yield and its components plant height (cm), branches (number plant^{-1}),seed weight (g plant^{-1}), pods (number plant^{-1}), seeds weight (g pod^{-1}), 100-seed weight (g) and seed yield (kg fed^{-1}) as well as seed biochemical constituents (oil (%), oil yield (kg fed^{-1}) macro and micro elements). The treatment improved oil quality as it affected fatty acids composition of canola oil, by increasing total unsaturated fatty acids and total essential fatty acids. Moreover, Water Use Efficiency (WUE) increased significantly as a result of irrigation with magnetic water by 19.05% compared to control plant. The present findings have shown that irrigation with magnetized water could be employed as one of the most valuable modern technologies that can assist in saving irrigation water and improving yield and quality of Canola under newly reclaimed sandy soil. The usage of magnetic water in the agricultural production will enable intense and more quantities and qualitative production.

Key words: Canola, magnetic water, water-use efficiency, nutritive value, oil, fatty acids.

INTRODUCTION

Water is an unusual substance, mostly due to its 3D network of hydrogen bond in the molecule. Its properties allow it to act as a solvent, as a reactant, as a molecule with a cohesive properties, as an environment and a

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temperature stabilizer (Ibrahim, 2006). No other liquid can replace water. It has relatively high melting and boiling points for a small molecule, high specific heat capacity, and higher density of liquid than that of solid (Eisnberg and Kauzmann, 1969). Several investigations into electromagnetic effects on plants have been carried out with some remarkable results. The optimal external electromagnetic field could accelerate the activation of seed germination (Maeda, 1993; Oomori, 1992), however, the mechanism of these actions is still poorly understood (Morar et al., 1988; Xiyao et al., 1988). Electric and/or magnetic treatments are assumed to enhance seed vigour by influencing the biochemical processes that involve free radicals and by stimulating the activity of proteins and enzymes (Kurinobu and Okazaki, 1995).

Magnetic field (MF) became a part of the environment and source of energy, thereby effects normal metabolisms (Belyavskaya et al., 1992) and has impact on meristem cell division (Aladjadjiyan, 2007). In addition, MF affects water absorption, preservation and ionization (Taia et al., 2007). Forces generated by MF may cause magnetophoresis in macromolecules (Paul et al., 2006). Metabolic substances as plants photosynthetic pigments could be affected by MF. It has been found that an increase occurs in chemical reactions of plants under MF, which has a positive effect on photochemical activity, respiration ratio and enzyme activity (Phirke et al., 1996; Martinez et al., 2000; Carbonell et al., 2000).

Oilseed plant has become a plant of major agro-economic importance, with a seed yield of 47 millions tones worldwide in 2007 (FAO, 2007). It is considered as one of the three major oil crops in many countries especially Canada, European Union and USA because it has a wide range of uses (oil production, animal feeding, alternative fuel, etc) (Howlett et al., 2001; Abdallah et al., 2010). Cultivation of canola in Egypt may provide an opportunity to overcome some of the local deficit of vegetable edible oil production, particularly it could be successfully grown during winter season in newly reclaimed land outside the old one of Nile valley to get-around the competition with other crops occupied the old cultivated area (Kandil, 1984; Sharaan, 1986; Ghallab and Sharaan, 2002; Sharaan et al., 2002; Megawer and Mahfouz, 2010). Suitability of growing canola under Egyptian conditions, compared with other oil crops, may be ascribed to its tolerance to harsh environmental influences frequently prevailing in such newly reclaimed soil such as salinity and drought (Weiss, 1983).

The target of this work is to increase the efficiency of growth and productivity of canola plant grown under environmental stresses by using magnetized water.

MATERIALS AND METHODS

Two field trials using canola (var. Serw-6) were conducted at Research and Production Station, National Research Centre, Alemam Malek Village, Al-Nubaria District, Al-Behaira Governorate, Egypt in 2009/10 and 2010/11 winter seasons to study and evaluate the effects of magnetizing irrigation water on growth, photosynthetic pigments, yield and yield components of canola winter crop. The experimental soil and water were analyzed according to the method described by Chapman and Pratt (1978) (Table 1).

Cultivation method and layout of experiment

The soil of experiment was ploughed twice and divided into plots (10 length m x 5 m width). Recommended rates of canola seeds (3 kg/fed; variety Serw-6; fed=4200 m^2) were sown by drilling seed manually in the rows at 15-cm apart at the first week of November in both seasons. Four replications were used in each treatment. Control treatment was irrigated with normal water, while the other treatment (magnetized water) was irrigated with water after magnetization through a two inch Magnetron [U.T.3, Magnetic Technologies LLC PO Box 27559, Dubai, UAE]. Phosphorus and potassium fertilizer were added before sowing at the rate of 200 kg/fed. as super phosphate (15.5 % P_2O_5) and50 kg/fed potassium sulphate (48 to 50% K_2O), respectively, while nitrogen fertilizer was added at the rate of 45 kg N/fed as ammonium nitrate (33.5%N) in two equal doses at 21 and 35 days after planting (DAP), respectively. Sprinkler irrigation was applied as plants needed. The layout of experiment was shown in (Figure 1).

Data recorded

Growth parameters

After 85 days from sowing, 10 plants from each treatment were cutting on 5 cm above ground to determined vegetative growth, that is, plant height, fresh and oven dry weight. Water content was determined according to (Henson et al., 1981) using the following formula:

WC = 100×(fresh mass – dry mass)/fresh mass.

Yield and yield components

At harvest time (180 day after sowing), a random sample of 20 plants from each plot were taken to determine some yield attributes such as number of siliqua/plant; number of seeds/siliqua, seed yield/plant (g) and 1000-seed weight (g). The whole plot was manually harvested to determine the above ground biomass (biological yield) after dried under sunshine for one week, pods were threshed to determine seed yield; straw yield was calculated by subtracting seed yield from biological yield; harvest and crop indexes were calculated by dividing seed yield/biological yield and straw yield, respectively.

Water-use efficiency (WUE)

WUE values were calculated with the following equations (Howell et al., 1990).

$$\mathrm{WUE} = \left(\frac{E_y}{E_t}\right) \times 100$$

Where WUE is the water use efficiency (kg/m^3); E_y is the economical yield (kg/fed./season); E_t is the total applied of irrigation water, m^3/fed/season.

Table 1. Soil and water analysis for site experiments.

Parameters	Soil depth (cm)		Irrigation water	
	0-15	15-30	Before magnetic	After magnetic
Particle size distribution				
Coarse sand	48.20	54.75	..	…
Fine sand	49.11	41.43	..	…
Clay + Silt	2.69	3.82	..	…
Texture	Sandy	Sandy	..	…
pH (1:2.5)	8.22	7.94	7.25	7.13
EC (dSm^{-1})(1:5)	0.20	0.15	0.50	0.40
Organic matter (%)	0.67	0.43	…	
Soluble cations (mq/l)				
Ca^{++}	0.60	0.50	2.15	2.05
Mg^{++}	0.50	0.30	0.50	0.65
Na^{+}	0.90	0.80	3.00	3.00
K^{+}	0.20	0.10	0.31	0.31
Soluble anions (mq/l)				
CO^{-3}	-	-	0.01	0.01
HCO^{-3}	0.60	0.40	2.33	2.46
Cl^{-}	0.75	0.70	2.17	1.72
SO^{-4}	0.85	0.60	1.45	1.82

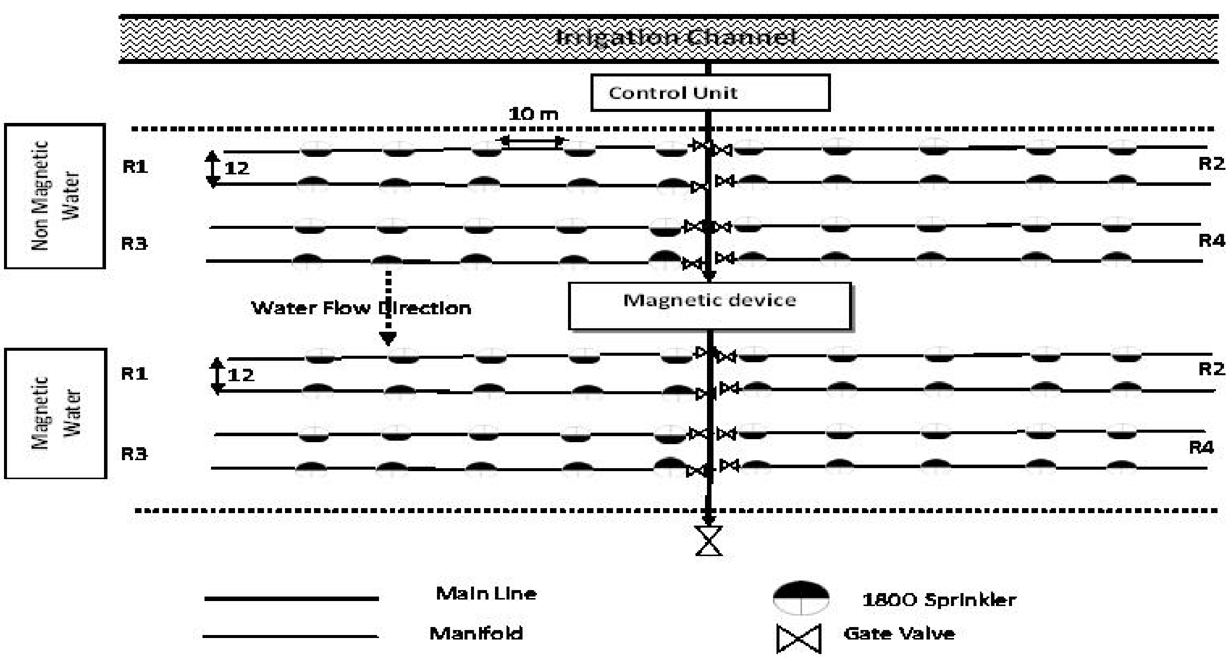

Figure 1. Layout of experiment design under solid set sprinkler system.

Photosynthetic pigments

Total chlorophyll a and b and carotenoids contents in fresh leaves were estimated using the method of (Lichtenthaler and Buschmann, 2001). The fresh tissue was fine ground in a mortar and pestles using 80% acetone. The optical density (OD) of the solution was recorded at 662 and 645 nm (for chlorophyll a and b, respectively) and 470 nm (for carotenoids) using a spectrophotometer (Shimadzu

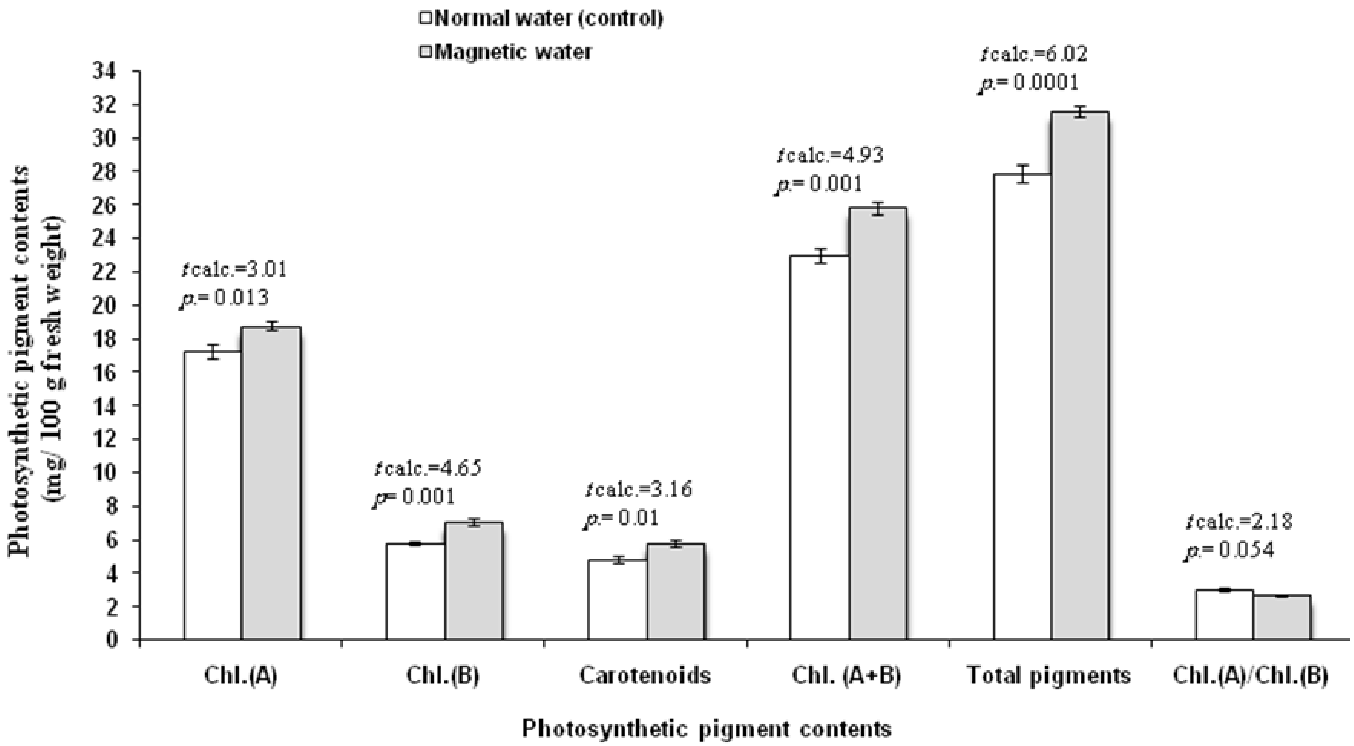

Figure 2. Effect of irrigation treatments on photosynthetic pigment contents (data average of 2009/10 and 2010/11 seasons). N=6, *, **, *** *t* is significant at the *P* **<** 0.05, 0.01 and 0.001 levels, respectively, P-value **>** 0.05 non-significant.

UV-1700, Tokyo, Japan). The values of photosynthetic pigments were expressed in mg/100 g FW. At harvest yield, yield components and quality of Canola crop were determined.

Oil determination

The oil of Canola seeds were extracted according to Kates and Eberhardt (1957). The powdered seeds were shaken overnight with isopropanol: chloroform (1:1). The solvent were evaporated under reduced pressure of CO_2 atmosphere. The lipid residue is taken up in a chloroform: methanol (2:1 v/v) and given a folch wash, the dissolved total oils were purified by washing with 1% aqueous saline solution. The aqueous phases were washed with chloroform that was combined with the pure oil solution. Chloroform was evaporated and the total pure oil was weighed.

Fatty acid determination

To oil sample 20 ml methanol, 10 ml benzene and 1ml concentrated sulphoric acid were added in glass tube and refluxed for 90 min, the methyl esters obtained were extracted with petroleum ether (b.p. 40 TO 60ºC). The petroleum ether was then evaporated; the residue was dissolved in chloroform (Harborne, 1984). The methylated samples were subjected to analysis by Gas Liquid Chromatography (GLC) equipped with dual flame ionization detector and dual channel recorder.

Nutritional value of yielded seeds

The dried seeds were fine ground to determine K, Mg, Ca, Na, Fe, Mn and Zn concentration as described by Cottenie et al. (1982).

Statistical analysis

Statistical analysis was carried out using SPSS program Version 16 (SPSS Inc., 2005). Independent *t*-test was also carried out to find the significant differences between magnetic and nonmagnetic water treatments.

RESULTS AND DISCUSSION

Photosynthetic pigment contents: Data in Figure 2 illustrate the photosynthetic pigment responses of canola plant irrigation with magnetized and normal water. The current study shows that photosynthetic pigments are significantly affected by the magnetic water where chlorophyll a, chlorophyll b, carotenoids and total pigments concentration recorded more value under magnetic water compared with plants irrigated with normal water (Figure 2). The percent of increments reached to 8.86, 22.22 19.71 and 1350% in the above parameters, respectively*.* Photosynthetic pigments are considered good criteria to monitor, explain and correlate the changes induced by stress, interacted with other treatments; it controlled the economic yield whether in direct or indirect manner especially under stress conditions. This result are in a good harmony with several

Table 2. Effect of irrigation treatments on growth parametrs and water content of Canola at 85 days after sowing (data average of 2009/10 and 2010/11 seasons).

Treatment / Character	Mean ± SE		*p-value*	Increase (+) (%) over control
	Normal water (control)	Magnetic water		
Plant height (cm)	78.80 ± 1.40	92.00 ± 1.81	0.001	16.75
Fresh weight (g plant^{-1})	65.26 ± 0.96	81.26 ± 1.44	0.001	24.52
Dry weight (g plant^{-1})	7.44 ± 0.13	8.11 ± 0.15	0.002	9.01
Water contents (%)	88.55 ± 0.27	89.96 ± 0.27	0.001	1.59

N = 15, **, *** *t* is Significant at the $P < 0.01$ and $P < 0.001$ level, respectively.

studies for different plants; where MF treatment increased the chlorophyll content in sugar beet (*Beta vulgaris* L.) leaves (Rochalska, 2005; Hozayn et al., 2013a) and content of chlorophyll a, b and carotenoids in potato (*Solanum tuberosum* L.) (Rakosy-Tican et al., 2005; Atak et al., 2003, 2007), found an increase in chlorophyll content appeared after exposure to a magnetic field for a short time. The stimulating effect of magnetic treatments on photosynthetic pigments may be due to increasing proline content, which increased some ions as Mg^{2+} needed for chlorophyll synthesis (Shaddad, 1990) and/or K^{+}, which led to increased photosynthetic efficiency possibly by increasing the number of chloroplasts per cell (Garcia-Reina and Arza, 2001). Also, the increase in the concentration of chlorophyll pigments due the magnetic treatments may be attributed to the increase in GA_3 content in plants (Selim et al., 2009), which led to increase in the green pigments in the treated plants by stimulating the production of chlorophyll in leaves (Bethke and Drew, 1992; Wafaa et al., 2007; Amira et al., 2010a, b; Hozayn et al., 2011) reported that, magnetic treatment increased photosynthetic pigment contents *via,* increasing growth promoters (IAA).

Growth parameters

Data in Table 2 show that irrigation canola plant with magnetized water caused significant increases in all growth tested parameters (plant height, fresh and dry weight of plant) and Relative Water Contents (RWC) of plant compared with plant irrigated with normal water. Data indicate that there was a significant increase in plant height, fresh and dry weights and water content, by 16.75, 24.52, 9.01 and 1.59%, respectively as compared with non magnetized water application. These results are in conformity with those obtained by (De Souza et al., 2006) on tomatoes, who found a significant increase in dry weights of root, shoot and whole plants as a result of treating plant with magnetic water. Flórez et al. (2007) observed an increase in the initial growth stages and an early sprouting of maize and rice seeds exposed to 125 and 250 mT stationary magnetic field. Martı´nez-Te´llez et al. (2002) observed similar effects on wheat and barley seeds magnetically treated. The mechanisms are not well known yet, but several theories have been proposed, including biochemical changes or altered enzyme activities by Phirke et al. (1996).

Yield and yield components

Table 3 show that yield and its components such as plant height (cm), branches (number plant^{-1}) , seed weight (g plant $^{-1}$), pods (number plant^{-1}), seed weight (g pod^{-1}), 100-seed weight (g), oil (%), seed yield (kg fed^{-1}) and oil yield (kgfed^{-1}) were significantly enhanced under irrigation with magnetic water. These results confirmed previous studies on wheat, flax, lentil, chickpea and sugar beet where magnetic treatment gave higher value of yield and yield components compared to control treatment (Hozayn and Abd El-Qodos, 2010a, b; Abd El-Qodos and Hozayn, 2010a, b; Hozayn et al., 2013a, b). Similar effects have been reported abroad on buckwheat, sunflower, flax, pea, wheat, pepper, tomato, soybean, potato and sugar beet yields (Gubbels 1982; Pietruszewski 1999; Takac et al 2002; Crnobarac et al 2002; Marinkovic et al., 2002). Regarding the increment in oil (%) and oil yield (kg fed^{-1}) with magnetic water, these increases might be due to the increase in vegetative growth and nutrients uptake. These results are in good agreement with those (Crnobarac, et al. 2002) showed an increase in yield of soybean from 5 to 25%, with a higher quantity of oil from 13.2 to 17.3%.

Water use efficiency

Water use efficiency (WUE) values were increased by the irrigation with magnetic water. Data recorded in Table (4) show that WUE for dry matter production of Canola was significantly increased as the result of application of magnetized water. These results are in good harmony with those obtained by Selim and El-Nady (2011). Water absorption by lettuce seeds previously treated in stationary magnetic field and found significance increase in the rate of water absorption accompanied with an increase in the total mass (Garcia-Reina and Arza, 2001).

Table 3. Effect of irrigation treatments on Canola yield and its components (Data average of 2009/10 and 2010/11 seasons).

Character \ Treatment	Mean ± SE		*p-value*	Increase (+) or decrease (-) (%) over control
	Normal water (control)	Magnetic water		
Plant height (cm)	133.22 ±2.40	150.00 ± 2.57	0.001	12.60
Branches (number plant^{-1})	6.94 ± 0.37	7.93 ± 0.27	0.038	14.27
Seed weight (g plant $^{-1}$)	64.00 ± 1.69	96.80± 4.46	0.001	51.25
Pods (number plant^{-1})	11.82 ± 0.24	14.81 ± 0.41	0.001	25.30
Seeds weight (g pod^{-1})	0.186 ± 0.004	0.159 ± 0.010	0.029	-14.52
1000-seed weight (g)	4.23 ± 0.02	4.00 ± 0.03	0.001	-5.44
Oil (%)	28.00 ± 0.15	32.00 ± 0.20	0.001	14.29
Seed yield (kg fed^{-1})	502.53 ±12.83	697.00 ± 11.80	0.001	38.70
Oil yield (kg fed^{-1})	140.71 ± 2.68	223.04 ± 3.40	0.001	58.51

N = 15 for all parameters except seed and oil yield where N=8, *, **, *** *t* is significant at the $P < 0.05$, 0.01and 0.001 levels, respectively.

Table 4. Effect of irrigation treatments on water use efficiency (WUE) of Canola (Data average of 2009/10 and 2010/11 seasons).

Character \ Treatment	Mean ± SE		*p-value*	Increase (+) or decrease (-) (%) over control
	Normal water (control)	Magnetic water		
WUE (kg seed m^3 water)	16.63	23.07	0.001	38.70
WUE (kg oil m^3 water)	4.66	7.38	0.001	58.51

N=8, *** *t* is significant at the $P < 0.001$ levels.

These beneficial effects of magnetic field may be due to the increase in ions up take (Duarte et al., 1997; Esitken and Turan, 2004), especially Ca^{2+}. In most studies in recent years, exogenous Ca^{2+} can enhance plant drought resistance, inhibit the synthesis of activating oxides, protect the structure of cellular plasma membranes and maintain normal photosynthesis as well as regulate the metabolism of plant hormones and other important chemicals (Song et al., 2008; Blum, 1993).

Fatty acid composition

Data presented in Table 5 show fatty acid constituents of Canola plants irrigated with magnetic and normal water. These fatty acids are palmitic (C16:0), Stearic (C18:0), Oleic (C18:1), Linoleic (C18:2), Linolenic (C18:3), and Beheric (C 22:0). However, the predominant saturated fatty acids were palmitic acid and stearic acid in the Canola plants, while Linoleic and Oleic acid were the predominant as unsaturated fatty acid. Concerning magnetic water treatment effect, it was evident that palmitic and stearic acids increased with application of magnetic water treatment when compared with that of the control treatment. Irrigation with magnetic water induced marked increases in the levels of unsaturated fatty acids particularly oleic acids. The magnitude of such increase was much more pronounced by applying magnetic water than that of normal water. Abdel Rahim et al. (2000) reported that the percentage of unsaturated fatty acids proved the efficiency of de-saturation in oil. There was also great increase in unsaturated fatty acid with slight increasing of saturated fatty acids and consequently, increasing in Tus/Ts. Thus the yielded oil becomes safer for human consumption.

Macro and micro elements

Table 6 presents the influence of magnetized water on micro and macronutrients of Canola plant. Magnetic water caused significant decreases in nitrogen by about 17.3% compared with non magnetized water as well as increased potassium, magnesium and calcium copper percent by about 3.5, 6.7 and 0.8% of Canola plant respectively (Table 6). Regarding the effect of magnetic water treatment on P percent, the results recorded non significant variation between treatments as compared with the corresponding control. With regard to the effect of MW on microelement contents of Canola, data (Table 6) revealed that, using magnetized water caused gradual decrease in Fe and Zn contents by about 7 and 18% respectively. In the meantime, magnetic water caused significant increase in both Mn and Cu microelement as compared with the corresponding control. Duarte et al. (1997) reported an increase in nutrient uptake by magnetic treatment in tomatoes. A marked increase in P content of citrus leaves by magnetically treated water

Table 5. Fatty acid composition seeds of Canola plants irrigated with magnetic and normal water.

Composition	Control	Magnetic water
Palmitic (C16:0)	3.01	3.62
Stearic (C18:0)	19.72	22.66
Oleic (C18:1)	13.57	34.10
Linoleic (C18:2)	9.71	-
Linolenic (C18:3)	-	-
Behenic (C22:0)	1.51	1.07
Total saturated (TS)	24.21	27.26
Total unsaturated (TUS)	23.28	34.10
TUS/TS	0.96	1.25

Table 6. Macro and micro elements in seeds of canola plants irrigated with magnetic and normal water.

Character \ Treatment		Mean		*p-value*	Increase (+) or decrease (-) (%) over control
		Normal water (control)	Magnetic water		
Macronutrients (%)	**N**	2.49	2.06	0.04	-17.27
	P	1.30	1.30	ns	0.00
	K	0.90	0.93	ns	3.33
	Mg	0.30	0.32	ns	6.67
	Ca	1.35	1.36		0.74
Micronutrients (ppm)	**Fe**	121.50	113.40	0.001	-6.67
	Mn	55.00	60.00	0.030	9.09
	Zn	76.50	63.00	0.020	-17.65
	Cu	10.50	13.50	0.040	28.57

N=6, *, **, *** *t* is significant at the $P < 0.05$, 0.01and 0.001 levels, respectively, P-value **>** 0.05 non-significant.

was also reported by Hilal et al. (2002). Algozari and Yao (2006) reported that the magnetic application led to easy breakthrough of water for the cell membrane of plants. The easy breakthrough of water leads to better absorption of water and mineral by plant roots (Barefoot and Reich, 1992). Kronenberg (2005) showed that the magnetic application led to an increase in the availability of minerals in soil through increasing of solubility of salts and minerals. Increasing of solubility of salts and minerals led to the increasing of macro and micro elements from soil and division (Tahir and Karim, 2010).

Conclusion

The present findings have shown that irrigation with magnetized water could be employed as one of the most valuable modern technologies that can assist in saving irrigation water and improving yield and quality of Canola under newly reclaimed sandy soil. The usage of magnetic water in the agricultural production will enable intense and more quantities and qualitative production.

Conflict of Interests

The authors have not declared any conflict of interests.

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