Emirates Journal of Food and Agriculture. 2022. 34(9): 784-791
doi: 10.9755/ejfa.2022.v34.i9.2945
http://www.ejfa.me/

RESEARCH ARTICLE

Magnetic treatment of irrigation water: Its effect on water properties and characteristics of eggplant (*Solanum melongena*)

Gottam Kishore[1]*, Ranjay Kumar Singh[2], Chandrakant Saxena[3], Yogesh Anand Rajwade[3], Karan Singh[2], Bhushana babu[3]

[1]Ph.D. Scholar, [2]Principal Scientist, [3]Senior Scientist, Central Institute of Agricultural Engineering-Bhopal, India

ABSTRACT

Poor quality water is a potential source for demand management in irrigated agriculture after essential treatment. Magnetic water treatment (MWT) is one of the emerging technologies among water treatment methods for the above-cited problems without harming the environment. The optimum configuration of the 7000 gauss magnetic treatment device and the effect of magnetized water on the yield parameters of the eggplant in a pot culture experiment were examined in this study. The maximum significant ($P< 0.05$) changes in physicochemical properties (pH, EC, total hardness, Langelier Saturation Index, Na, etc.) of water occurred at an optimized velocity of 0.8 m/s and less. The mean plant height was maximum under magnetized bore water treatment compared to all other treatments ($P< 0.05$). In particular, the average yield per plant was increased by 17 per cent in magnetized bore water treatment compared to the control. Overall, the results have shown that an optimum configuration of the water treatment device is needed before the start of the experiment based on magnetic strength. Moreover, magnetically treated irrigation water positively impacted plant growth parameters and the yield of the eggplant.

Keywords: Irrigation, Magnetic water, Total hardness, Langelier Saturation Index, yield per plant

INTRODUCTION

Water resources are essential for ensuring an adequate food supply and a healthy environment for all living things. Water availability for any crop plays a significant role in their growth, yield and for photosynthesis reaction. In India, approximately 85 per cent (688 BCM) of water usage is diverted for irrigation, with this figure expected to rise to 1072 BCM by 2050 (Kaur et al., 2012). Because of limited water supplies, reclaimed water, hard water, low saline water and moderate saline water are alternate for irrigation. As a result, to treat poor quality water, global agriculture is currently looking for an effective eco-friendly water quality enhancement technology that can increase crop productivity without harming the environment.

Magnetic field (MF) treated water, also known as magnetized water (MW), is one such application of magnetic fields, which has been known for centuries (Colic and Morse, 1999). The physicochemical properties of fluids are influenced by differences in magnetic field strength (Teixeira and Dobranszk, 2014; Aliverdi et al., 2015; Hozayn et al., 2016; Teixeira and Dobránszki, 2016). When water is exposed to a magnetic field, its properties such as viscosity, dielectric constant, electric conductivity, boiling temperatures and surface tension force vary in contrast to pure water. Various studies have been conducted using MWT device on essential element uptake (Maheshwari and Grewal, 2009); seed yield (Selim and El-Nady, 2011); seed germination percentages (Matwijczuk et al., 2012) and root growth of crop (Turker et al., 2007) and the yield of high-quality tomatoes (Yusuf and Ogunlela, 2017; Helaly, 2018). All have reported that benefits were achieved by employing magnetized irrigation water from magnetically treated irrigation water. Similarly, adverse effects of magnetic fields on the root growth of many plant species have been observed (Belyavskaya, 2004; Turker et al., 2007). Mohamed and Ebead (2013) passed three different water sources

***Corresponding author:**
Gottam Kishore, ICAR- Central Institute of Agricultural Engineering, Bhopal (CIAE), Madhya Pradesh-462038, India,
Phone: +91-9492-146205. **E-mail:** reddykishore469@gmail.com

Received: 04 April 2022; **Accepted:** 30 August 2022

with different numbers of cations and anions through an magnetic field (with 1000 G strength) and concluded that the electrical conductivity increased from 3.81, 1.37, and 0.33 dSm^{-1} to 3.70, 1.36, and 0.32 dSm^{-1} respectively. Water that has been magnetized can significantly boost water productivity by increasing the solubility of water-soluble minerals like nitrogen, potassium, lead and iron which can help crops absorb more nutrients (Al-tarjuman et al., 2020). The magnetic field has a significant impact on Zeta's ability to form solution-forming particles and can distribute those particles on a microscopic scale (Gilani et al., 2017).

Moreover, to enhance water quality ensure adequate exposure of irrigation water to the magnetic field (Lipus et al., 2015), credentials of magnetic field (Yee et al., 2014), adjustment of the water flow rate, velocity following changes in physicochemical properties and functioning of the water treatment device need to be carried out, modified and extended (Gabrielli et al., 2001). For the effective and efficient application of MWT so far, the optimum configuration of the device is the best way which has potential. Few studies were carried out by mounting two powerful magnets on the top and bottom of a pipe with a specific magnetic strength. However, to date hardly any study has reported the impact of three stages (electrolysis, de-ionization and magnetization) processed irrigation water on crop performance and water properties.

In view of the above, this study was conducted to investigate the effects of the magnetic treatment on the quality characteristics (pH, EC, total hardness, Ca, Mg, Langelier saturation index (LSI), Cl) of the bore, saline and hard water at various device configurations and the influence of magnetically treated water on the attributes of eggplant (*Solanum melongena*).

MATERIALS AND METHODS

Study area and experimental plan

Two sets of experiments were carried out from March 2020 to November 2021 at ICAR-Central Institute of Agricultural Engineering, Bhopal (23^0 18› 35» N and 77^0 24› 10» E), situated 527 m above mean sea level (MSL). The experimental plan comprised laboratory studies such as the optimum configuration of MTD and pot culture experiment with test crop as eggplant. The selected treatments are bore water, hard water (1000 ppm) and saline water (EC=3 mS/cm) of both magnetically treated and control.

Optimum configuration of magnetic water treatment (MWT) device

A 5 HP pump having discharge of 5 litres per second (lps) was utilized to generate the necessary pressure required to pass water through the control head and various accessories through a pipe network that was connected to a 3000-litre capacity tank to give an adequate water supply. The pump was then connected to a filtration system and the outlet of the filters was further connected to an MWT device (Fig. 1). The MTD is 1200 cm long with a 3.5 cm diameter inflow outflow connection. For the optimum configuration of 7000 gauss magnetic strength, 18 trials were conducted on flow rate and velocity. Finally, three different flow rates 3.0, 4.0 and 5.0 lps having velocities of 0.8, 1.0 and 1.2 m/s were selected respectively. The water was magnetized by passing it through a magnetic treatment device, as described by (Helaly, 2018).

This water quality improvement device comprises an electrolysis unit, a dynamic pulse unit and an electromagnetic unit (Fig. 2). It works on the principle of ionization of dissolved solids using an anode and cathode of copper coil, electrolysis of water using a dynamic pulse current with 50 kHz frequency and energization of cations with Faraday's law of EMF phenomena. The velocity of water flow was adjusted using an ultrasonic flowmeter, which measures the passage time of sound in both directions by alternating transmitting and receiving a burst of ultrasound between the two transducers (Fig. 3)

Physicochemical properties of irrigation water

The solutions were analyzed using standard analytical procedures (Table 1) as per prescribed IS 3025 test codes. The normal water required for the study was taken from the bore well, while research lab companies' standard chemicals of AR grade were used to create synthetic hard water (1000 ppm) and saline water (EC =3 mS/cm) (Table 2).

Cultivation method, growing conditions and soil properties

Twenty-one days old healthy seedlings of eggplant were transplanted in pots. The single seedling was planted as

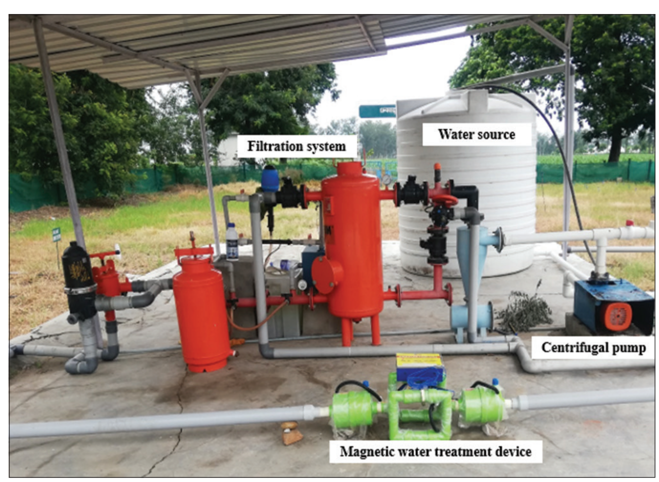

Fig 1. Schematic illustration of the experimental set-up.

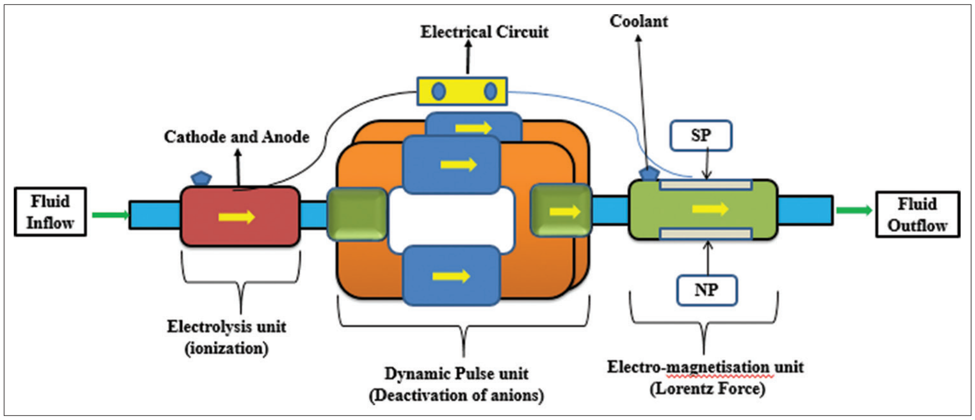

Fig 2. Magnetic water treatment device (Bornare, et al., 2018).

Fig 3. Transducers fixed on pipe to measure velocity of water flow.

per the treatment combinations. Just after transplanting the pots were given light irrigation. Later on, irrigation was given as per irrigation treatments. Crop cultivation and protection measures were implemented as per the standard practices. FAO CROPWAT software was used to calculate irrigation requirements and schedules (FAO, 2009). The soil used in the experiment was tested in the laboratory and found to have a clay texture (52.2 %), a pH of 7.54 and an EC of 1.01 mS/cm (Table 3).

Data collection and analysis

The plant biometric data (plant height, number of branches, days to flowering, plant spread) were recorded at an interval of 30, 60, 90 days and at final harvest in every treatment. The eggplants fruits were picked after reaching the harvesting stage and the overall yield was estimated. The statistical analysis was accomplished in a full factorial design in which each treatment was replicated three times (Table 4). The analysis of variance (ANOVA) was used to determine the major effects of irrigation water types, magnetic treatment and velocities at various flow rates as well as their interactions with the physicochemical properties of water. The differences between pairs of treatment means were investigated at a 5 per cent level of significance using the Dunnett test and Paired t-test (treatment vs control) in the SAS software.

Table 1: Test method and device used for the physiochemical analysis of irrigation water

S. No	Parameter	Test method	Device used
1	pH	IS 3025 P11 1983 RA 2017	EUTECH PCD650
2	EC (mS/cm)	IS 3025 P14 2013 RA 2019	EUTECH PCD650
3	Total Hardness (meq/l)	IS 3025 P21 2009 RA 2019	Chemical analysis
4	Chlorides (meq/l)	IS 3025 P32 1988 RA 2019	Chemical analysis
5	Ca (meq/l)	IS 3025 P44 1991 RA 2019	Chemical analysis
6	Mg (meq/l)	IS 3025 P46 1994 RA 2019	Chemical analysis
7	Carbonates (meq/l)	IS 3025 P51 2001 RA 2017	Chemical analysis
8	Bi-carbonates (meq/l)	IS 3025 P51 2001 RA 2017	Chemical analysis
9	Na ((meq/l)	IS 3025 P45 2001 RA 2017	Flame Photometer (Systronics)

Table 2: Physicochemical characteristics of the irrigation water for different treatments

Parameters	Bore Water	Hard water	Saline water
pH	7.17	7.31	7.26
EC (dS/m)	0.92	1.48	3.00
Total Hardness (meq/l)	11.60	10.00	12.80
Ca (meq/l)	7.04	9.90	6.66
Mg (meq/l)	5.08	5.39	5.00
Carbonates (meq/l)	2.18	3.00	2.78
Bi-carbonates (meq/l)	4.43	4.79	5.08
Chlorides (meq/l)	3.43	3.64	6.29
Na ((meq/l)	1.64	1.78	5.41
SAR	0.67	0.73	2.20

Table 3: Physicochemical properties of experimental soil

Soil characteristics	Particulars	Composition
Textural composition	Sand, (%)	20.60
	Silt, (%)	26.50
	Clay, (%)	52.2
	Porosity, (%)	43.50
Chemical properties	pH	7.54
	EC (dS/m)	1.01
Physical properties	Bulk density, g/cc	1.42
	Field capacity, (%)	31.30
	Wilting point, (%)	18.22
	Infiltration rate, cm/hr	1.25

Table 4: Main and sub-treatments of the experiment

Main treatments	Sub-treatments	
Water type	**Water quality**	**Flow rate**
1) Magnetized water 2) Non-magnetized water	1) Bore water 2) Hard water, 1000 ppm 3) Saline water, EC 3 mS/cm	1) Flow rate of 3.0 lps at velocity of 0.8 m/s (F1) 2) Flow rate of 4.0 lps at velocity of 1.0 m/s (F2) 3) Flow rate of 5.0 lps at velocity of 1.2 m/s (F3)
Fixed parameters	Water passage between south pole (sp) and north pole (np) Magnetic strength: 7000 gauss	
Statistical parameters	3 replications and 18 treatments	

RESULTS AND DISCUSSIONS

Impact of the magnetic treatment on physicochemical properties of water

Each water sample was tested after one, two and three passes through the MWT device to determine changes in sample properties. Minor physicochemical changes were observed when water passed through the system more than once. Maximum physicochemical changes in parameters of poor quality (hard and saline) water were observed at a velocity of 0.8 m/s (Discharge= 3.0 lps) in comparison to bore water treatment. Hereafter the flow rate and velocity will be indicated as velocity only for easy understanding.

Effect on pH

The pH has varied from 7.10 to 7.78 in bore water, 7.54 to 8.0 in hard water and 7.21 to 7.85 in saline water treatments. The effect of magnetic water, water type and their interaction effect in combination with velocity and flow rate were statistically significant at a 5 per cent level on pH (Table 5). In this experiment, a gradual increase in pH (Fig. 4) was found throughout the experiment. The changes in hydrogen bonding might be the possible reason for the change in pH due to more exposure time for magnetization. The ions H^+ and OH^- are always paired as the concentration of increased ease, the other will decrease, which impacts pH value. This has led to different streams of opinions regarding the impact of magnetic treatment

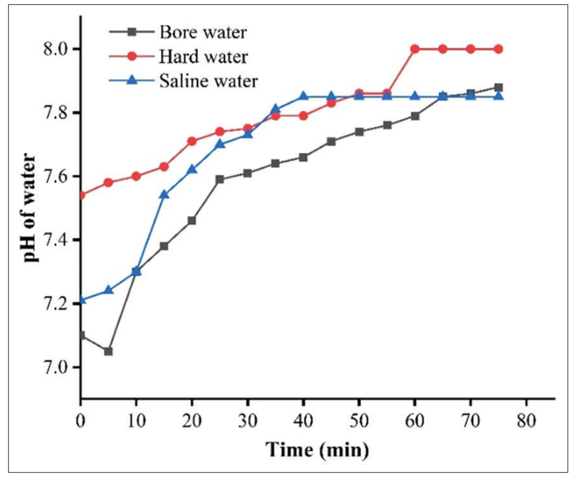

Fig 4. pH of irrigation water over continuous treatment.

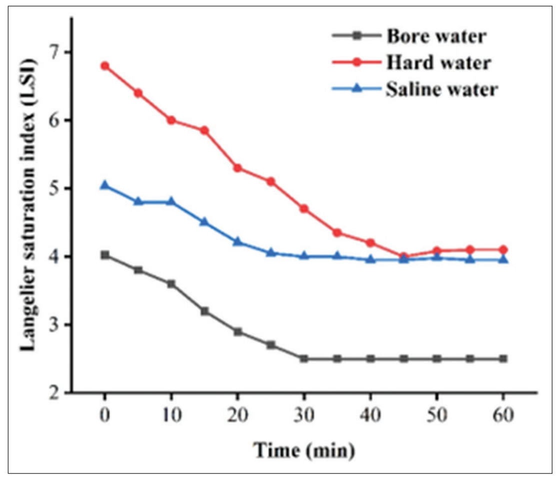

Fig 5. LSI of irrigation water over continuous treatment.

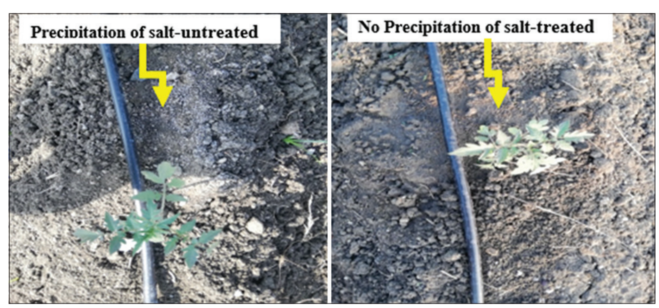

Fig 6. Salt encrustation with untreated and treated irrigation water.

on the pH of water. The findings are similar to those of researchers (Chang and Weng, 2008; Surendran et al., 2016), who discovered changes in water's physical and chemical properties viz. polarity, hydrogen bonding, conductivity, surface tension, refractive index, pH, and solubility of salts because of exposing to the magnetic field.

Effect on electrical conductivity (EC)

The EC of hard water and saline water was significantly reduced by magnetic treatment of irrigation water,

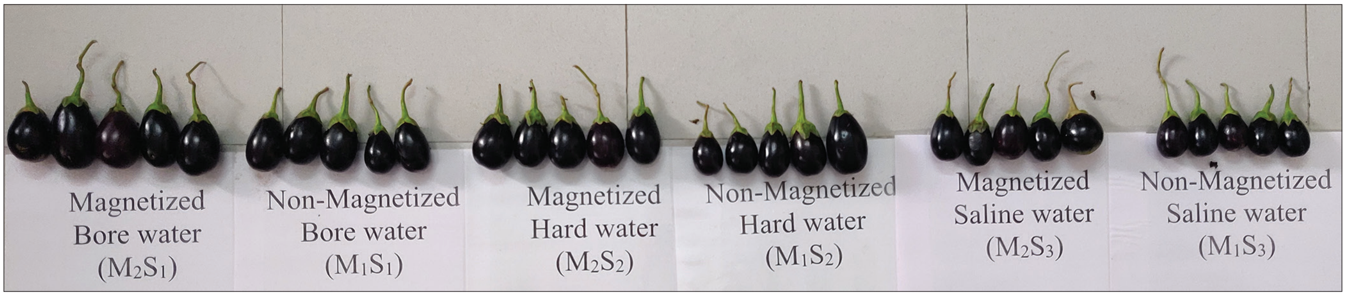

Fig 7. Yield of the eggplant (third harvest) under different irrigation treatments .

Table 5: ANOVA (mean squares) for the measured parameters under different irrigation treatments

Parameter	df	pH	EC (dS/m)	Hardness	Ca	Mg	Carbonates	Bi-carbonates	Cl	Na	LSI	SAR
M	1	1.6120*	0.2576*	19.0579*	0.9923*	0.0600^{ns}	0.1656*	0.3902*	0.8288*	0.4988*	38.1528*	0.0634*
S	2	1.2309*	14.0088*	376.3292*	55.4956*	0.7983*	2.2939^{ns}	1.9714*	45.6824*	77.2438*	21.7391*	14.2426*
F	2	0.0137^{ns}	0.0060^{ns}	0.0108^{ns}	0.0031^{ns}	0.0035*	0.0072*	0.0104*	0.0083*	0.0176*	0.0383*	0.0016*
M*S	2	0.0025^{ns}	0.0562*	1.3572*	0.0382**	0.0022^{ns}	0.0819*	0.0016^{ns}	0.0047^{ns}	0.0783*	3.2225*	0.0120*
M*F	2	0.0137^{ns}	0.0060^{ns}	0.0108^{ns}	0.0031^{ns}	0.0035^{ns}	0.0072*	0.0104*	0.0083*	0.0176*	0.0383*	0.0016*
S*F	4	0.0047^{ns}	0.0031^{ns}	0.0039^{ns}	0.0011^{ns}	0.0038^{ns}	0.0270*	0.0012^{ns}	0.0032^{ns}	0.0030*	0.0026*	0.0002^{ns}
M*S*F	4	0.0051**	0.0029^{ns}	0.0032^{ns}	0.0010^{ns}	0.0041^{ns}	0.0210*	0.0010^{ns}	0.0028^{ns}	0.0029^{ns}	0.0020**	0.0002^{ns}
Error	38	0.0117	0.0210	0.0210	0.0065	0.0035	0.0035	0.0022	0.0025	0.0028	0.0012	0.0004

* and ns indicates significant at 5 per cent level and non-significant respectively; M, S, F represents the irrigation water type, irrigation water quality and flow rates respectively.

but the EC of bore water was not found statistically significant when compared to control (Table 6). At a velocity of 0.8 m/s, the recorded values of EC were observed significantly lower in magnetic treated hard water (1.29 mS/cm) and saline water (2.68 mS/cm) compared to untreated hard water (1.48 mS/cm) and saline water (3.0 mS/cm). The decreased EC of water due to magnetic treatment was ascribed to physical changes caused in fine constantly colloidal molecules resembling Brownian motion and electrolytic substances resulting in increased binding of ions on colloidal molecules (Surendran et al., 2016). The applied magnetic field has affected the hydrogen bonding forms between water molecules that have led to confirmable changes. Variations in physical and chemical properties of water viz. solubility of salts, conductivity and hydrogen bonding are due to magnetic field exposure (Otsuka and Ozeki, 2006).

Effect on cations

The magnetic treatments of water significantly influenced Na content in all the treatments, but the effect of magnetic water treatment on Mg was found as non-significant in all treatments irrespective of various flow velocities (Table 6). This may be due to mineral ions' crystallization and precipitation processes resulting from the magnetic treatment. A higher sodium concentration was registered in magnetic untreated saline water and was decreased by treating with a magnetic field. The magnetic force breaks hydrogen bonds between water molecules and ions, causing these separated ions to join with other elements and precipitate, resulting in a concentration difference. Chang and Weng (2008) reported a similar conclusion, mentioning that the enhanced mobility of the ions in a magnetic field harmed the hydrogen bonding in the high sodium concentration solution. On the other hand, in a low sodium concentration solution, the structural behaviour may be governed by the properties of the water and thus the bonding ability of hydrogen molecules may be enhanced by increasing the strength of the magnetic field.

The mean LSI of magnetically treated water was statistically significant ($P< 0.05$) and lower than the non-magnetic treated water in all treatments. The maximum value of LSI was found in the control treatment of hard water. Moreover, after the magnetic treatment of water, the LSI continuously decreased from 4.02 to 2.50 in bore water, 6.80 to 4.10 in hard water and 5.04 to 3.98 in saline water treatments respectively (Fig. 5). Hence salt precipitation was less on top of soil when water was passed through MTD (Fig. 6). Furthermore, when carbonate and calcium ions enter the influence zone of the magnets, their opposing charges cause them to move in different directions. Since all calcium cations move in one direction while the carbonate anions move in the opposite direction, they tend to collide. When these collisions happen, the ions bond together and create aragonite, a solid calcium carbonate system. These tiny crystals cannot attach to the pipelines while moving through water. As a result, the salts refuse to stay relatively in the pipeline. Aragonite, which results from metastable

Table 6: Effect of magnetic treatment at different water velocities on mean values of physicochemical parameters in different types of irrigation water

Treatments	Bore water				Hard water				Saline water			
Parameters	Control	F1	F2	F3	Control	F1	F2	F3	Control	F1	F2	F3
pH	7.10	7.46 *	7.41*	7.25ns	7.54	7.95*	7.90*	7.88*	7.21	7.60*	7.58*	7.55ns
EC (dS/m)	0.95	0.84ns	0.88ns	0.91ns	1.48	1.29*	1.32ns	1.35ns	3.00ns	2.68*	2.76ns	2.85ns
Hardness (meq/l)	11.60	9.80*	9.84*	10.00ns	20.00	18.76*	18.78*	18.80*	12.80ns	12.16*	12.17*	12.20ns
Ca (meq/l)	7.04	6.69ns	6.66ns	6.73ns	9.90	9.55*	9.62*	9.64ns	6.66ns	6.47ns	6.50ns	6.50ns
Mg (meq/l)	5.08	5.10ns	5.09ns	5.17ns	5.39	5.48ns	5.48ns	5.44ns	5.00ns	5.00ns	5.09ns	5.14ns
Carbonates (meq/l)	2.33	2.02*	2.17ns	2.28ns	3.00	2.76*	2.77*	2.80*	2.78ns	2.53*	2.65*	2.70ns
Bi-carbonates (meq/l)	4.43	4.20ns	4.20ns	4.33ns	4.79	4.60*	4.65*	4.67ns	5.08ns	4.89*	4.89*	4.95ns
Cl (meq/l)	3.43	3.13ns	3.20ns	3.31ns	3.64	3.35*	3.36*	3.51ns	6.29ns	6.01*	6.07ns	6.05ns
Na (meq/l)	1.64	1.47*	1.51ns	1.56ns	1.78	1.63*	1.68	1.70ns	5.41ns	4.97*	5.13ns	5.13ns
LSI (meq/l)	4.02	2.48*	2.62*	2.63*	6.80	4.08*	4.15*	4.31*	5.04ns	3.98*	4.05*	4.15*
SAR (meq/l)	0.67	0.64ns	0.63ns	0.65ns	0.64	0.59ns	0.61ns	0.62ns	2.24ns	2.08ns	2.13ns	2.13ns

* and ns indicates significant at 5 percent level and non-significant respectively; F1, F2 and F3 represents the flow rate of 3.0, 4.0 and 5.0 lps at velocities of 0.8,1.0 and 1.2 m/s respectively.

Table 7: Effect of the magnetically treated irrigation water on biometric parameters of eggplant

	Plant height (cm)			No of branches/plant			Plant spread (cm)			Days to first flowering		
Treatment	Control	Magnetized	p-value	Control	Magnetized	p-value	Control	Magnetized	p-value	Control	Magnetized	p-value
Bore water	96.2	103.1	0.046*	6.3	6.7	0.018*	85.5	88.7	0.015*	39.9	34.8	0.002*
Hard water	90.8	100.4	0.002*	6.5	8.2	0.026*	73.4	80.2	0.046*	41.7	38.5	0.081ns
Saline water	73.4	79.9	0.076ns	3.9	4.3	0.002*	63.8	66.4	0.082ns	55.4	52.6	0.083ns

* and ns denotes significant at 5 per cent and non-significant respectively

Table 8: Effect of magnetic water treatment on yield of eggplant (kg/plant)

Treatment	Control	Magnetized	p-value
Bore water	3.5	4.1	0.03*
Hard water	2.9	3.5	0.04*
Saline water	1.7	2.1	0.08ns

* and ns denotes significant at 5 per cent and non-significant

vaterite nuclei transformation, has a distinct needle-like morphology and good adhesion to the pipe's substrate (Fathi et al., 2006).

Effect on anions

Passing water through the magnetic device significantly reduced the mean chloride contents over magnetic untreated water in both hard and saline treatments at a velocity of 0.8 m/s (Table 6). Bicarbonate concentration of the water was also significantly influenced by magnetic treatments in hard water and saline water at both velocities of 0.8 and 1.0 m/s. the treatment of magnetically untreated saline water had recorded the highest bicarbonate content of 5.08 me L^{-1}. Across different treatments, the bicarbonate content decreased significantly ($P<0.05$) due to the effect of magnetic treatment and variations in velocity. Madsen (2004) assumed that this diminution was caused by the magnetic field exposure accelerating the crystallization of weakly soluble diamagnetic salts of weak acids, such as carbonates, which decreased the concentrations of bicarbonates and carbonates in the water.

Biometric parameters of eggplant

This study showed that different treatments significantly influenced the plant height which varied from 73.4 to 103.1 cm (Table 7). Among all analyzed treatments, magnetized bore water treatment had the highest plant height, followed by magnetized hard water treatment, and this height was found significantly higher than the other treatments.

The total number of branches per plant varied from minimum of 3.9 to maximum of 8.2 under various treatments. The highest proportion of branches per plant was observed in magnetized hard water treatment. The plant spread ranged from 63.8 to 88.7 cm. The least number of days for first flowering was found in bore water. However, regarding the number of branches per plant, no significant difference was observed between hard and saline water treatments. These results can presumably be explained by the idea that by passing a volume unit through a magnetic field, more water molecules were produced, which enhanced the water molecules' capacity to absorb nutrients (Teixeira and Dobranszki, 2014). Furthermore, the effects of magnetic fields on plant metabolism viz. hormonal, photosynthesis, enzymatic activities and movements of endogenous solutes, particularly hormones and carbohydrates moved from synthesis zones to the growth zone of the crop (Ali et al., 2014).

In-bore water treatments (Table 8), magnetically treated solution of bore water produced a significantly higher yield of 4.1 kg/plant as compared to the control treatment of 3.5 kg/plant (Fig. 7). The current study's findings are comparable to those of (Esitken and Turan, 2004), who found that magnetic fields boosted strawberry and tomato fruit production. Increased enzymatic activity, as well as water and nutrient molecular mobility, might have enhanced crop development and productivity (Vashisth and Nagarajan, 2010).

CONCLUSIONS

Magnetic irrigation water treatment has demonstrated good agricultural potential, with a wide range of benefits in this study. In this investigation, the results indicated that the optimum configuration of the water treatment device based on the velocity of water flow and magnetic strength of the device is necessary to achieve the intended results. The maximum changes in physicochemical properties of irrigation water occurred at a velocity of 0.8 m/s and discharge of 3.0 lps for a 7000 gauss magnetic strength device. A definite increase in water pH and reduction in EC, total hardness, and LSI were observed for all the treatments. In some situations, pH change can also be used as an indicator for magnetically treated water. Also, a decrease in some ions (carbonates, bi-carbonates and chlorides) was observed after passing water through the device. The magnetized irrigation water positively affected plant height, number of branches and yield of the eggplant as compared to control plots. It can be concluded that magnetized irrigation water has a positive impact on plant growth and yield of the eggplant, implying that even poor-quality water can be used to irrigate crops.

ACKNOWLEDGEMENTS

The authors are grateful to the ICAR-CIAE, Bhopal as well as IARI-New Delhi for funding and providing a convenient location for research and would like to thank the Irrigation and Drainage Engineering division scientists for providing the insight and expertise, that assisted the research. The author wish to thank Ethix company for providing and modifying the device as per our requirement. Laboratory and field assistance provided by Mr. Santosh is also acknowledged.

Authors' contributions

The corresponding author Kishore: Ph. D scholar, conceptualized, carried out the experimental work and prepared the manuscript, data curation and original draft preparation. Ranjay Kumar Singh supervised the project and contributed to the final version of the manuscript. C.K. Saxena and Yogesh Anand Rajwade extended laboratory facilities, reviewed and edited the manuscript. Karan Singh and Bhushana Babu fine-tuned the protocols, reviewed and edited the manuscript.

Conflicts of interest

The authors declare no conflict of interest.

REFERENCES

Ali, Y., R. Samaneh, R. Zohre and J. Mostafa. 2014. Magnetic water treatment in environmental management: A review of the recent advances and future perspectives. Curr. World Environ. 9: 1008-1016.

Aliverdi, A., M. Parsa and H. Hammami. 2015. Increased soyabean-rhizobium symbiosis by magnetically treated water. Biol. Agric. Hortic. 31: 167-176.

AL-Tarjuman, J. K., F. N. MulaAbed, H. A. Qasim. and F. K. AL-Dulaimi. 2020. The effect of diluted foliar fertilizer with magnetic treated water in vegetable growth characteristics and productivity of tomato. Plant Arch. 20: 2760-2764.

Belyavskaya, N. A. 2004. Biological effects due to weak magnetic field on plants. Adv. Space Res. 34: 1566-1574.

Bornare, D., R. Nagarajan and R. Barge. 2018. Improvement of supplementary irrigation water quality for rainfed agriculture in the semi-arid region using magnetization techniques. J. Water Res. Prot. 10: 1198-1209.

Chang, K. T. and C. I. Weng. 2008. An investigation into the structure of aqueous NaCl electrolyte solutions under magnetic fields. Comput. Mater. Sci. 43: 1048-55.

Colic, M. and D. Morse. 1999. The elusive mechanism of the magnetic 'memory' of water. Coll. Surf. 154: 167-174.

Da Silva, J. A. and J. Dobranszki. 2014. Impact of magnetic water on plant growth. Environ. Exp. Biol. 12: 137-142.

Da Silva, J. A. and J. Dobranszki. 2016. Magnetic fields: How is plant growth and development impacted? Protoplasma. 253: 231-248.

Esitken, A. and M. Turan. 2004. Alternating magnetic field effects on yield and plant nutrient element composition of strawberry (*Fragaria x ananassa cv. Camarosa*). Acta Agric. Scandinavica Sect B Soil Plant Sci. 54: 135-139.

FAO. 2009. Cropwat 8.0 for Windows User Guide. Food and Agriculture Organization, Rome, Italy.

Fathi, A., T. Mohamed, G. Claude, G. Maurin and B. A. Mohamed. 2006. Effect of a magnetic water treatment on homogeneous and heterogeneous precipitation of calcium carbonate. Water Res. 40: 1941-1950.

Gabrielli, C., R. Jaouhari, G. Maurin and M. Keddam. 2001. Magnetic water treatment for scale prevention. Water Res. 35: 3249-3259.

Gilani, A., H. Kermanshahi, M. Gholizadeh and A. Golian. 2017. Agricultural water management through magnetization of irrigation and drinking water: A review. J. Aridland Agric. 3: 23-27.

Helaly, A. A. 2018. Impact of irrigation with magnetized water under different levels of nitrogen and potassium fertilizers on growth and productivity of tomato (*Solanum lycopersicon L.*). Middle East J. 7: 1874-1884.

Hozayn, M., M. M. Abdallha, A. A. El-Saady and M. A. Darwish. 2016. Applications of magnetic technology in agriculture: A novel tool for improving crop productivity of canola. Afr. J. Agric. Res. 11: 441-449.

Kaur, R., S. P. Wani, A. K. Singh and K. Lal. 2012. Wastewater Production, Treatment and use in India. National Report Presented at the 2nd Regional Workshop on Safe use of Wastewater in Agriculture. IARI, New Delhi, pp. 1-13.

Lipus, L. C., A. Hamler, I. Ban and B. Acko. 2015. Permanent magnets for water-scale prevention. Adv. Prod. Eng. Manage. 10: 209-216.

Madsen, H. E. L. 2004. Crystallization of calcium carbonate in magnetic field in ordinary and heavy water. J. Cryst. Growth. 267: 251-255.

Maheshwari, B. L. and H. S. Grewal. 2009. Magnetic treatment of irrigation water: Its effects on vegetable crop yield and water productivity. Agric. Water Manage. 96: 1229-1236.

Matwijczuk, A., K. Kornarzynski and S. Pietruszewski. 2012. Effect of magnetic field on seed germination and seedling growth of sunflower. Int. Agrophys. 26: 271-278.

Mohamed, A. I. and B. M. Ebead. 2013. Effect of magnetic treated irrigation water on salt removal from a sandy soil and on the availability of certain nutrients. Int. J. Eng. 2: 36-44.

Otsuka, I. and S. Ozeki. 2006. Does magnetic treatment of water change its properties? J. Phys. Chem. B. 110: 1509-1512.

Selim, A. F. and M. F. El-Nady. 2011. Physio-anatomical responses of drought-stressed tomato plants to magnetic field. Acta Astron. 69: 387-396.

Surendran, U., O. Sandeep and E. J. Joseph. 2016. The impacts of magnetic treatment of irrigation water on plant, water and soil characteristics. Agric. Water Manage. 178: 21-29.

Surendran, U., V. Ramesh, M. Jayakumar, S. Marimuthu and G. Sridevi. 2016. Improved sugarcane productivity with tillage and trash management practices in semi-arid tropical agro ecosystem in India. Soil Till. Res. 158: 10-21.

Turker, M., C. Temirci, P. Battal and M. Erez. 2007. The effects of an artificial and static magnetic field on plant growth, chlorophyll and phytohormone levels in maize and sunflower plants. Int. Phys. Ann. Rev. Bot. 46: 241-284.

Vashisth, A. and S. Nagarajan. 2010. Characterization of water distribution and activities of enzymes during Germination in magnetically-exposed maize (*Zea Mays L*) Seeds. Indian. J. Biochem. Biophys. 47: 311-318.

Yee, E., Y. Jang and B. Chun. 2015. Substrate modification and magnetic water treatment on the maintenance of tunnel drainage systems. I: Feasibility tests. J. Perform Constr. Fac. 29: 04014076.

Yusuf, K. O. and A. O. Ogunlela. 2017. Effects of deficit irrigation on the growth and yield of tomato irrigated with magnetized water. Environ. Res. Eng. Manage. 73: 59-68.