

Do Magnetic Water Affect Water Use Efficiency, Quality and Yield of Sugar Beet (*Beta vulgaris* L.) Plant under Arid Regions Conditions?

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Abstract: Regarding our previous and promising results, magnetic technology as a nontraditional method may be used for improving crop productivity and water use efficiency under field condition. To achieve the aforementioned objective, two field trials using sugar beet (*Beta vulgaris* L.) (var. Baraca) 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. The experiments contained two treatments i.e., (1) Irrigation with normal water and (2) Irrigation with normal water after magnetization through a two inch Magnetron [U.T.3, Magnetic Technologies LLC PO Box 27559, Dubai, UAE]. The results showed significant positive effects of magnetic treatment of water on quantity and quality of the studied parameters. The percent of increase due to using magnetized water application reached to 21.22% for root weight (kg), 5.72% for root length (cm), 16.22 for root diameter (cm), 19.05% for root yield (ton fed.⁻¹), 23.79% for sugar yield (ton fed.⁻¹). The increase was 4.04, 2.93, 7.57 and 3.41% for sugar (%), purity (%), recoverable sugar and quality index, respectively. Meanwhile, irrigation sugar beet with magnetized water reduced value of impurity parameters by 13.40, 12.37 and 16.63% for Na, K, Amino-N (mmol 100 g root fresh weight⁻¹), respectively compared to irrigation with normal water. Moreover, Water-Use Efficiency (WUE) increased as a result of irrigation by 19.05% compared to control treatment. It appears that utilization of magnetized water can lead to improve yield and quality of sugar beet crop and water use efficiency under newly reclaimed sand soil.

Key words: Sugar beet, magnetic water, yield, quality, impurity, water use efficiency

INTRODUCTION

With rapid population growth which is estimated to reach about 85 million people at the end of this year, there will be an increase of sugar demand. Approximately 66% of our local needs are produced locally from sugar beet and sugar cane while, the rest (34%) is imported from foreign countries (<http://faostat.fao.org/site/342/default.aspx>). This situation pushes Egypt to accelerate the completion of sugar beets projects planned in several provinces especially in newly reclaimed sand soil. Improvement of sugar beet production can be achieved through application of traditional and nontraditional methods. Magnetic technology as a nontraditional method is used for improving seed quality, seed vigour and field emergence which reflected in improvement of yield and quality of sugar beet yield (Wilczek *et al.*, 2005; Rochalska and Orzeszko-Rywka, 2005, 2008; Rochalska *et al.*, 2008).

In Egypt, crop Water Use Efficiency (WUE) takes great attention where irrigation water resources are limited or diminishing and where rainfall is a limiting factor. Magnetic treatment of irrigation water is a promising technique for achieving high water use efficiencies due to its effect on some physical and chemical properties of water and soil (Noran *et al.*, 1996; Basant *et al.*, 2007; Maheshwari and Grewal, 2009).

Moreover, our previous and promising studies (Hozayn and Abd El-Qodos, 2010a, b; Abd El-Qodos and Hozayn, 2010a, b; Hozayn *et al.*, 2011) under greenhouse condition observed that, wheat, lentil, chickpeas, flax, sunflower, as well as on ground nut, faba bean and mung bean irrigated with magnetized water gave more value of all recorded parameter. The increase in yield plant⁻¹ ranged between 11-47% depended on tested plants. So, one of the main objectives is to study the effect of magnetic water on increasing yields of sugar beet yield and quality and water productivity under field conditions.

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Several investigators in many works reported positive effects of magnetic fields on the germination of seeds, plant growth and development, the ripening and yield of field crops (De Souza *et al.*, 2006; Shabrangi and Majd, 2009). Where, magnetic field was shown to induce germination traits in wheat, soybean, cotton (Phirke *et al.*, 1996), barley (Martinez *et al.*, 2000), rice (Carbonell *et al.*, 2000), corn (Florez *et al.*, 2007) and chickpea (Vashisth and Nagarajan, 2008). When the seeds were exposed to magnetic field, the percentage of germination increased while the time required for germination decreased. The positive effects of magnetic field were also shown on metabolic processes i.e., protein biosynthesis, cell reproduction, photochemical activity, respiration rate, enzyme activities, nucleic acid content and growth-development period (Stange *et al.*, 2002).

Moreover, in macro trials, application of variable electro and static magnetic fields with different frequency increased yield up to 144.8% in potato (Malesevic *et al.*, 2002), rice by 13-23% (Tian *et al.*, 1989), pepper by 64.9% (Takac *et al.*, 2002), soybean from 5-25%, with a higher quantity of oil and protein and at sunflower from 13.2-17.3% (Crnobarac *et al.*, 2002), cereal by 20% (Marinkovic *et al.*, 2000), wheat by 6.3-10.6% (Kordas, 2002), broad bean and pea by 10 and 15%, respectively (Podleony *et al.*, 2004; Podlesny *et al.*, 2005). In addition, Vasilevski (2003) showed 94% increase of the root mass of sugar beet, leaf surface up to 52%, yield to 12,88 t ha⁻¹ and the percentage of sugar was increased for 0.70%. Consequently, the magnetic field effect can be used as an alternative for the chemical methods of plant treatment for improving the production efficiency (Aladjadjiyan, 2002, 2003).

Therefore, the aim of this study is to study the effect of irrigation using magnetic and non-magnetic waters on yield, quality and water use efficiency of sugar beet under arid regions conditions.

MATERIALS AND METHODS

Two field trials using sugar beet (var. Baraca) 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 photosynthetic pigments, yield and quality of sugar beet as well as water use efficiency.

The experimental area is located at the North of Cairo (30.8667N latitude and 31.1667E longitude) at an elevation of 21 m above the sea level. It has an semi-arid climate with cool winters and hot dry summers prevailing in the experimental area. Estimation of the total irrigation water (m³/fed./season) and irrigation water requirements (m³/fed./day) for sugar beet was calculated according to Penman-Monteith equation as shown in Fig. 1. The seasonal water irrigation applied was found 3972 m³/faddan. The experimental soil and water were analyzed according to the method described by Cottenie *et al.* (1982) (Table 1).

Cultivation method and layout of experiment: Sugar beet seeds were obtained from Sugar Research Institute, Agriculture Research Centre, Giza, Egypt. The soil of experiment was ploughed triple, settled, ridged and divided into plots (10 m length×12 m width). During soil preparation, the recommended rate of phosphorus

Table 1: Physiochemical analysis of soil for site experiments and analysis of irrigation water before and after magnetic treatment (average of both seasons)

Parameters	Soil depth		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 (dS m ⁻¹) (1:5)	0.20	0.15	0.50	0.40
Organic matter (%)	0.67	0.43	-	-
Soluble cations (mq L⁻¹)				
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⁻¹)				
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

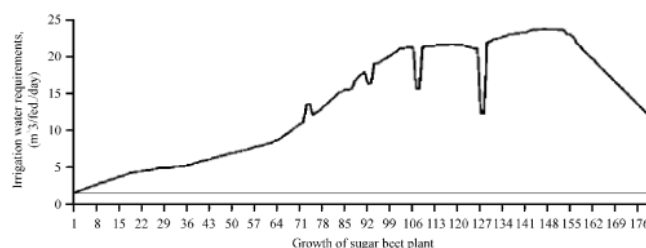


Fig. 1: Relation between growth duration of sugar beet and irrigation water consumption

fertilizer was applied at a level of 200 kg calcium super phosphate fed^{-1} (15.5% P_2O_5). Two-three of sugar beet seed balls “cv. Baraca” was sown in hill spaced 20 cm apart on one side of ridge (50 cm apart) on the first week of October in both seasons. Both treatments were irrigated immediately after sowing. 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]. Four replications were used in each treatment. Plants were thinned twice and the later one was done to ensure one plant/hill. Nitrogen fertilizers were added in four equal doses after thinning (35 days from sowing), 15, 30 and 45 days later, respectively. Potassium in the form of potassium sulphate (48% K_2O) was added at the rate of 50 kg fed^{-1} in two equal doses after thinning and 15 days later, respectively. Other agricultural practices were done as normally practiced in growing sugar beet fields. Sprinkler irrigation was applied as plants needed. The layout of experiment was shown in Fig. 2. For the sprinkler irrigation treatments, the sprinkler is a metal impact sprinkler 3/4" male (NAAN Sprinkler 233 A-S) with a discharge of $1.17 \text{ m}^3 \text{ h}^{-1}$, wetted radius of 13.5 m, working pressure of 300 KPa and irrigation intensity of 8.10 mmh^{-1} .

Data recorded:

Photosynthetic pigment: After 85 days from sowing, leaves of three sugar beet plants were taken from each plot. Photosynthetic pigment contents (chlorophyll a, chlorophyll b and carotenoids) of leaves were estimated spectrophotometrically as the method described by Moran (1982).

Yield and root parameters: At harvest, ten plants were taken at random from each plot to determine fresh root parameters (length (cm), diameter (cm) and weight (kg). Plants in the four inner ridge of each plot were collected and cleaned, therefore roots were separated and weighed in kilograms to estimate root yield (ton fed^{-1}). Sugar yield (ton fed^{-1}) was calculated by multiplying root yield by root sucrose percentage.

Root quality and impurity parameters: A sample of 10 kg of roots were taken at random from each plot and sent to the Beet Laboratory at Nubaria Sugar Factory to determine root quality. Alpha amino nitrogen (α -amino N), sodium (Na) and potassium (K) concentrations were estimated according to the procedure of Sugar Company by Auto Analyzer described by Cooke and Scott (1993). TSS and sucrose percentage estimated in fresh samples of sugar beet root by using Saccharometer according to the method described by AOAC (1995). Sugar loss was calculated using the following formula:

$$\text{Sugar loss (\%)} = 0.29 + 0.343 (\text{K} + \text{Na}) + 0.094 \alpha\text{-amino N}$$

Sugar recovery % was calculated using the following equation (Cooke and Scott, 1993):

$$\text{Sugar recovery (\%)} = \text{Sucrose (\%)} - \text{sugar loss (\%)}$$

Recoverable sugar yield (ton fed^{-1}) was calculated using the following equation of Mohamed (2002):

$$\text{Recoverable sugar yield} = \text{Root yield} (\text{ton fed}^{-1}) \times \text{sugar recovery}$$

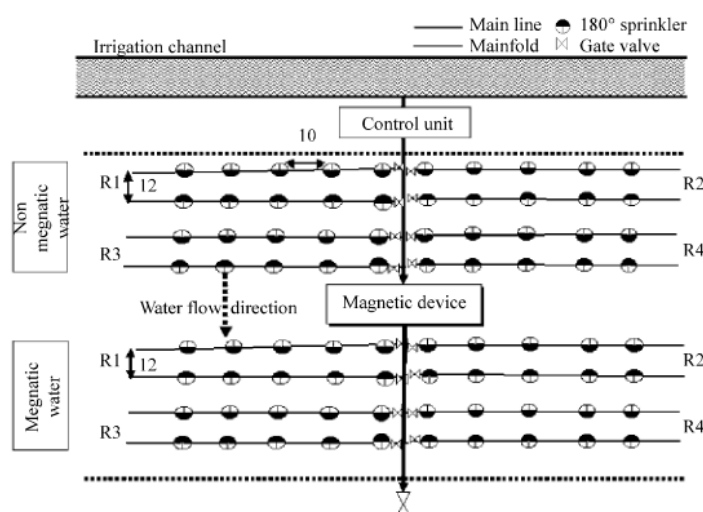


Fig. 2: Layout of experiment design under solid set sprinkler system

Quality index was calculated as:

$$\frac{\text{Sugar recovery (\%)}}{\text{Sucrose (\%)}} \times 100$$

$$\text{Gross sugar yield (ton fed.}^{-1}\text{)} = \text{root yield (ton fed.}^{-1}\text{)} \times \text{sucrose (\%)}$$

Sugar loss yield was computed as:

$$\text{Root yield (ton fed.}^{-1}\text{)} \times \text{Sugar loss}$$

Water use efficiency (WUE): Water-Use Efficiency (WUE) values were calculated with the following equation (Howell *et al.*, 1990):

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

where, WUE is the water use efficiency (kg m^{-3}), E_y is the economical yield (kg/fed./season) and E_t is the total applied of irrigation water, $\text{m}^3/\text{fed./season}$.

Statistical analysis: Statistical analysis was carried out using SPSS program Version 16. An independent t-test was also carried out to find the significant differences between magnetic and nonmagnetic water treatments.

RESULTS AND DISCUSSION

Photosynthetic pigment: Data illustrated in Fig. 3 show that, irrigation of sugar beet plants with magnetized water increased significantly photosynthetic pigment contents (Chl. a, Chl. b, Carotenoids, Chl a+Chl b, Total pigment

and Chl a/Chl b) by 31.28, 26.18, 29.54, 30.17, 30.05 and 4.06%, respectively, as compared with sugar beet plants irrigated with normal water. Chlorophyll contents have a basic importance for plant productivity, the most important issue for farmers. Low chlorophyll content, below 2 mg dm^{-2} of leaf surface, causes insufficient absorption of the sun light and low plant productivity. About 3 mg of chlorophyll dm^{-2} of leaf surface ensures the optimal (95-97%) consumption of sun light absorbed by plants (Rochalska, 2005).

Such effect could be attributed to the magnetic field on plants which is sensible to it and the increases in its energy. Later this energy is distributed among the atoms and causes the accelerated metabolism and germination. Magnetic treatment of water has been reported to change some of the physical and chemical properties of water, mainly hydrogen bonding, polarity, surface tension, conductivity, pH and solubility of salts (Amiri and Dadkhah, 2006; Ozeki and Otsuka, 2006). These changes in water properties may be capable of affecting the growth of plants.

The stimulatory effect of Magnetic Water (MW) on photosynthetic pigment contents may be due to the effect of Magnetic Treatment (MT) on alteration the key of cellular processes such as gene transcription which play an important role in altering cellular processes. The same result was obtained by Atak *et al.* (2003, 2007) who found an increase in chlorophyll content specifically appeared after exposure to a magnetic field for a short time. They also suggested that, increase in photosynthetic pigment through the increase in cytokinin synthesis which accompanied by an increase in auxin synthesis that induced by magnetic field treatment of soybean plants. Recently, Abd El-Qodos

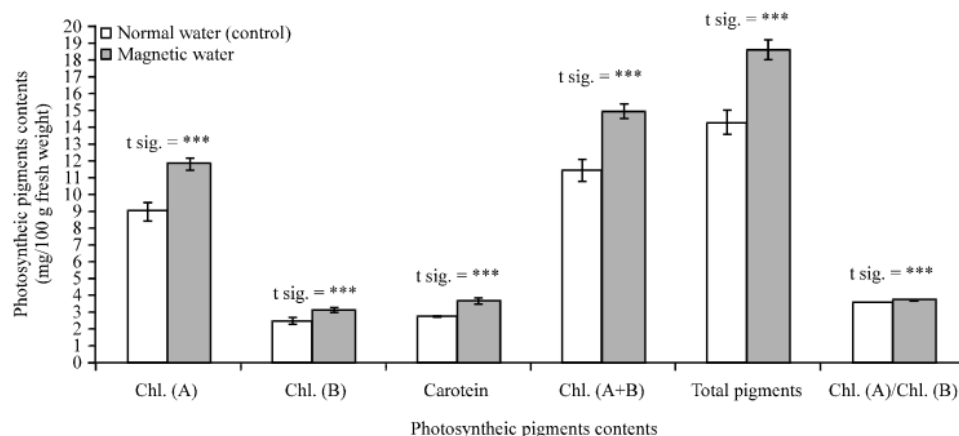


Fig. 3: Pigment contents in the leaves of sugar beet plants irrigated with normal and magnetized water. Mean values for 2 seasons of experiment. N = 10 in all parameters, ***significance at 0.0001, error bars expressed as SD

and Hozayn (2010a, b) and Hozayn *et al.* (2011) reported that, magnetic treatment increased photosynthetic pigment contents via., increasing growth promoters (IAA). Moussa (2011) reported that, irrigation with magnetic water exhibited marked significant increase in the photosynthetic pigments (chlorophyll a, chlorophyll b and carotenoids), photosynthetic activity and translocation efficiency of the photo assimilates of common bean over the control. These results for increasing photosynthetic activity are confirmed with that of Mihaela *et al.* (2007, 2009). They showed an increase in chlorophyll and carotenoids content specifically appeared after treatment with magnetic water.

Root parameters at harvest: Sugar beet root parameters are considered the main indicators for root yield. Irrigation of sugar beet plants with magnetized water induced significant increases in root yield criteria (weight, length and diameter) by 21.53, 5.68 and 16.23%, respectively as compared with non magnetized water application (Table 2). The results obtained by different authors confirmed the beneficial effect of low frequency of magnetic field on root and leave growth of sugar beet (Marinkovic *et al.*, 2000, Vasilevski, 2003; Rochalska *et al.*, 2008).

Sugar beet yield (ton fed.⁻¹): Root, white sugar, molasses and Recoverable sugar yield (ton fed.⁻¹) exhibited significant increases in response to magnetic water

treatment by 19.05, 23.63, 3.51 and 28.96%, respectively as compared with normal water treatment (Fig. 4). Generally, the stimulatory effect of magnetic treatment to yield and its components may attribute to their role in increasing photosynthetic pigment (Fig. 3) consequently increasing yield characters (Table 3). These results are in agreement with those obtained by several authors, Marinkoviae *et al.* (2008) showed that, application of the variable electromagnetic field caused a 94% increase of the root mass of sugar beet, leaf surface up to 52%, yield to 12.88 t ha⁻¹ and the percentage of sugar was increased for 0.70%. In similar trials performed with corn a higher root mass (55%), vegetative mass (57%) and yield (18.70%) was achieved. Marinkovic *et al.* (2000) noted that some results using magnetic stimulation on cereal seed, in Canada, increased the yield for 20%. Variable electromagnetic fields with different frequency in a macro trial with potato showed a yield increase up to 144.80% (Marinkovic *et al.*, 2002). The yield of pepper was increased by 64,9% with resonant impulse electromagnetic stimulation in the trials of (Takac *et al.*, 2002). Crnobarac *et al.* (2002) showed an increase in yield of soybean from 5-25%, with a higher quantity of oil and protein and at sunflower from 13,2-17,3%. Govedarica and Milosevic (2002), achieved results with electromagnetic stimulation of soil. They concluded that total microbial abundance in soil was increased and decreased abundance of fungi, ureolithic microorganisms, denitrifying organisms and urease activity. The yield of cultivars in trials (sugar beet, corn) was increased.

Table 2: Root parameters of sugar beet plants irrigated with normal and magnetized water

Treatment	Mean±SD				
Root parameter	Normal water (control)	Magnetic water	t-calc.	t-sig.	Increase (+) or decrease (-) (%) over control
Weight (kg)	1.44±0.05	1.75±0.07	3.54	**	21.53
Length (cm)	16.90±0.43	17.86±0.36	1.71	ns	5.68
Diameter (cm)	32.85±0.79	38.18±0.54	5.57	***	16.23

Mean values for 2 seasons of experiment, N = 60 in all parameters, ns, ****Non significant (p-value>0.01, >0.001), respectively

Table 3: Quality and impurity parameters of sugar beet juice plants irrigated with normal and magnetized water

Treatment	Mean±SD				
Technology parameter	Normal water (control)	Magnetic water	t-calc.	t-sign.	Increase (+) or decrease (-) (%) Over control
Quality parameter (%)					
Purity	80.81±2.25	83.16±1.34	2.85	*	2.91
TSS	19.19±0.37	19.39±0.41	1.15	ns	1.04
Sugar	15.49±0.37	16.12±0.13	5.09	***	4.07
Recoverable sugar	12.48±0.22	13.51±0.37	7.56	***	8.25
Molasses sugar	2.61±0.07	3.02±0.09	11.00	***	15.71
Impurity (mmol/100 g fresh root)					
Na	4.80±0.34	4.23±0.16	4.90	***	-11.88
α-Amino nitrogen	3.86±0.27	3.28±0.14	6.01	***	-15.03
Na+K	6.68±0.48	5.84±0.16	0.65	***	-12.57
K/Na ratio	0.39±0.03	0.38±0.03	5.28	ns	-2.56
Alkalinity coefficient	1.79±0.09	1.73±0.08	1.35	ns	-3.35

Mean values for two seasons, N = 10 in all parameters, ns, ****Non significant (p-value>0.01, >0.001), respectively

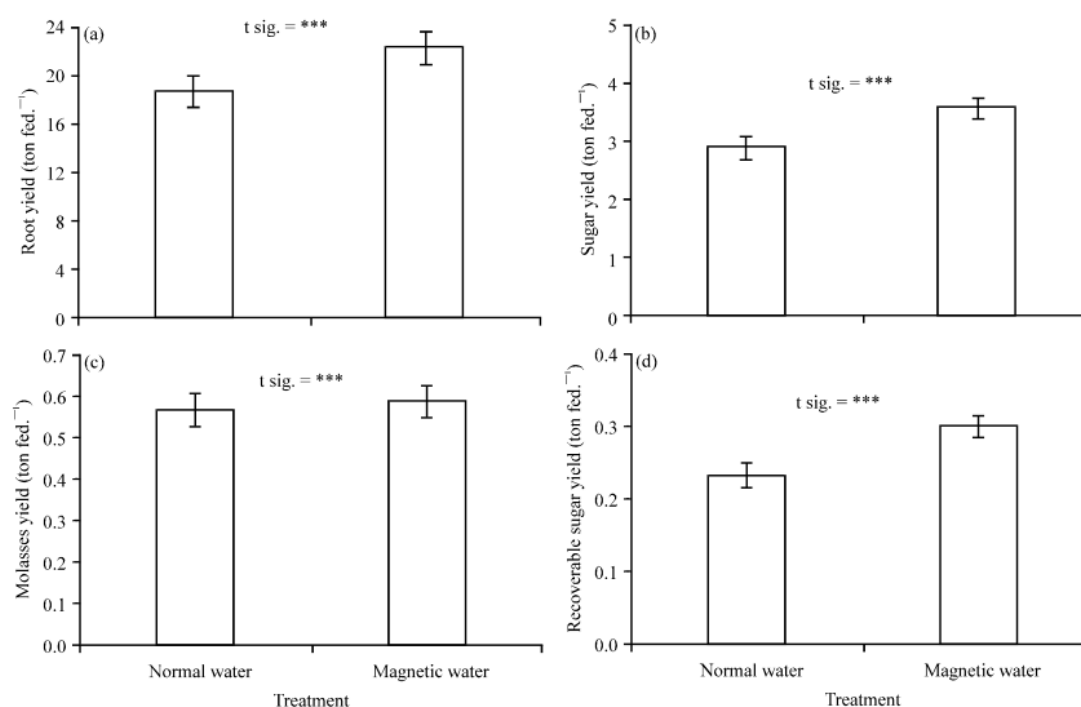


Fig. 4(a-d): Fresh root, sugar, recoverable sugar and molasses yields (ton fed.⁻¹) of sugar beet plants irrigated with normal and magnetized water. Mean values for 2 seasons of experiment, N = 10 in all parameters, ns, ****Non significant ($p > 0.01$, > 0.001), respectively. Error bars expressed as SD (fed. = 4200 m²) (a) Root, (b) Sugar, (c) Molasses sugar and (d) Recoverable sugar

Tian *et al.* (1989) who indicated that, MW increased yield of rice by 13.23%. This was accompanied the stimulation effect of MW on leaf chlorophyll content. Kordas (2002) found that, the exposure of green tops and root systems of wheat plant to MF increased quantity of coarse grain by 10.6 and 6.3%, respectively. Recently, Hozayn and Abd El-Qodos (2010a, b), Abd El-Qodos and Hozayn (2010a, b) and Hozayn *et al.* (2011) observed that, wheat, lentil, chickpeas, flax, sunflower, as well as on ground nut, faba bean and mung bean (data unpublished) irrigated with magnetized water gave more value of all recorded parameter. The increase in yield per plant ranged between 11-47% depended on tested plants.

Sugar beet quality characters: Beet quality is an important issue for farmer's income in Egypt. Recently, the main purpose to cultivate sugar beet is the production of a maximum amount of white sugar. The sucrose concentration in the beet is the major factor affecting white sugar yield. Data presented in Table 3 show that irrigation of sugar beet plants with magnetized water increased significantly beet quality by increasing sugar concentration by 4.07%, TSS by 1.04%, quality by 2.91%

and recoverable sugar by 8.25% compared to beet plants irrigated with normal water. Several investigators showed the beneficial effects of the electric and magnetic field on yield and some features of the technological quality of sugar beet roots (Hernandez *et al.* 2010; Kacharava *et al.*, 2009; Koper *et al.*, 1996; Marinkoviae *et al.*, 2008; Pietruszewski and Wojcik 2000a, b; Bialczyk *et al.* 2011; Rochalska and Orzeszko-Rywka, 2005, 2008; Vasilevski, 2003; Wojcik *et al.*, 2004; Malesevic *et al.*, 2002; Govedarica and Milosevic, 2002).

Root impurities (K⁺, Na⁺ and α -amino-N) are important factors which influence the production of white sugar yield. The highest K⁺, Na⁺ and α -amino-N concentrations in beets were determined for plants irrigated with normal water. However, the lowest concentrations were in plants irrigated with magnetic water (Table 3). Generally, irrigating beet plant with magnetized water decreased significantly the impurities which effect yield quality (K⁺, Na⁺ and α -amino-N) by 14.36, 11.88, 15.03 and 13.11%, respectively as compared with non magnetized water application (Table 3). The increase in sugar% was accompanied by the decrease in impurities% and could be attributed to the role of

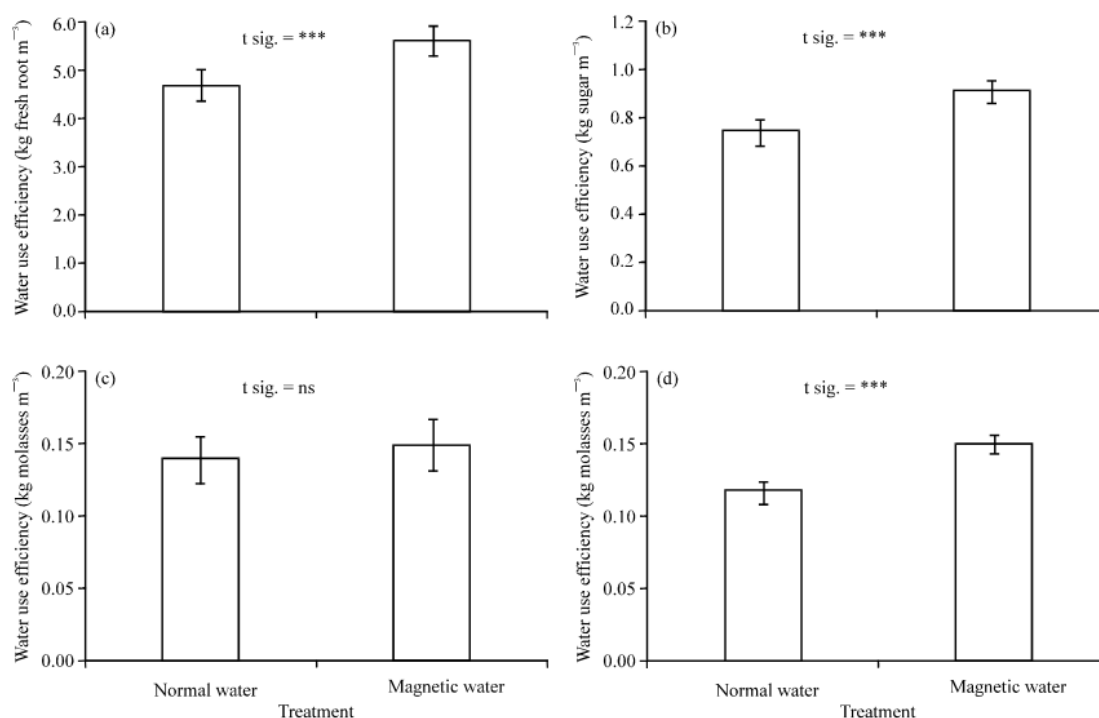


Fig. 5(a-d): Water use efficiency for fresh root, sugar, recoverable sugar and molasses yields (kg m⁻³ water) of sugar beet plants irrigated with normal and magnetized water. Mean values for 2 seasons of experiment, N = 10 in all parameters, ns, ***, **** Non significant ($p > 0.01$, > 0.001), respectively. Error bars expressed as SD (a) Root, (b) Sugar, (c) Molasses sugar and (d) Recoverable sugar

magnetic water in increasing sucrose substances and proteins (Abd El-Qodos and Hozayn, 2010a, b). Similar results also, were reported by Malesevic *et al.* (2002), Govedarica and Milosevic (2002) and Marinkoviae *et al.* (2008).

Water use efficiency (WUE): Data in our study revealed that, application of magnetic water technology increased significantly crop water use efficiency by 19.19, 28.81, 22.97 and 7.14% for root fresh, sugar, recoverable sugar and molasses sugar yields (kg m⁻³ water), respectively compared to irrigation with normal water (Fig. 5). Mulook *et al.* (2011) recorded that irrigation of jojoba plants with magnetized water led to increase water use efficiency under normal and drought water stress as compared to the recommended irrigation. Magnetic treatment of irrigation water is an acknowledged technique for achieving high water use efficiencies due to its effect on some physical and chemical properties of water and soil (Noran *et al.*, 1996; Basant *et al.*, 2007; Maheshwari and Grewal, 2009). These changes result in an increased ability of soil to get rid of salts and consequently better assimilation of nutrients and fertilizers in plants during the vegetative stage.

CONCLUSION

The present study confirmed the promising and previous studies under greenhouse condition. Generally, 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 sugar beet under newly reclaimed sandy soil. The usage of magnetic water in the agricultural production will enable intense and more quantities and qualitative production.

Surely wider acceptance of this method is not to be expected, but one thing is crystal clear that the acceded results are indisputable and they are paving the road for their wider implementation in the agricultural production.

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