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Evaluation of $CaCO_3$ clogging in emitters with magnetized saline waters

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ABSTRACT

High water application uniformity is essential for an effective irrigation. Clogging of emitters in drip irrigation systems is one of the most important factors decreasing uniformity. In this study, the possible effect of magnetization of water on chemical clogging of dripline emitters was investigated. Separate experiments were conducted with three different saline waters (W-1: 0.314 dS m^{-1}, W-2: 0.665 dS m^{-1}, W-3: 0.937 dS m^{-1}) having a high pH and a positive Langelier saturation index (LSI). Discharge rates, electrical conductivity (EC) and pH's of discharge water from emitters in driplines were measured. Uniformity of driplines was evaluated by using the statistical uniformity coefficient (U_c) and the emission uniformity coefficient (E_u). The pH and EC values of discharge water from emitters in driplines were found to be slightly lower when operated with magnetized water. However, discharge rates under non-magnetized water were lower than those of magnetized water. Magnetic effect was observed to be decreased as the water salinity increased. The U_c and the E_u values indicated that when the medium saline water was magnetized before its release into the system, a better uniformity due to a lower emitter clogging rate can be achieved. When higher saline water was magnetized, lower U_c and the E_u values were observed.

Keywords: Calcium carbonate precipitation; Emitter; Magnetic water treatment; Uniformity

1. Introduction

Drip irrigation is the most effective system among the irrigation methods. As water becomes more limited in arid and drought prone areas, adoption of the system increases [1]. The greatest concern in the maintenance of a drip irrigation system is the clogging of emitters [2]. Clogging is directly related to the quality of irrigation water and occurs as a result of multiple factors, including physical, biological and chemical agents [3–5].

Chemical precipitates are formed due to reactions of dissolved cationic constituents with anions [6]. Calcium carbonate is the most common deposit in arid regions [1,7]. For waters which are rich in calcium and bicarbonates, calcium carbonate is the prevalent precipitate [6]. An approximation to the calcium carbonate precipitation can be made using the saturation index of Langelier (LSI) which simply says that lime ($CaCO_3$) will precipitate from the solution upon reaching the calcium saturation point in the presence of bicarbonate [8].

The general recommendation to prevent chemical clogging is to lower the water pH by acid injection [1]. Sulfuric (H_2SO_4), hydrochloric (HCl), phosphoric (H_3PO_4) and nitric (HNO_3) acids are used for this purpose [4]. Antiscale water treatment using chemical methods can be very expensive [7]. Furthermore, these chemicals are

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generally harmful for environment and human health [9]. Physical methods can be possible alternatives to the chemicals in order to decrease clogging rate of emitters. Magnetic water treatment can be an alternative to control scale [10]. The magnetic methods are attractive due to their ecological purity, safety, and simplicity [11]. In particular, magnetic treatment of hard water is currently used to prevent mineral salts incrustation [12–14]. Therefore, magnetic water treatment is becoming more and more popular. It is possible to find different kinds of devices on the market for the magnetization of water. They consist of either electromagnets used for high water flow capacities in industrial plants or of permanent magnets for lower capacities [15].

Numerous different experimental results have been published on magnetic treatment. Chibowski et al. [16] found the precipitation to be up to 40% less with magnetic treated hard water regarding on temperature and kind of the solid surface (i.e., stainless steel, copper, aluminium, and glass). Madsen [17] studied influence of magnetic field effect on inorganic salt precipitates, and reported that magnetic field had significant effect on carbonates and phosphates with diamagnetic metal ions. The results of a study conducted by Aali et al. [1] showed that the application of non-magnetic saline water in drip irrigation system had the potential to induce emitter clogging and the acid injection provided better performance than the magnetic treatment. Alimi et al. [13] concluded that scale significantly decreased when magnetic field applied through non-conductive pipe materials. Ozdemir et al. [18] observed that pH and EC of hard-alkaline water were decreased by electromagnetic treatment. Maheshwari and Grewal [19] reported that magnetic treatment of irrigation water changed the soil pH and EC. Banejad and Abdosalehi [20] found that the water quality was affected by magnetic field. Water hardness, particle size and greater particles number were reduced with magnetic treatment.

Total dissolved solids in irrigation water are used to classify the potential emitter clogging risk [5]. Hazard rating increases as electrical conductivity (EC) of irrigation water increases [3].

Studies on emitter clogging in drip irrigation for different water salinity levels under magnetic treatment are limited. The main purpose of this study was to investigate the influence of magnetic field on chemical clogging of emitters under different saline water applications.

2. Materials and methods

2.1. Experimental system

Three different experimental systems for different saline water treatments each including two driplines, a water tank and a magnetic unit were set up in laboratory conditions (Fig. 1). All driplines (L-1, L-2, L-3, L-4, L-5, L-6) were formed with 12 m length round drip irrigation pipes (Ø 16 mm). Magnets were placed in inlets of L-1, L-3 and L-5 driplines. L-2, L-4 and L-6 driplines were used for non-magnetic water treatments. Magnetic field of magnets was in the range of 80–100 mT. Magnetic unit was a special design (Fig. 1). Slope along the driplines was 0%. Emitters in the driplines were in-line type with double exit (ag plastik). The manufacturing coefficient of variation is less than 5%. The discharge equation of emitters and its determination coefficient (r^2) is:

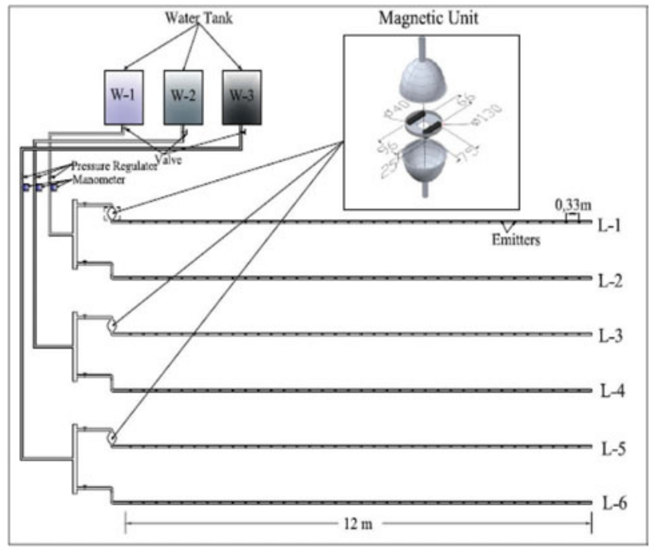

Fig. 1. Experimental system layout.

$$q = 12.92\ h^{0.531}$$

$$r^2 = 0.997$$

where q is the emitters discharge rate (L h^{-1}) and h is the operation pressure (MPa).

2.2. Treatment

Each system was run independently from each other for 30 d by saline water treatment. Three different saline levels were tested in experiments (Table 1). Different saline levels were provided by adding NaCl (0 ppm for W-1, 160 ppm for W-2, 300 ppm for W-3) into tap water (underground water). Tap water was free from suspended solids. In addition, the W-1, W-2, W-3 waters had a high pH and a positive LSI (Table 1). Positive LSI and high pH values were constituted by adding $CaCO_3$ (30 ppm) and NaOH (5 ppm) into the saline waters. L-1 and L-2 driplines were treated with W-1 water, L-3 and L-4 driplines were treated with W-2 water and L-5 and L-6 driplines were treated

Table 1
Chemical properties of waters used in the experiment

	Cations (meq l^{-1})				Anions (meq l^{-1})				EC[a] (dS m^{-1})	pH	LSI[b]
	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4			
W-1	2.08	0.90	0.43	0.03	–	0.40	1.35	1.12	0.314 ± 0.007	8.62 ± 0.03	+0.20
W-2	2.07	0.90	3.63	0.04	–	0.40	5.30	1.09	0.665 ± 0.012	8.58 ± 0.06	+0.11
W-3	2.07	0.90	6.26	0.05	0.20	0.20	7.90	1.05	0.937 ± 0.009	8.53 ± 0.09	+0.03

[a]EC: Electrical conductivity.
[b]LSI: Langelier saturation index.

with W-3 water during experiment. Water temperatures in the tanks were set to 25 ± 1°C. The daily total discharge for each dripline was adjusted as 0.5 m^3. So, at the beginning of experiments, each dripline was operated for 6 h daily.

2.3. Measurement and evaluation

The discharge rates of emitters in driplines under operation pressure of 0.04 MPa and EC and pH values of discharge water were measured with three day intervals during the water treatment period. The EC and pH values were monitored using WTW type pH/Cond 340i.

There are various approaches to evaluate emitter performance on a dripline [21–24]. Two factors can determine the emitter performance: statistical uniformity coefficient (U_c) and emission uniformity coefficient (E_u) along a dripline [1,3,4,24–27].

The U_c equation is:

$$U_c = 100\left(1 - \frac{s_q}{q_{ort}}\right)$$

where S_q is the standard deviation of emitters discharge rate (l h^{-1}) and q_{ort} is the mean of emitters discharge rate on a given dripline (l h^{-1}).

The E_u was calculated according to Capra and Tanburino equation [1,3,28,29]:

$$E_u = 100\left(\frac{q_{\text{ort-low qaurter}}}{q_{ort}}\right)$$

where $q_{\text{ort-low quarter}}$ is the mean discharge rate of the 25% of the emitters with the lowest discharge rate on a given dripline (l h^{-1}).

Analysis of variance (ANOVA) for the data of EC and pH was performed.

3. Results and discussion

The EC and pH values of discharge water from emitters in driplines throughout the water treatment period are shown in Figs. 2 and 3. The EC and pH values of the discharge water from emitters in driplines (L-2, L-4, L-6) treated with non-magnetic water were higher than those of emitters in driplines (L-1, L-2, L-3) treated with magnetic water (Figs. 2 and 3). But, the magnetic water treatments did not significantly affect the EC and pH

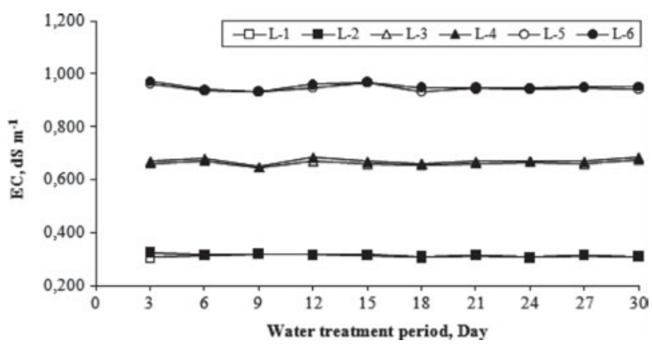

Fig. 2. The EC values of discharge water from emitters in driplines throughout the water treatment period.

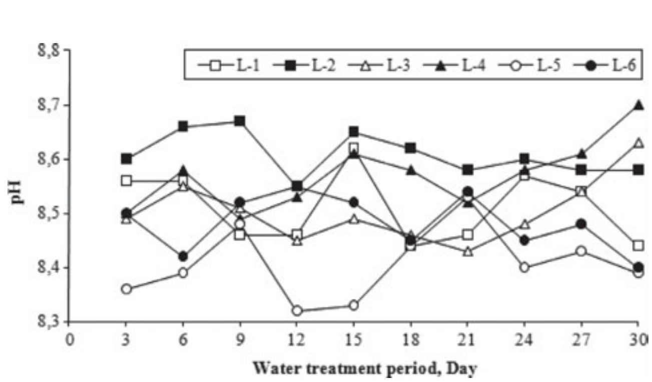

Fig. 3. The pH values of discharge water from emitters in driplines throughout the water treatment period.

values of discharge water. Zhang et al. [14] found that a series of changes have taken place in water's physico-chemical characters after exposed to electromagnetic field. According the results reported by Ozdemir et al. [18], electromagnetic treatment decreased water alkalinity, hardness, pH and EC. Parsons et al. [30] also showed that magnetic field reduced pH. On the contrary, Quickenden [31] could not detect a pH change in doubly distilled water which passed through magnetic fields in the range 0 to 24000 Gauss.

The pHs of all discharge waters were above 8.00 (Fig. 3). $CaCO_3$ is more likely to precipitate in high pH [7]. According to the pH values observed in this study, the clogging hazard in emitters was severe [5].

Fig. 4 shows the relative discharge rate of emitters in driplines throughout the water treatment period. At the end of water treatment period, the discharge rate from emitters in driplines (L-2, L-4, L-6) treated with non-magnetic water were lower than those from the emitters in driplines (L-1, L-3, L-5) treated with magnetic water (Fig. 4). While the lowest discharge rate from emitters was determined under the W-1 water treatment, the highest discharge rate was determined under the W-2 water treatment (Fig. 4). The LSI and pH values of the W-1 water were the highest (Table 1). It could be said that higher pH of water resulted in more precipitation [32]. Similarly, Nakayama et al. [6] expressed that higher pH values can cause higher calcium carbonate precipitation regarding the LSI. The results of a study conducted by Aali et al. [1] also indicated precipitation of calcium carbonate in the emitters is likely when the pH is high and water is not magnetically treated. Relatively, the highest magnetic effect was determined under the W-1 water treatment (Fig. 4). A decrease in the water pH or an increase in salinity decreased the relative effect of magnetic treatment. Alimi et al. [9] discussed that the efficiency of magnetic field treatment increased with the hardness and pH. Similarly, Parsons et al. [30] indicated that pH played an important role in the mechanism by which magnetic fields reduce scale. Higher EC values are also one of the reasons of emitter clogging [3], in consistence with discharge rates from driplines for the W-3 water treatment were lower than the W-2 water treatment although pH and LSI values of the W-3 water lower than the W-2 water.

The values of U_c and E_u of driplines throughout the water treatment period are shown in Figs. 5 and 6. The U_c value shows deviation from average conditions and the E_u value shows the condition of the least watered plants as compared with that of the average watered plant [3]. While the performances of driplines according to the U_c value is evaluated in three categories as good (U_c > 89%), medium (71% < U_c > 89%) and poor (U_c < 71%), according to the E_u is also evaluated in three categories as high (E_u > 84%), medium (66% < E_u > 84%) and poor (E_u < 66%) [1,25]. The mean U_c values were determined as 56.0%, 39.5%, 94.8%, 80.9%, 64.0% and 81.7%, while the mean E_u values were 38.6%, 0.4%, 94.1%, 79.0%, 59.3% and 79.9% for L-1, L-2, L-3, L-4, L-5 and L-6 driplines, respectively (Figs. 5 and 6). The U_c and E_u values generally decreased during the water treatment period for all driplines except the L-3 dripline (Figs. 5 and 6). Discharge rates of the L-3 dripline stayed almost stable throughout the water treatment period (Fig. 4). So, low U_c and E_u values resulted in a decrease of discharge rates in other driplines. The U_c and E_u values for driplines (L-1, L-3) treated with magnetic water were higher than those of driplines (L-2, L-4) treated with non-magnetic water under the W-1 and W-2 water treatments. Conversely, these values for the L-5 dripline treated with magnetic water were lower than of the L-6

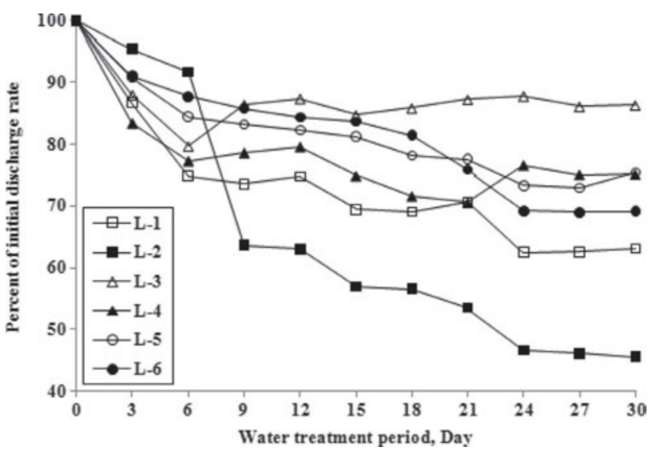

Fig. 4. The rates of discharge water from emitters in driplines throughout the water treatment period.

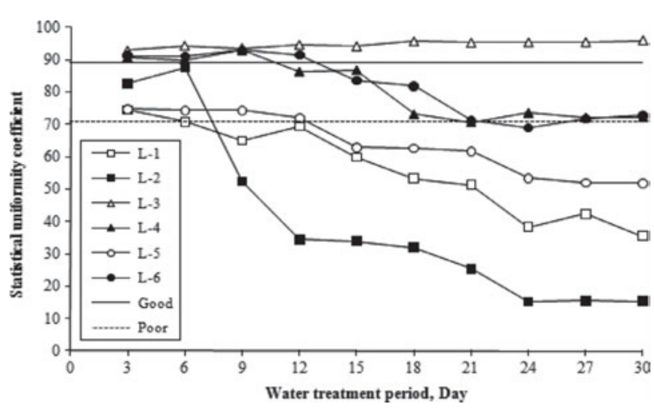

Fig. 5. The statistical uniformity coefficient of driplines throughout the water treatment period.

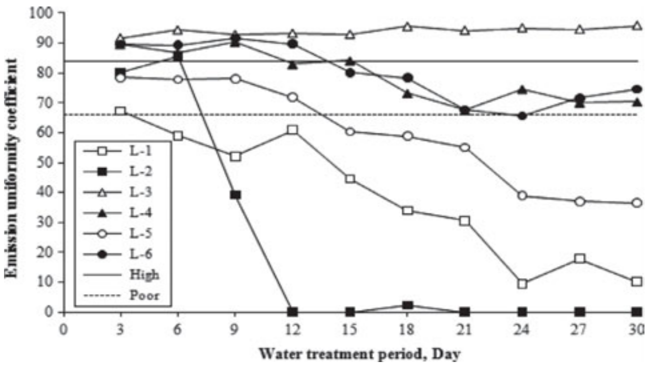

Fig. 6. The emission uniformity coefficient of driplines throughout the water treatment period.

dripline treated with non-magnetic water under the W-3 water treatment. Effect of magnetic water treatment on the dripline uniformity was poor under the W-1 and W-3 water treatments. But, good/high performances were determined under the W-2 water treatment (Figs. 5 and 6). It could be said that salinity has affected the magnetic treatment efficiency. Botello-Zubiate et al. [33] demonstrated that the effects of magnetic treatment on water depend on the water chemical composition.

4. Conclusions

Application of magnetized water had a positive impact in terms of prevention of clogging of the emitters because magnetized water is softer. The effect of magnetic water on delaying emitter clogging was the highest with lower salinity and higher pH and LSI values. On the contrary, magnetic effect was less when pH and LSI were low and salinity was high. Magnetic treatment can be an attractive alternative method to fight against $CaCO_3$ clogging in emitters under medium-salinity water since the U_c and the E_u of driplines were good and high, respectively.

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