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The impacts of magnetic treatment of irrigation water on plant, water and soil characteristics

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ABSTRACT

Magnetic treatment has remained a controversial process for antiscale treatment of industrial and domestic water treatment over the past many years. Hence a study was initiated to evaluate the magnetic treatment of irrigation water on growth and yield parameters of cow pea and brinjal using pot and field experiments. Also, the impact of magnetic treatment on water properties and soil moisture were also evaluated. Under pot experiment, the treatments tried are normal water, hard water 150 and 300 ppm, saline water 500, 1000 and 2000 ppm of both control and magnetic treated solutions, respectively. Two permanent magnets with the strength of 1800–2000 G was used. The results showed that magnetic treatment of irrigation water types led to an improvement in crop growth and yield parameters of cow pea. Magnetic treatments tend to reduce electrical conductivity, total dissolved solids and salinity levels of all solutions except normal irrigation water, whereas a definite trend of increase in pH was noticed for all the treatments. Soil moisture study results showed that the differences in soil moisture for days 1–3 after irrigation with magnetized irrigation water were lesser than those for the control solutions. Irrigation with magnetized irrigation water caused higher soil moisture compared with the control for different solution of saline and hard water respectively. In the field experiment with brinjal also the magnetic treatment of normal and saline water improved the yield by 25.8 and 17.0% over control. Scanning electron microscope image analysis results confirmed that under magnetic treated hard water, there was variation in the crystal structure of calcium carbonate. The length of these crystals is more when compared to control solutions. These results indicated the beneficial effect of magnetically treated irrigation water on growth and yield of crops, the properties of water and confirmed the possibility of using low quality water for agriculture.

1. Introduction

In India, agriculture is the largest (81%) consumer of water and hence more efficient use of water in agriculture needs to be top most priority (WRI, 2007). Agricultural water input per unit area will have to be reduced in response to current water scarcity, increasing competition from other sectors of water use and other environmental concerns (Surendran et al., 2014, 2016). Due to various reasons, water resources are being constantly under pressure and require a scientific approach to sustain the productivity of agricultural crops. Besides, the use of low quality irrigation water *viz.*, high salinity, hardness and waste water, is gaining importance in Indian agriculture as well as in many other countries because of the water quality problems and due to the scarcity of good quality water. Hence, modern agricultural efforts are now in search of an efficient ecofriendly production technology for improving the crop productivity without harming the environment.

Magnetic water treatment is one such area, and the magnetic field applications have been known for centuries (Colic and Morse, 1999) Michael Faraday introduced the concept of induction as early as 1830, claiming that when a magnetic field flux is crossed by flow ions or a conductive material, electrical current is induced. Although magnetic field applications were rapidly pursued in order to prove Faraday's claim, attention from researchers and industrialists worldwide was still lacking (Zaidi et al., 2014) The first commercial magnetic device for water treatment was patented in Belgium by Vemeiren (1958).

Experiments have shown that water may be magnetized by a magnetic field, even though the magnetized effect is small (Amiri and Dadkhah, 2006; Chang and Weng, 2006; Ji et al., 2007; XiaoFeng and Bo, 2008) and researchers are trying to use the practical applications in different fields. Some of the earlier stud-

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ies showed that, when water is exposed to a magnetic field, the magnetization of water changes its properties including optics, electromagnetism, thermodynamics and mechanics, for example, changes in the dielectric constant, viscosity, surface tension force, freezing and boiling points and electric conductivity compared with pure water. Thus, magnetized water has extensive applications in industry, agriculture and medicine (Fathi et al., 2006; Kney and Parsons, 2006; Maheshwari and Grewal, 2009; Selim and El-Nady, 2011; Teixeira da Silva and Dobránszki, 2014, 2016).

The review by Teixeira da Silva and Dobránszki, 2014; Zaidi et al., 2014, quotes that the practical application of using magnetic field on agriculture starting from seed treatment, germination studies, seedling development and yields of different species, such as agricultural, horticultural, herbs and medicinal plants, fodder and industrial crops have been reported. The results tend to be both positive and negative. The effects of magnetic field on plant growth and development depend on many factors of magnetic fields (MFs), such as polarity, intensity, exposure time, and magnet type. Since the observed effects were always genotype-dependent, all MFs should be tested individually before going in a larger scale.

Most of these studies, however, employed a static magnetic field on seed (Tanaka et al., 2010). However, some studies have employed magnetized water and found that it can improve water productivity and crop yield (Maheshwari and Grewal, 2009). These findings suggest that, there is a possibility of using magnetic treatment of water to improve the crop production even with the use of low quality water. Using of magnetic field treatment to improve plant growth is not so expensive, if we consider on long term basis and at the same time not hazardous to the environment. Using of low quality water is also gaining popularity in India because of water scarcity, spatially and temporally in the context of climate change associated impacts of drought. There is hardly any study reported in India, with valid scientific experiments, on the effects of magnetic treatment of water on crop yield and water productivity. However, some closely related studies conducted elsewhere have reported on some beneficial effects of magnetic field, and it has been referred herewith.

Review of literature suggests that water can be magnetized when exposed to a magnetic field (Turker et al., 2007; Pang and Deng, 2008; Maheshwari and Grewal, 2009). The beneficial effects of magnetically treated irrigation water have also been reported on germination percentages of seeds (Hilal and Hilal, 2000; Matwijczuk et al., 2012); emergence rate (Podleoeny et al., 2004), root growth (Turker et al., 2007), essential element uptake (Maheshwari and Grewal, 2009), and seed yield (Selim and El-Nady, 2011). Apart from these an increase in soil electrical conductivity (Maheshwari and Grewal, 2009), mobility of nutrients from fertilizers (Hozayn and Abdul Qados, 2010), water holding capacity of soil (Al-Khazan et al., 2011); and a reduction in soil pH, water viscosity (Chang and Weng, 2006), surface tension (Rashed-Mohassel et al., 2009), vaporization rate (Toledo et al., 2008), and pH of water (Fathi et al., 2006) were observed by all these researchers. Tomato seeds irrigated with magnetized water and magnetized seeds irrigated with magnetized water treatments were the best treatments for overcoming the bad effects of water deficit on tomato plant growth characteristics, water relations, proline concentration and photosynthetic pigments, as well as anatomical structure of some organs of tomato plants (Selim and El-Nady, 2011).

Similarly negative effects on MFs on the root growth of various plant species (Belyavskaya, 2001, 2004; Turker et al., 2007) were also reported. Turker et al. (2007) reported that weak magnetic field had inhibitory effect on growth of primary roots during early growth. Overall, it appears that the influence of magnetically treated water depends upon the plant species, the pathway length in the magnetic field, and the flow rate (Gabrielli et al., 2001).

According to Baker and Judd (1996), the effectiveness of magnetic field for water treatment applications is still a controversial question, and the relevant phenomena cannot be clearly explained. The mechanism of magnetic applications has not been completely confirmed scientifically by researchers. Many papers describe different types of magnetic mechanisms, and several of them are even in conflict with each other. Potential of magnetic field in various environmental engineering applications, specifically, in water and wastewater treatment systems have been widely studied. However, magnetic treatment has remained a controversial process for antiscale treatment of industrial and domestic water treatment over the past many years. While the increase in the number of commercial magnetic treatment devices might seem to be an indicator of the effectiveness of magnetic fields in the control of scale, independent review of the performance of these devices has been highly controversial. Claims have been made that magnetic fields change the physiochemical properties of water, or prepared laboratory solutions (Zaidi et al., 2014; Ali et al., 2014; Teixeira da Silva and Dobránszki, 2014 and 2016; Aliverdi et al., 2015; Hozayn et al., 2016).

But the reproducibility of both laboratory and industrial trials has been poor, and conclusions drawn on the basis of laboratory work have sometimes been criticized. Higher magnetic field intensity may halt the bacterial activity, thus causing an adverse effect to the treatment performance. The past studies have indicated that there are possibly some positive effects of magnetic field on plant growth and yield improvement. However, water treatment by magnetic field is still a controversial subject, because the reported results have low reproducibility and little consistence and seldom accepted by physicists. Besides, there is no clear understanding yet on the mechanisms behind these effects and the changes that magnetic treatment brings in water and in the plant and seedling growth. By keeping all these points, an attempt has been made to study the effects of magnetic treatment of irrigation water types viz., normal irrigation water, saline water and hard water and its influence on the growth and yield parameters on different crops; influence on soil moisture and water properties.

2. Materials and methods

2.1. Study site

The study area of Kozhikode district is located in Kerala State, which is in southern part of India and it lies between North latitudes 11°08′ and 11°50′ and East longitudes 75°30′ and 76°8′. The district has a humid climate with a very hot season extending from March to May. The most important rainy season is during the South West Monsoon which sets in the first week of June and extends up to September. The North-East Monsoon extends from the second half of October through November. The average annual rainfall is 3240 mm. During December to March, practically no rain is received and from October onwards, the temperature gradually increase to reach the maximum in March, which is the hottest month of the year. The moisture stress is experienced in this district for the period of 4–6 months. This study comprises of pot experiment under green house, field experiment for soil moisture studies, field experiment with brinjal and laboratory studies during the period of 2011–2014.

2.2. Magnetic treatment

A permanent magnet having Magnet gauss strength of 1800–2000 G was used for treating the water. It contains two permanent magnets that are 120 mm in length and 130 mm width, separated by a distance of 30 mm. A static non-uniform mag-

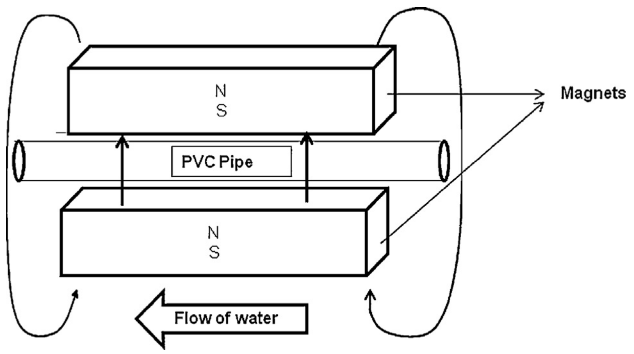

Fig. 1. Schematic line diagram of the Magnetic device showing their north and south poles, the direction of magnetic field generated, and water flow between the two magnets in the PVC pipe.

netic field was generated between the two permanent magnets. The arrangement of their north and south poles and direction of the magnetic field generated are shown in Fig. 1. The permanent magnets were made of Strontium Ferrite Ceramic magnets ($SrO{\cdot}6Fe_2O_3$), a common material for permanent magnet applications. To ensure adequate exposure to the magnetic field, the water for magnetic treatment was passed in a cycle continuously for 10 min through the device. The magnetic treatment of the water was under dynamic conditions because there was a continuous flow of water by the way of pumping it with ½ HP pump through PVC pipes at the rate of 2 l/s through the magnet. All the solutions were analysed before and after magnetic treatment for properties such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Salinity, Ca, K and Na content using standard analytical procedures prescribed by Central Pollution Control Board of India. pH, EC, TDS and salinity were measured, by using multiparameter meter EUTECH model PC650 and Ca, K and Na were measured using Flame Photometer SYSTRONICS model 128.

2.3. Pot experiment

Greenhouse pot experiments were conducted in the Green house at Centre for Water Resources Development and Management (CWRDM) located in Kozhikode district using magnetically treated water and non treated water of different sources (normal irrigation water, hard water and saline water) with laterite soil type and cow pea as the test crop. Cow pea (*Vigna unguiculata* variety *Kanakamani)* obtained from Agricultural Research Station, Anakayam of Kerala Agricultural University (KAU) was used in this study. The treatments are Irrigation water, Hard water 150 ppm, Hard water 300 ppm, Saline water 500 ppm, Saline water 1000 ppm and Saline water 2000 ppm of both control and magnet treated. Required concentrations of hard water and saline water were prepared using Merck Standard chemicals. All the cultural and management practices were adopted as per the package of practices of Kerala Agricultural University (KAU, 2011). Irrigation requirement and schedule were prepared using FAO – CROPWAT software (FAO, 2009). Biometric observations such as plant height, number of internodes, number of leaves, shoot weight and root weight were carried out at 30, 60 90 days after sowing and at final harvest. Picking was done after the maturity and the total yield was calculated by combining all the pickings. Statistical analysis was accomplished by means of average values, standard error and *t*-test (treatments *vs.* control) using IN STAT software V. 3.36.

2.4. Field experiments

2.4.1. Experiment – I. Influence of magnetic treatment on soil moisture using drip irrigation

A drip irrigation experiment was carried out at R&D farm of CWRDM located in Kozhikode district and it lies in 11°17′22″N and 75°52′20″E to study the impact of magnetic treatment of irrigation water on soil moisture content. The drip irrigation system had been designed according to the standard procedures. The distance between the laterals was 1.5 m and the diameter of laterals is 16 mm. Each lateral had 10 drippers, spaced 1 m apart. The con-

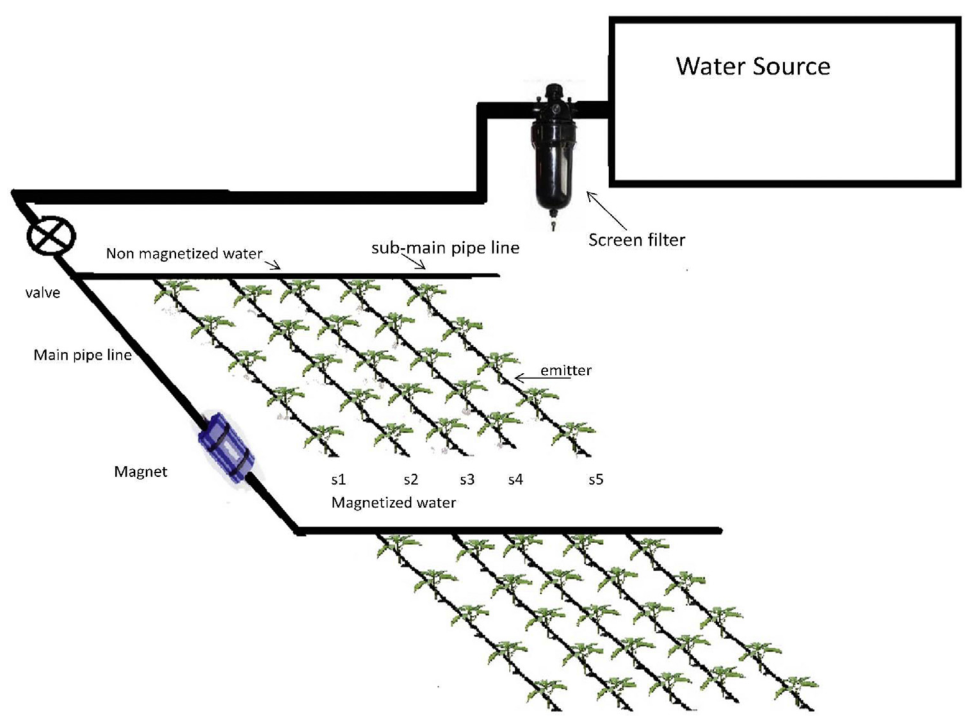

Fig. 2. Experimental set up showing the magnetic treatment and field layout.

trol valves using tap system were installed at the beginning of each lateral to control the flow of water. Required pressure of 1 atmosphere was maintained using 1 HP pump. Online drippers were used for irrigation with 8 l/h discharge. All pipes were made of polyethylene and there were 10 irrigations with an irrigation interval of 10 days. The amount of applied water was based on the initial soil moisture content and irrigation was carried out for 2 h to ensure enough moisture around the measurement points. The two main treatments were magnetic and non-magnetic irrigation water hereafter referred as control and five sub-treatments included Normal Irrigation water (Tap water), Hard water- 150 ppm, Hard water- 300 ppm, Saline water- 500 ppm, Saline water- 1000 ppm and Saline water- 2000 ppm of both control and magnet treated. Soil moisture measurements were made near the drippers after the first, second, third and fifth day after irrigation, (24, 48 and 72 h after irrigation) using a ICT soil moisture measurement device manufactured by Australia. This device was calibrated for the experimental field using gravimetric soil moisture measurements. Besides, soil moisture was measured at horizontal distances of 0, 25, and 50 cm from the drippers and at depths of 0, 15, 30 and 45 cm. There was no rainfall during the period that soil moisture measurements were made. The field was irrigated for the first time with no crop cover. The field was initially fallow and weed growth was controlled during the 10 days of the experiment. To determine the dry soil bulk density, three undisturbed samples were taken from each soil layer and the mass of dry soil was divided by the bulk volume of soil. Soil moisture differences after 1, 2 and 3 days after irrigation for the different locations of the drippers were analysed using Excel and INSTAT software. Comparison of the mean values for each treatment was performed using the LSD test at 1% and 5% significance levels.

2.4.2. Field experiment II- Influence of magnetic treatment on crop growth and yield parameters under drip irrigation

Field experiment was conducted at CWRDM campus farm using magnetically treated water and non treated water (control) of different sources (normal irrigation water, and saline water of 1000 ppm) to study the impact of magnetic treatment on crop yield and soil properties. Brinjal variety *Haritha* obtained from Agricultural Research Station, Anakayam of Kerala Agricultural University was used in this study. The cultural and management practices were followed as per the recommendations of Package of Practices of Kerala Agricultural University (KAU, 2011). Fertilizer dose applied was 75:40:25 kg of N, P_2O_5 and K_2O, respectively. Initial, post-harvest soils and plant produces at harvest of the experimental fields were analysed for their physico-chemical properties. Irrigation requirement and schedule was prepared using FAO – CROPWAT software (FAO, 2009) and it was done using drip irrigation. A schematic drawing of part of the irrigation system that was used is shown in Fig. 2. Biometric observations such as plant height, number of internodes, number of leaves, leaf area, fruit weight were carried out at 30, 60 90 days after sowing and at final harvest using standard procedures. Picking was done after the maturity and the total yield was calculated by combining all the pickings. Statistical analysis was accomplished by means of average values, standard error and *t*-test (treatments *vs.* control) using IN STAT software V. 3.36.

2.5. Identification of mechanisms

To identify the mechanisms we attempted to confirm the changes of microscopic structures, including the electronic, atomic and molecular structures of water, by the techniques of spectra of visible light and ultraviolet light because these spectra represent the features of electronic motion, atomic and molecular structures of water, respectively. We measured the spectra of visible and ultraviolet light for magnetized and control solutions (Normal irrigation water, Saline and hard water) using a Hitachi Model U-2800 UV–vis spectrometer. In addition to the test solutions as mentioned above, pure distilled water (Quartz Double distillation) have also been subjected to magnetization and the microscopic structural changes were measured in similar way. Similarly the samples were subjected to Scanning Electron Microscope (SEM) image analysis.

3. Results and discussion

3.1. Influence of magnetic treatment on water properties

The mean values of pH and EC, of different irrigation water types before and after magnetic treatment (Control vs treated) are presented in Table 1. Magnetic treatment of solutions tends to reduce EC of all the solutions except tap water, whereas a definite trend of increase in pH was noticed for all the solutions. However, this difference in parameters is nullified after 108 h and the solutions are going back to the original values. With respect to, TDS, Salinity, Ca and Na there is reduction in the content in hard water and saline solutions respectively (Data not shown). The values of K and Cl content of different water types were not affected by magnetic treatment. The reduction in EC, TDS and increase in pH in magnetically treated solutions may be due to changes in hydrogen bonding and increased mobility of ions. The decrease in EC may be explained as thus, that water treated by magnetic power contains fine colloidal molecules (in the state of constant motion resembling Brownian motion) and electrolytic substances, which respond to magnetic treatment, by their increasing ability to sediment that results in a decreased EC. Similar results have also been quoted by researchers who found changes in physical and chemical properties of water such as hydrogen bonding, polarity, surface tension, conductivity, pH, refractive index and solubility of salts because of magnetic field exposure (Amiri and Dadkhah, 2006; Chang and Weng, 2008). Busch and Busch (1997) also reported a change in the pH difference between the surface and the bulk of magnetically treated water. However, Maheshwari and Grewal (2009) stated that the use of magnetically treated irrigation water reduced soil pH. In addition to the breakage of hydrogen bonds electromagnetic fields may perturb the gas/liquid interface and produce reactive oxygen species. Changes in hydrogen bonding may affect carbon dioxide hydration. Those results are in accordance Kney and Parsons (2006) who pointed out the role of the magnetic field in the increase of water nucleation.

3.2. Influence of magnetic treatment on growth and yield parameters of cow pea

The magnetic treatment of irrigation water solutions increased the plant height *vs.* control; statistical analysis of the data reveals significant differences for all the treatments against control except hard water 300 ppm and saline water 2000 ppm (significant means the value is statistically significant at 95% confidence level when compared with the control treatment with student- *t*-test and the calculated t value is shown in table). Among the different type of irrigation water tried, hard water 150 ppm recorded the higher plant height and the lowest was recorded in saline solution 2000 ppm (Tables 2a and 2b). With respect to shoot weight, magnetically treated solutions showed statistically significant difference over control, except the saline solution of 2000 ppm, which was not statistically significant. Yield data showed that magnetic treated solutions of hard water 150 ppm, saline water 500, 1000 and 2000 ppm recorded significantly higher yield than the control pots. Even though in magnetic treated irrigation water and hard water 300 ppm the yield was more than the control, but the increase

Table 1
Influence of magnetic treatment of different solutions on pH and EC.

Solutions	pH			EC (mS)		
	Magnet treated	Control	t stat	Magnet treated	Control	t stat
Irrigation water	7.70*	6.50	3.53	0.068	0.067	NS
Hard water 150 ppm	5.00*	4.00	3.42	0.40**	0.50	2.82
Hard water 300 ppm	4.52*	3.52	3.21	0.80**	1.00	3.48
Saline water 500 ppm	6.40**	6.00	2.89	2.40**	2.60	3.45
Saline water 1000 ppm	6.49**	5.98	3.45	4.60**	4.90	3.65
Saline water 2000 ppm	7.00*	6.10	3.46	9.50**	9.80	2.91

* and ** represents significance at 5% and at 1% levels, respectively; and NS- Non significant.

Table 2a
Impact of magnetic treated water on growth parameters of cowpea.

Solutions	Plant height (cm)			Shoot weight (g)		
	Magnet treated	Control	t stat	Magnet treated	Control	t stat
Irrigation water	45.6*	41.3	3.35	52.4	60.7*	−3.37
Hard water 150 ppm	48.0*	45.1	2.81	71.8*	59.4	5.72
Hard water 300 ppm	42.3	43.5	NS	80.3*	64.6	6.29
Saline water 500 ppm	47.0*	44.3	2.64	80.4*	71.7	3.54
Saline water 1000 ppm	47.3*	40.5	3.59	75.0*	50.9	3.53
Saline water 2000 ppm	49.8	48.6	NS	61.6	59.6	NS

* Represents significance at 5% level in student- *t*-test; NS- Non Significant at 5% level in student- *t*-test.

Table 2b
Impact of magnetic treated water on root growth and yield of cowpea.

Solutions	Root weight (g)			Yield (g)		
	Magnet treated	Control	t stat	Magnet treated	Control	t stat
Irrigation water	4.30	4.63	NS	196.4	191.5	NS
Hard water 150 ppm	5.16*	4.81	2.65	203.2*	186.0	2.64
Hard water 300 ppm	6.27*	5.68	3.67	189.5	181.1	NS
Saline water 500 ppm	5.90	5.69	NS	223.0*	178.1	3.51
Saline water 1000 ppm	5.65*	5.23	3.12	202.2*	148.6	6.58
Saline water 2000 ppm	5.19*	5.06	NS	174.8*	157.6	2.97

* Represents significance at 5% level in student- *t*-test; NS- Non Significant at 5% level in student- *t*-test.

was not statistically significant. The changes induced in pH and EC in magnetically treated irrigation solutions resulted in accentuated biological activity in plants and consequently influenced the growth of plants. Furthermore, the high gradient magnetic field might have resulted in faster activations of enzymes and hormones during the growth process and which might have resulted probably an improvement in the mobilization and transportation of nutrients (Maheshwari and Grewal 2009; Surendran et al., 2013). Besides, the magnetic treatment could act on the Soil/water interface and may lead to destabilisation of gas bubbles (air), thus disturbing the ionic balance between the shell of adsorbed negative ions and counter ions (Hilal and Hilal, 2000). In the present study, it is likely that such interfacial effects through the gas bubble/water interface are responsible for the remarkable effects of magnetically treated irrigation water on growth and yield of cowpea.

3.3. Results from the soil moisture studies using drip irrigation

All the measured soil moisture contents for the magnetized and control treatments were evaluated using INSTAT program. Table 3 compares the measured average soil moisture difference for days 1 and 2 after irrigation for different dripper locations. Results show that the effect of magnetized irrigation water on soil moisture differences between the first and the second days after irrigation at all the dripper distances were significant at the 5% level. At all distances from the dripper, the reductions in soil moisture between the first and the third days after irrigation for the magnetized irrigation water treatment were less than for the control (non-magnetized irrigation water treatment) and the differences were significant at 1% or 5% level (Table 4).

Table 3
Surface soil moisture differences for 1st day and 2nd days after irrigation.

Treatment	Magnet treated	Control
Irrigation water	0.96	1.27**
Hard water 150 ppm	0.92	1.13*
Hard water 300 ppm	0.91	1.05 *
Saline water 500 ppm	0.82	1.00 *
Saline water 1000 ppm	0.76	0.90*
Saline water 2000 ppm	0.75	0.90 *
Mean	0.85	1.04*

* and ** represents significance at 5% and at 1% levels, respectively.

Table 4
Surface soil moisture differences for 1st day and 3rd days after irrigation.

Treatment	Magnet treated	Control	t stat
Irrigation water	1.01	1.32*	3.53
Hard water 150 ppm	0.94	1.15**	2.98
Hard water 300 ppm	0.90	1.04**	3.12
Saline water 500 ppm	0.99	1.17**	3.24
Saline water 1000 ppm	0.98	1.12**	2.89
Saline water 2000 ppm	0.92	1.07**	3.21
Mean	0.96	1.15**	3.53

* and ** represents significance at 5% and at 1% levels, respectively.

The differences in reducing soil moisture for the second and for the third days after irrigation for the magnetized irrigation water treatments were less than for the non- magnetized irrigation water

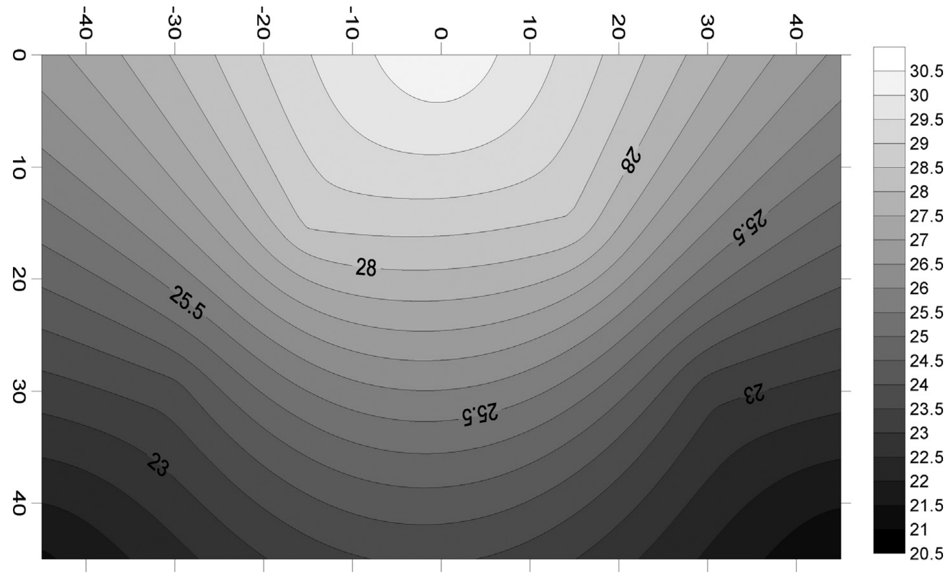

Fig. 3. Volumetric soil moistures at different depth from the dripper for magnet treated water.

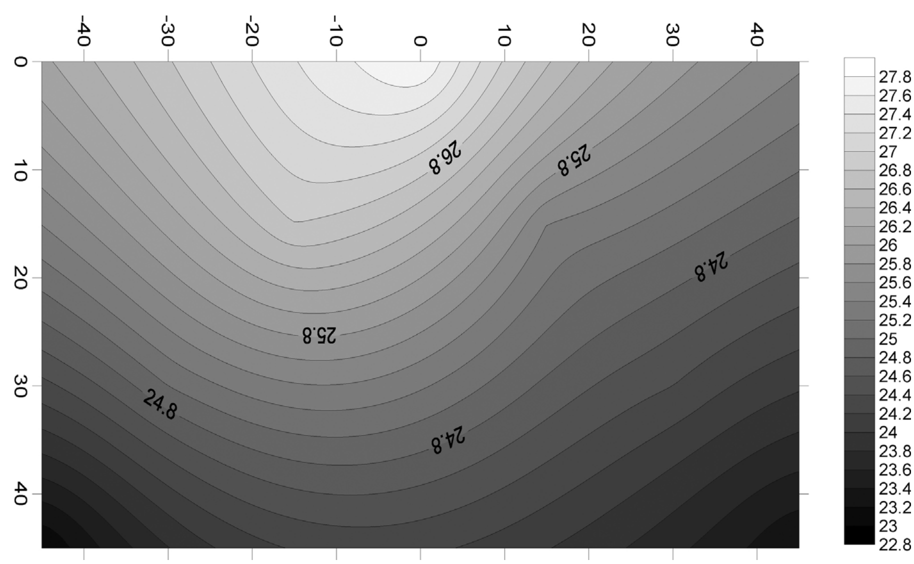

Fig. 4. Volumetric soil moistures at different depth from the dripper for control.

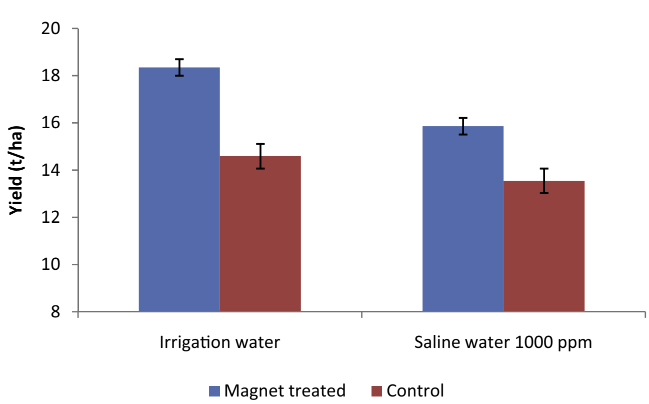

Fig. 5. Influence of magnetic treatment on brinjal yield along with Standard Error (SE) shown as black lines.

treatments. These effects were more evident at the soil surface. The reason that soil moisture was higher for the magnetized irrigation water might be because of two reasons. Firstly, in the magnetization process, the water molecules which had been influenced by hydrogen bonds and Van der Waals forces and were in reaction with the ions are released to make the water more cohesive. Thus, the water molecules were easily attached to soil particles and did not leach to lower depths and also the water molecules easily penetrated into the micro spaces of soil particles and were thus impeded from moving to the lower depths. Secondly, when water passes through the magnetized field, its structure and some physical characteristics will be changed. As calcium and carbonate ions enter into the zone that is influenced by the magnets, they are pushed in opposite directions ascribable to their opposite charges. As all of the calcium ions are pushed in one direction and all of the carbonate anions are pushed in the opposite, they collide with the resultant formation of aragonite. Because these microscopic crystals are forced to form whilst moving in the water, they do not have an opportunity to attach themselves to the pipes. Therefore, the salts do not precipitate in the pipes and are moved in the soil profile causing higher soil osmotic pressure (Gabrielli et al., 2001). Similar is the

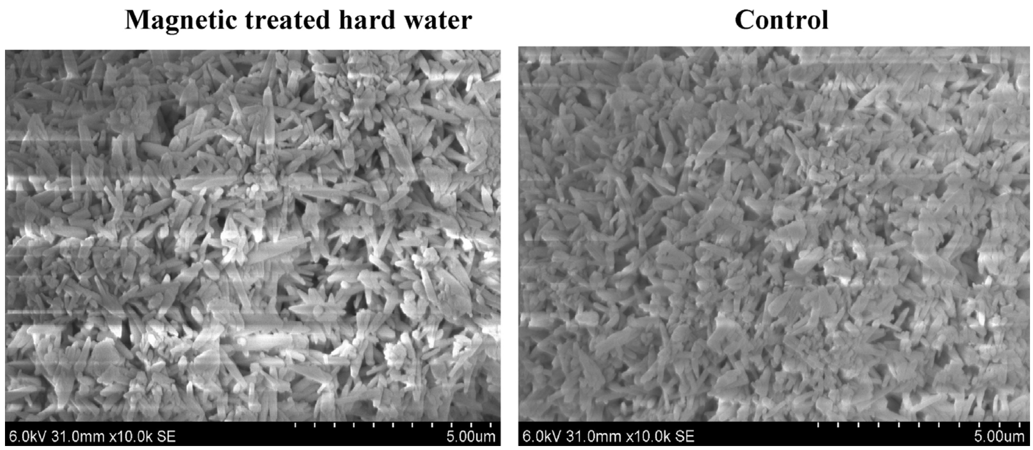

Fig. 6. SEM images of Hard water ($CaCO_3$) crystals.

case with saline solution also. This reduces the evapotranspiration rate and consequently greater soil moisture content occurs in the soil. Table 4 shows that the lowest soil moisture reduction occurred with irrigation water containing hard water 300 ppm.

Table 5 compares soil moisture at surface soil near to the dripper after one day and two days after the irrigation. This table shows that irrigation with the magnetized irrigation water caused higher soil moisture contents compared with the control (non-magnetized irrigation water) irrespective of the solutions. It also shows that in general the soil moisture was greater with increasing saline concentration treatments. Irrigation water with greater salinity causes salt accumulation in the soil resulting in an increase in osmotic pressure causing less available soil moisture for evaporation. In saline soils, the strength required to extract soil water must be greater than the osmotic pressure; and evapotranspiration is mainly affected by soil salinity.

Figs. 3 and 4 compare the average soil moisture at the depth of 0–45 cm from the dripper for magnetic treatment and control. These figures show that irrigation with the magnetized irrigation water caused higher soil moisture content compared with the control (non-magnetized irrigation water) irrespective of the solutions (Average values of all the treatments). It also showed that soil moisture is uniformly spread across the depth upto 45 cm under magnetic treatment whereas the soil moisture is not uniformly spread in control. Besides, the soil moisture was higher in deeper depths i.e 45 cm for control when compared to the magnetic treatment. This confirms the hypothesis, that during the magnetization process, the water molecules which had been influenced by hydrogen bonds and Van der Waals forces and were in reaction with the ions are released to make the water more cohesive (Kronenberg 1985; Khoshravesh et al., 2011). Thus, the water molecules were easily attached to soil particles and did not leach to lower depths and also the water molecules easily penetrated into the micro spaces of soil particles and were thus impeded from moving to the lower depths, whereas in control, this might not happened and hence the soil moisture is higher in deeper depths.

3.4. Influence of magnetic treatment on growth and yield parameters of brinjal

The magnetic treatment of irrigation water solutions increased the plant height, number of leaves, leaf area and individual fruit weight *vs*. control; statistical analysis of the data reveals significant differences for all the treatments against control. Among the different type of irrigation water tried, normal irrigation water recorded the higher plant height and the lowest was recorded in control treatment of saline solution 1000 ppm (Table 6). The same trend was observed in all other growth and yield parameters.

Yield data showed that magnetic treated solutions of normal irrigation water recorded significantly higher yield than the control plots (Fig. 5). In saline water also the magnetic treated solution recorded the higher yield than the control. However the yield increase percent was higher with normal irrigation water with 25.8% whereas in saline water it was17.0%, however in both case the increase was statistically significant. The reasons mentioned in cowpea holds good for brinjal also and the greater activities of enzymes as well as higher mobility of water molecules, nutrient molecules might be responsible for better growth and yield parameters (Vashisth and Nagarajan, 2010; Grewal and Maheshwari, 2011). Earlier a lab study confirmed that the shoot and root growth were increased with the help of magnetic treated water and as a result of increase in roots length of these plants, it may increase the ability of these plants to absorb water and nutrients efficiently and it might have resulted in higher growth and yield compared to control solutions (Surendran et al., 2013). In brinjal also the same trend observed (data not shown). The improved root length suggests that magnetic treatment can be used in practical agriculture where better root growth will enable extraction of moisture from deeper soil layers. This improved shoot and root growth may lead to an early canopy cover and a better competition against weeds, and thus more efficient use of nutrients and irrigation water and ultimately result in yield improvement.

3.5. Spectral and SEM image analysis

The spectral analysis established that magnetic fields influence the properties of water and confirm the change in the distribution of molecules and electrons (data not shown, refer Surendran et al., 2013). SEM image analysis was also done for hard water and found that under magnetic treated water, there was variation in the crystal structure of calcium carbonate (Figs. 6, 7a and b). The SEM image observation reveals that the circular disc-shaped micro crystals of $CaCO_3$ deteriorate slowly by a solid state transformation into bundles of $CaCO_3$ needles called aragonite in the case of magnetically treated water, whereas in control this transformation seems to be partial. The length of these crystals is more when compared to control solutions (indicated in Figs. 6, 7a and b).

The main component in hard water, calcium carbonate appears in different shapes if the water has passed through magnetic fields. Without the magnetic fields this hard water is characterized by the scarcity of nucleation centers; super-saturation develops and accordingly the minerals start to solidify at the substrate in the form of dendritic crystallization, which indicates the scaling of pipes

Table 5
Comparison of volumetric soil moistures surface soil near the dripper after 1st and 3rd day of irrigation for magnet treated water and control.

Solutions	Moisture (%) after 1st day			Moisture (%) after 3rd day		
	Magnet treated	Control	t stat	Magnet treated	Control	t stat
Irrigation water	29.42*	28.46	3.36	28.41**	27.14	2.53
Hard water 150 ppm	31.12**	30.20	4.26	30.18**	29.05	3.58
Hard water 300 ppm	31.20**	30.29	5.72	30.30**	29.25	3.36
Saline water 500 ppm	30.80**	29.98	6.29	29.81**	28.81	4.64
Saline water 1000 ppm	31.40**	30.64	3.29	30.42**	29.52	3.69
Saline water 2000 ppm	33.20**	32.45	3.53	32.28**	31.38	3.36

* and ** represents significance at 5% and at 1% levels, respectively.

Table 6
Impact of magnetic treated water on growth parameters and yield of brinjal.

Solutions	Plant height (cm)			Number of Leaves per plant (g)		
	Magnet treated	Control	t stat	Magnet treated	Control	t stat
Irrigation water	67.8*	61.4	2.89	86.02*	78.45	3.53
Saline water 1000 ppm	59.2*	52.6	3.41	71.56*	65.40	3.12
Solutions	**Leaf area (cm2)**			**Individual Fruit Weight (g)**		
	Magnet treated	Control	t stat	Magnet treated	Control	t stat
Irrigation water	112.51*	105.2	2.98	84.5*	76.8	3.78
Saline water 1000 ppm	102.2*	96.4	3.02	80.2*	72.6	4.21

* Represents significance at 5% level in student- *t*-test; Magnet treated value is statistically significant at 95% confidence level (0.05 probability level) when compared with the control in student- *t*-test.

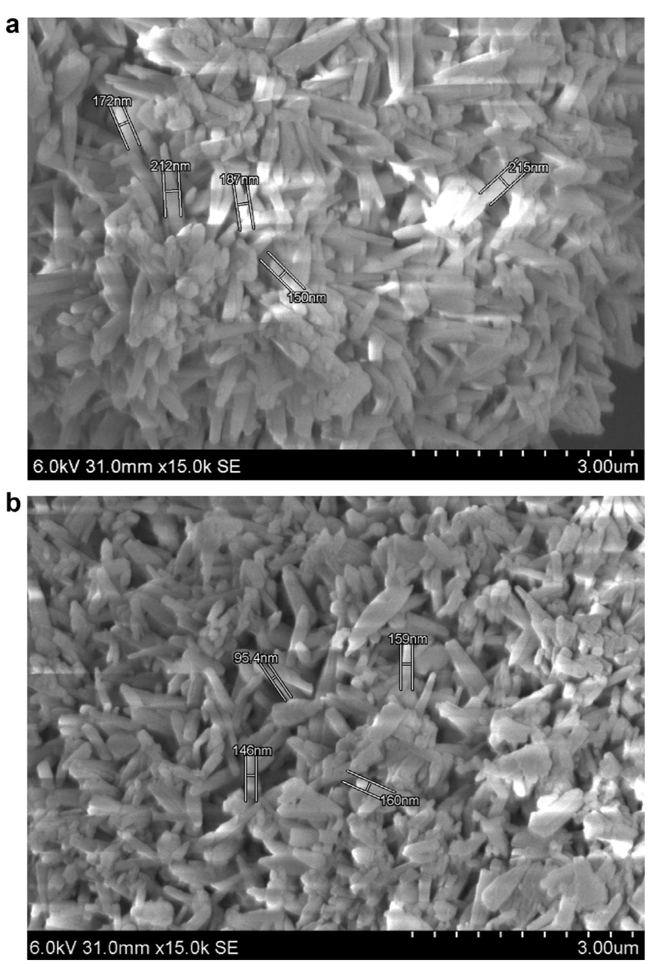

Fig. 7. (a) SEM images of Hard water ($CaCO_3$) crystals showing the length for Magnet treated water. (b) SEM images of Hard water ($CaCO_3$) crystals showing the length of crystals for control.

(Fathi et al., 2006). They grow to form thick, interconnected crystals and are firmly attached to the point where the nucleation started. From this we can arrive at a conclusion that the weak interaction between the magnetic fields and the hydrogen bonds is amplified to the breaking point by resonance. The magnetic treatment is usually most effective when the water passes through magnetic field. This confirms the hypothesis of the complex-formation in liquid water with ion of formerly dissolved minerals from the liquid water by forming micro crystals which move with the water in suspension (Zhou et al., 2000; XiaoFeng and Bo, 2008). The energy for this entropy reduction is provided by the kinetic energy of the moving water. The liquid water is then depleted of its mineral content, and it is therefore able to dissolve minerals available in water. The capability of magnetically treated water to redissolve old lime scale deposits is often observed and reported by researchers. In our case, this principle might have helped for better mobilization and transportation of nutrients, apart from maintaining the optimum soil moisture in the root zone as evidenced in soil moisture studies which ultimately resulted in the improvement of crop productivity.

4. Conclusions

To conclude, the results showed that magnetic treatment of irrigation water types led to an improvement in crop growth, yield parameters and yield of cow pea. Magnetic treatment tends to reduce electrical conductivity, total dissolved solids and salinity levels of all solutions except normal irrigation water, whereas a definite trend of increase in pH was noticed for all the treatments. Soil moisture study results showed that the differences in soil moisture for days 1–3 after irrigation with magnetized irrigation water were lesser than those for the control solutions. Irrigation with magnetized irrigation water caused higher soil moisture compared with the control for different solution of saline and hard water, respectively. In the field experiment with brinjal also the magnetic treatment of normal and saline water improved the yield by 25.8 and 17.0% over control. Scanning Electron Micorscope (SEM) image analysis results confirmed that under magnetic treated hard water, there was variation in the crystal structure of calcium carbonate.

The length of these crystals is more when compared to control solutions. The results of the current study demonstrated significant effects of magnetically treated irrigation solutions, which imply that even low quality water can be utilized for agriculture under water scarcity conditions.

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