



## The Effect of Acidification and Magnetic Field on Emitter Clogging under Saline Water Application

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### Abstract

Up to day, drip irrigation systems have reached to a high level of technology. But, these systems are not able to show their potential benefits, due to various reasons. Emitter clogging can affect distribution uniformity and the system performance, which has direct relationship with water quality. In this study five types of emitters with different nominal discharges, with or without self-flushing system and with or without pressure compensating system were evaluated under three management schemes; untreated well water (S1), acidic treated water (S2) and magnetic treated water (S3) in order to reduce chemical clogging. Flow reduction rate, statistical uniformity coefficient (Uc), emission uniformity coefficient (Eu) and variation coefficient of emitters' performance in the field (Vf) were monitored. The emitter performance indexes (Uc and Eu) decreased during the experiment due to emitter clogging. The Uc and Eu values in different management schemes confirmed that the acidification has better performance than the magnetic water in order to control emitter clogging and keep high distribution uniformity. Regarding to Vf values, the priority of untreated and treated water was as  $S2 > S3 > S1$  for each emitter.

**Keywords:** Drip irrigation system, Discharge, Emitter, Acidification, Magnetic treatment

### 1. Introduction

Drip irrigation systems are designed to deliver a certain amounts of water and nutrient to the plant. As water becomes more limited in arid and drought prone areas, these systems are used more widely. There are numerous advantages using drip irrigation systems. However, these advantages could be nullified by emitter clogging, which is directly related to the quality of the irrigation water (Dehghanisani et al., 2007; Gilbert et al., 1979). Therefore, drip irrigation systems need a high maintenance. The greatest problem and concern dealing with these systems is emitter clogging. Nakayama and Bucks (1981) found a significant reduction in uniformity when 1-5% of emitters were completely clogged even with 2 to 8 emitters/plant. Partial or complete clogging drastically reduces water application uniformity (Nakayama and Bucks, 1981) and consequently decreases irrigation efficiency and crop production. Bucks and Nakayama (1982) proposed an irrigation water quality classification for potential clogging hazard. They classified the hazard into three main categories of physical, chemical and biological clogging that play major roles in the clogging process. Physical clogging may be caused by factors such as suspended inorganic materials (sand, silt, clay or plastic particles) and organic materials (plant and animal residuals, etc.). Biological clogging is due to organic sediments plus iron or hydrogen sulfide that accumulated

in emitters and laterals (Dehghanisani et al., 2005; Tajrishy et al., 1994). Chemical clogging is contributed to precipitation of calcium carbonate that is common in arid regions with waters rich in calcium and bicarbonates. Iron deposits (ocher) have created severe clogging primarily in the United States. The soluble and reduced form of Iron (ferrous ion or  $\text{Fe}^{+2}$ ) is presented in groundwater of many places. Manganese might be oxidized and transform into particulate form that cause emitter clogging.

Chemical clogging, through salt precipitation, is very difficult to be controlled. The general recommendation to prevent chemical clogging is to lower the water pH, by acid injection, to a value such that salt precipitation does not occur.

Water passing through magnetic field might get new properties and is called magnetic water. Magnetic treatment (MT) of hard water is currently used to prevent scale formation on hot surfaces, in particular in heat exchangers, as well as in domestic equipments. This treatment process has been developed to substitute chemical water treatment methods employing chemical product that might be harmful to the environment and human health.

Comprehensive experimental researches were carried out on modification of  $\text{CaCO}_3$  precipitation process by MT. According to the literature, the efficiency of magnetic treatment depends on numerous parameters. For example, Chibowski et al. (2003) and Barrett and Parsons (1998) found out that the magnetic treatment applied on hard water decreased the quantity of scale formation on the wall. The principle of this phenomenon has not been understood well. Various contradictory hypotheses have been suggested that attributed these to the Lorentz forces  $\vec{F} = q \cdot \vec{v} \times \vec{B}$  exerted either on moving ions or on charged solid particles (Higashitani et al., 1993). The magnetic field (MF) would be able to disturb the double ionic layer surrounding the colloidal particles and their zeta potential (Gamayunov, 1983; Higashitani and Oshitani, 1998; Parsons et al., 1997).

The objective of this study was to investigate the effectiveness of three management schemes in decreasing chemical clogging and evaluate the change in discharge rate and uniformity of laterals equipped with different type of emitters.

## 2. Materials and methods

### 2.1 Experimental location

The climate of Iran is one of the greatest extremes due to its geographic location and variation in topography. The summer is extremely hot with temperatures in the interior rising possibly higher than anywhere else in the world; certainly over  $55^\circ\text{C}$  has been recorded. Iran with an area of 165 million hectares has 37 million hectares arable land of which only 8 million hectares are irrigated, 6 million hectares are rain-fed, and 4.5 million hectares remain in the form of fallow land. Annual rainfall ranges from less than 50 mm in the deserts to more than 1600 mm on the Caspian Plain. The average annual rainfall is 252 mm and approximately 90% of the country is arid or semiarid. Overall, about two-thirds of the country receives less than 250 mm of rainfall per year. Most of the rain falls during the winter season, particularly in northern part of country. In the central and southern part of Iran, the annual rainfall range from 0 to 200 mm.

About half of the area is irrigated by groundwater, including spring water. Over extraction from ground water resources and limited rainfalls have led receding ground water table and poorer water quality over time. From the total 8.1 million ha of irrigated lands in Iran; 7.6 million ha (95%) are under surface irrigation and 0.4 million ha (5%) under the pressurized irrigation. With limited renewable water resources and annual rainfall, particularly during the past two decades, drip irrigation systems have been introduced in agricultural regions of Iran to increase water use efficiency. However, water quality reduction over time has led emitter clogging in most of drip irrigation systems.

### 2.2 Experimental layout

A field study involving a drip irrigation system was conducted in Hasanabad, Iran ( $35^\circ 25'\text{N}$ ,  $51^\circ 10'\text{E}$ ) from August to November 2007. Five different type of emitters (see Table 1), differing in the nominal discharge, pressure compensating and non-pressure compensating were used (Dehghanisani et al., 2005, 2007). The in-line (EM3 and EM5) and on-line emitters (EM1, EM2 and EM4) were 0.5 m apart. Water pressure at the inlet was 0.10 MPa. Figure 1 illustrates a schematic layout of the drip irrigation system, including three similar subunits, in the field. Three management schemes with application of non-treated water (S1), treated water with acid injection (S2) and magnetic water (S3), each in a subunit, were evaluated for the proposed emitters. Each subunit consisted of 5 laterals with 50 m length and 0.5 m apart, was connected to the sub-main pipe of the drip irrigation system. Each lateral was equipped with a flow meter. No crops were grown in the field during the study. The irrigation system was automated to irrigate 8 hours per day (9:00 am to 17:00 pm) over the 12 weeks in summer of 2007. All subunits were connected to a control station equipped with a pump, backflow-prevention device, screen and silicone filters and pressure gauges.

Sulfuric acid was injecting into subunit 2 continuously in order to lower pH from 8.18 to 6.5 and decrease the possibility of  $\text{CaCO}_3$  precipitation. The flow rate of emitters was measured every two weeks and according to ASAE EP405 method (ASAE Standards, 2003b). Twenty five catch-cans were placed under the emitters along each lateral. Water samples were

collected every two weeks and electrical conductivity, pH, Cat ions such as calcium, sodium and magnesium and anions such as carbonate, bicarbonate and sulfate were measured.

### 2.3 Emitter performance

Laboratory tests were performed to determine the manufacturing coefficient of variation ( $V_m$ ) of new emitters using Solomon's equation (1979):

$$V_m = 100 \frac{Sq_e}{\bar{q}_e} \quad (1)$$

Where  $Sq_e$  and  $\bar{q}_e$  are the standard deviation and the average of emitter discharge ( $Lh^{-1}$ ), respectively. The  $V_m$  values ranged from 3.05 to 7.69 percent (Table 1) which attribute a good quality class to emitters, according to ASAE standard method of EP405.1 (ASAE Standards, 2003a). The emitters with a given size and  $V_m < 5$  percent were selected to ensure minimum manufacturing variation in discharge in the field.

In the second test of this study, 50 emitters with a given size, selected on the basis of least variation (Equation 1) were fitted to a lateral in order to assess emitter discharge performance at five different pressure heads. The emitter discharge performance is characterized by the  $k$  and  $x$  parameters of Karmeli's (1977) Equation:

$$q_e = k h^x \quad (2)$$

Where  $q_e$  is discharge from individual emitter ( $Lh^{-1}$ ),  $h$  is entry water pressure (m  $H_2O$ ; 1 m  $H_2O = 0.098 \times 10^5$  Pa),  $k$  is emitter discharge coefficient and  $x$  is emitter discharge exponent, which characterizes the flow regime and  $q$  vs.  $h$  relationship.

### 2.4 Statistical analysis

Three statistical factors were used to assess the emitter performance in the field: uniformity coefficient ( $Uc$ ), emission uniformity coefficient ( $Eu$ ) and the coefficient of variation of emitters ( $Vf$ ) along a lateral in the field.

The statistical uniformity coefficient ( $Uc$ ) provides a measure of deviation from average conditions on each lateral. It was computed using the modified form of Wilcox and Swailes (1947) equation proposed by Bralts et al. (1987) for drip irrigation system:

$$Uc = 100 \left(1 - \frac{Sq}{\bar{q}}\right) \quad (3)$$

Where,  $Sq$  is standard deviation of emitter discharge ( $Lh^{-1}$ ) and  $\bar{q}$  is average of emitter discharge in the field on a given lateral ( $Lh^{-1}$ ).

The emission uniformity coefficient ( $Eu$ ) was computed using Capra and Tamburino (1995) equation:

$$Eu = 100 \frac{\bar{q}_{1/4\min}}{\bar{q}} \quad (4)$$

Where  $\bar{q}_{1/4\min}$  is the mean of low quarter of emitter discharge ( $Lh^{-1}$ ).  $Uc$  and  $Eu$  assume a different meaning, the former showing deviation from average conditions, and the latter showing the conditions of the least watered plants as compared with that of the average watered plants.

The coefficient of variation of the emitters' performance along a lateral line in the field ( $Vf$  %) shows the variation of emitter discharge at a constant pressure head. It was computed using Bralts' (1986) equation:

$$Vf = \sqrt{\left(\frac{Sq}{\bar{q}}\right)^2 - x^2 \left(\frac{S_h}{h}\right)^2} \quad (5)$$

Where  $S_h$  the standard deviation of pressure is head (m $H_2O$ ), and  $h$  is the mean pressure head (m $H_2O$ ). Other parameters were already defined in equation 3.

## 3. Results and discussion

### 3.1 Water quality

Table 2 shows some chemical characteristics of the non-treated (well) water and treated (magnetic) well water. This table indicates that the magnetic field does not change the chemical properties of the well water significantly. Figure 3 illustrates the variation of pH and EC of the well water during the field experiment. The pH values were higher than 8 all over the experiment, indicating a feasible precipitation of carbonate calcium in the system and consequently emitter clogging.

Equilibrium equations (6, 7 and 8) were used to assess the possibility of calcium sulfate precipitation in the system. If multiplication (product) of calcium and sulfate ions (mol/l) is greater than KSP, it may be resulted in precipitation of calcium sulfate. Value of KSP for calcium sulfate in 25°C is  $2.4 \times 10^{-5}$  ( $\text{mol}^2 \cdot \text{l}^{-2}$ ).



$$\frac{[\text{Ca}^{2+}][\text{So}_4^{2-}]}{\text{CaSo}_4} = K \quad (7)$$

$$[\text{Ca}^{2+}][\text{SO}_4^{2-}] = K [\text{CaSO}_4] = \text{KSP} \quad (8)$$

According to Nakayama and Bucks (1991) pH levels of <7.0, 7.0–8.0 and > 8.0 could lead to slight, medium and severe clogging, respectively. Therefore, pH values of well water (table 2 and Figure. 3) certify sever clogging problems during the experiment. Although, it has been reported that the pH may not have a direct impact on clogging; but it could accelerate the chemical reactions or biological growth involved in clogging process (Nakayama and Bucks 1991; Dehghanisanij et al. 2004, 2005).

### 3.2 Emitter performance

The manufacturing coefficient of variation (Vm) values determined in the laboratory ranged from 3 to 8 (table 1). The minimum value (3.05%) was corresponded to EM5 and the maximum value (7.69%) to EM2. According to ASAE standard EP405.1 (ASAE standards, 2003a), Vm value between 3-11% classify emitters in a moderate category.

Figure 4 (a, b and c) shows the relative flow rate in different emitters during the experiment in subunits irrigated with well water, acidic water and magnetic water, respectively. This Figure illustrates a fairly continuous flow rate reduction in all emitters over the time, especially at the first month of the experiment, which could be attributed to emitter clogging.

Figure 4 also show a less reduction rate in emitters irrigated with acidic water, as compared to the ones irrigated with well and magnetic water. The reason can be explained by the fact that the acid injection to well water lowering the pH which consequently prevents and reduces carbonate precipitation.

Table 4 presents the total discharged and total nominal water and reduction rate in all emitters under different management schemes (well, acidic and magnetic irrigation water).

According to table 4, the maximum reduction of flow rate was occurred in EM4 (14.98%) and after that in EM3 (12.32%) irrigated with non-treated well water and the minimum reduction was occurred in EM2 (2.76%) irrigated with acidic water. The flow rate in EM1, EM2 and EM5 with self flushing feature did not reduce significantly during the experiment, even in subunit irrigated with untreated well water. Self flushing system allows the emitters to pass large particles but the orifice is constricted at normal operation pressure to regulate the flow rate (Hills and El-Ebaby1990).

Dehghanisanij et al. (2004, 2005 and 2007) showed that emitters with pressure compensating feature have smaller variation in emitter discharge than non pressure compensating emitters when low quality water was induced by algae and protozoa and they showed that emitters with self flushing and pressure compensating features have priority for use in drip irrigation under saline water.

The EM2 with the largest nominal discharge, self flushing and pressure compensating features showed less flow rate reduction than the other emitters in different management schemes.

Figure 5 shows the variation of Uc, Eu and Vf in different subunits irrigated with well, acidic and magnetic water. These parameters help us to evaluate the effect of emitter clogging and manufacturing coefficient of variation on flow rate changes of different emitters. Figure 5 shows a declined trend for Uc and Eu in different subunits over the time. However, the acidic water subunit had the highest values of Uc and Eu for all emitters. The Uc provides a measure of deviation from the average (Wilcox and swales 1947). According to Bralts (1986), the performance of emitters is classified and evaluated in three categories; “good” for the Uc values greater than 89%, “medium” for the Uc values between 71% and 89%, and “poor” for the Uc values less than 71%. In this study, the value of Uc was greater than 71% for all emitters under different water management and during the experiment. The high values of Uc belong to EM2 and the low values belong to EM3 and EM4. At the end of experiment, Uc values for EM2 were measured 93.1, 96.19 and 92.86 for well, acidic and magnetic water, respectively. These values for EM4 were measured 89.7, 93.89 and 87.94. The nominal discharge was the same for EM2 and EM4. The better performance of EM2 can be attributed to the self flushing feature. The nominal discharge in EM4 was higher than that in EM5. However, EM5 with self flushing feature showed better performance as compared to EM4.

The Eu parameter provides a measure of the least water consumed plants condition. According to Bralts (1986), if the Eu values are greater than 84%, then the performance is classified as high; between 66% and 84%, the performance is medium; and less than 66%, the performance is poor. According to Eu values, the performance of emitters in subunits is

organized as acidic>well>magnetic water. But the Eu value decreased suddenly at the end of experiment (The 10th of October) due to complete clogging of one emitter among 25 emitters.

Both Eu and Uc have negative correlation with the percentage of complete clogged emitters (Dehghanisani et al. 2007). EM5 and EM4 showed better performance as compared to the others in different water management schemes. The Eu value was greater than 84% for all emitters in acidic water subunit, so their performance classified as high. Consequently, the hazard of chemical clogging under saline water usage can be reduced by acidification and high performance can be promised.

The Vf values also show differences among different types of emitters (Figure. 5). According to Bralts (1986), emitters are classified as high, medium and poor performance on the basis of Vf values; less than 11%, between 11 and 29% and greater than 29%, respectively. As the Vf values become smaller, the variation of discharge among emitters on the laterals are decreased (Bralts 1986). According to Figure 6, the performance of all emitters (with the exception of EM4) in different subunits was high. The performance of EM4 in well, acidic and magnetic water subunits was medium, high and medium, respectively. These results suggest that the mist spray emitter type was characterized as less clogging and could be used for more than one irrigation season with good result.

#### 4. Conclusion

The results of this study showed that the application of well saline water in drip irrigation system have the potential to induce emitter clogging. The concentration of Fe and Mg in well water was lower than the hazardous levels that could clog emitters. It was found that the flow rate reduction in emitters is affected by emitter characteristics and water treatment methods. The priority of emitters according to flow rate reduction and clogging are as follow: EM4> EM3> EM5> EM1> EM2.

It was found that the acid injection treatment provide better performance than the magnetic field. In the other hand, less flow rate reduction was occurred in emitters using acidic water. There was no significant difference between subunits using untreated well water and treated magnetic water. All the emitters used in this experiment (with the exception of EM4) were ranked as high performance class. The performance of EM4 with untreated well water and treated magnetic water was moderate and with treated acidic water was high. The Eu and Uc decreased over the time and increased by emitter clogging. Regarding to Eu and Uc, acidification was found to be one of the most effective method in controlling emitter clogging and conserving high distribution uniformity.

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Table 1. Some characteristics of the five different types of drip irrigation emitters

Emitter	Type of Emitter	Nominal			V <sub>m</sub> %	Other Characteristics <sup>[a]</sup>
		Discharge (Lh <sup>-1</sup> )	k	x		
EM1	On - line PC	4	5.009	-0.0559	3.61	self-flushing
EM2	On - line PC	4	2.843	0.136	7.69	self-flushing
EM3	In - line PC	3.6	3.2846	0.036	4.04	anti-drain
EM4	On - line NPC	4	1.1957	0.5258	4.76	turbulent flow emitter
EM5	In - line PC	2.4	0.95	0.4202	3.05	turbulent labyrinth flow, self cleaning

<sup>[a]</sup> According to manufacture's manual.

Note: PC = pressure compensating; NPC = non-pressure compensating; k = emitter discharge coefficient and x = emitter discharge exponent

Table 2. Mean chemical characteristics of the waters

Parameters	Unite	Well water	Magnetic water
EC	dS/m	4.8	4.76
pH*		8.19	8.09
Ca	(me/L)	9.7	9.65
Mg	(me/L)	9.08	8.85
Na	(me/L)	31.96	32.02
HCO <sub>3</sub>	(me/L)	7.3	7.01
SO <sub>4</sub> <sup>-2</sup>	(me/L)	21.46	23.4
Cl	(me/L)	21.29	20.05

\* During acid injection, pH was less than 6.5

Table 3. Chemical analyses of well water and the Possibility of CaCO<sub>3</sub> and CaSO<sub>4</sub> precipitation

Date	pHm	pHc	LSI	Ca <sup>+2</sup> (mol/l) × 10 <sup>3</sup>	SO <sub>4</sub> <sup>-2</sup> (mol/l) × 10 <sup>3</sup>	[Ca <sup>+2</sup> ][SO <sub>4</sub> <sup>-2</sup> ] (mol <sup>2</sup> /l <sup>2</sup> ) × 10 <sup>5</sup>	Possibility of CaCO <sub>3</sub> precipitation	Possibility of CaSO <sub>4</sub> precipitation
8/24	8.12	7.01	1.11	18	47.4	85.32	+	+
9/7	8.05	7.02	1.03	18.8	50.16	94.3008	+	+
9/21	8.27	6.93	1.35	18	39.46	71.028	+	+
10/5	8.03	6.95	1.08	21	38.54	80.934	+	+
10/19	8.11	7.02	1.09	20.8	39.68	82.5344	+	+
11/2	8.02	6.87	1.16	17.4	43.62	75.8988	+	+
11/16	8.70	6.89	1.81	21.8	41.6	90.688	+	+

Table 4. Total discharged and nominal water and reduction rate in all emitters under different management schemes

Lateral No.	Total nominal water use (m3)	S1		S2		S3	
		Total water used (m3)	Reduction (%)	Total water used (m3)	Reduction (%)	Total water used (m3)	Reduction (%)
EM1	284.66	270.24	5.07	271.66	4.57	269.45	5.34
EM2	286.94	273.28	4.76	279.03	2.76	278.54	2.93
EM3	249.98	219.18	12.32	241.21	3.51	222	11.19
EM4	272.16	231.39	14.98	256.77	5.65	233.82	14.09
EM5	181.44	170.58	5.99	172.22	5.08	170.92	5.80

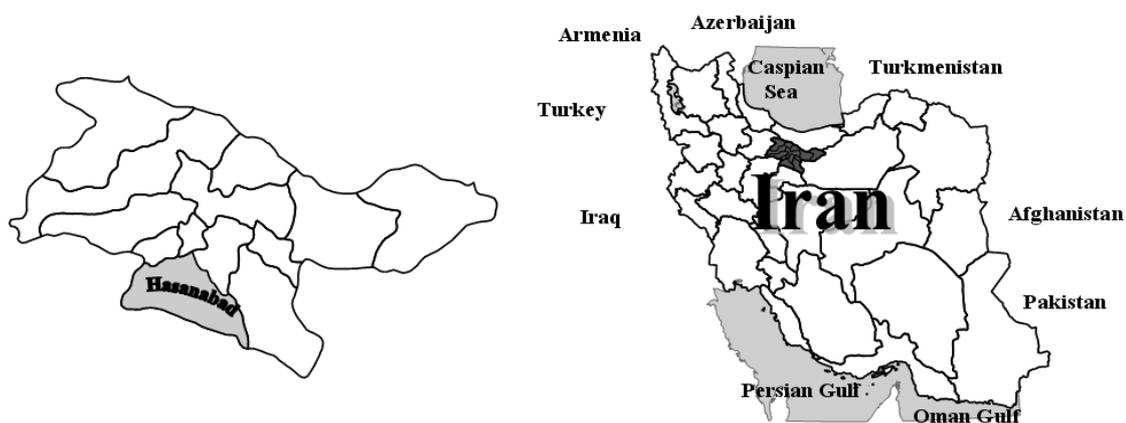
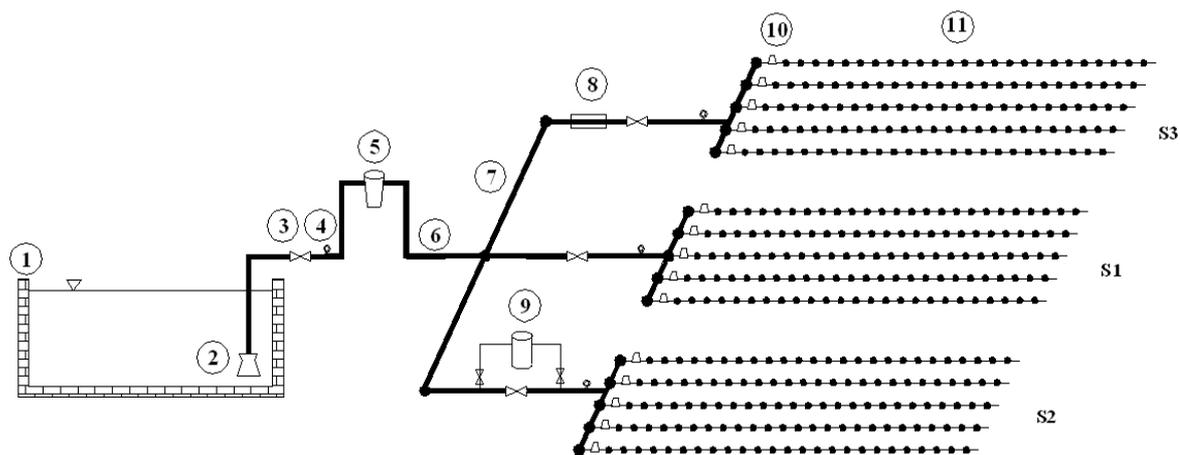


Figure 1. Activity area in Iran



- |              |                   |                   |                           |
|--------------|-------------------|-------------------|---------------------------|
| 1. Reservoir | 4. Pressure gages | 7. Sub-main line  | 10. Flow meters           |
| 2. Pump      | 5. Screen filter  | 8. Magnetic Water | 11. Emitters and laterals |
| 3. Valves    | 6. Main line      | 9. Injector       |                           |

Figure 2. Field experiment layout

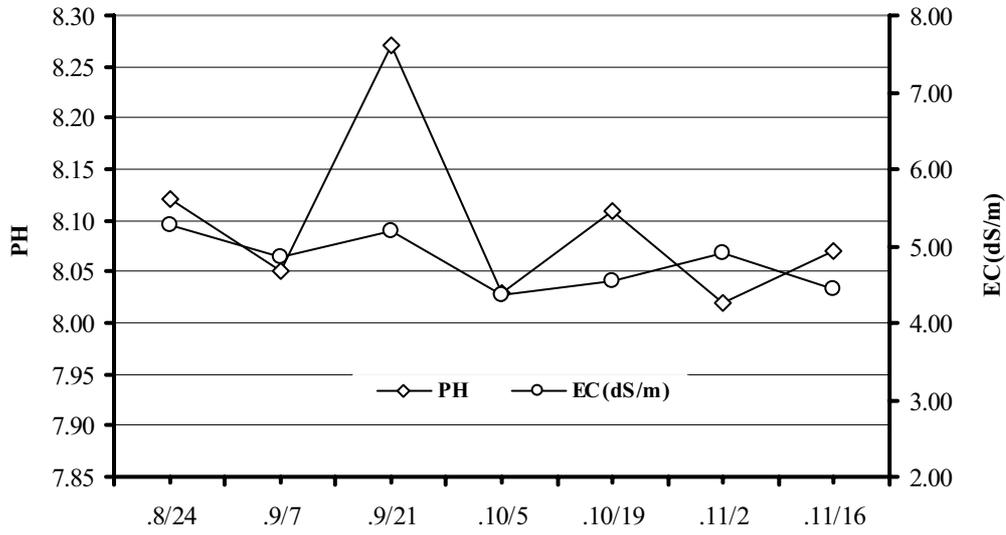


Figure 3. Variation of pH and EC during the experiment

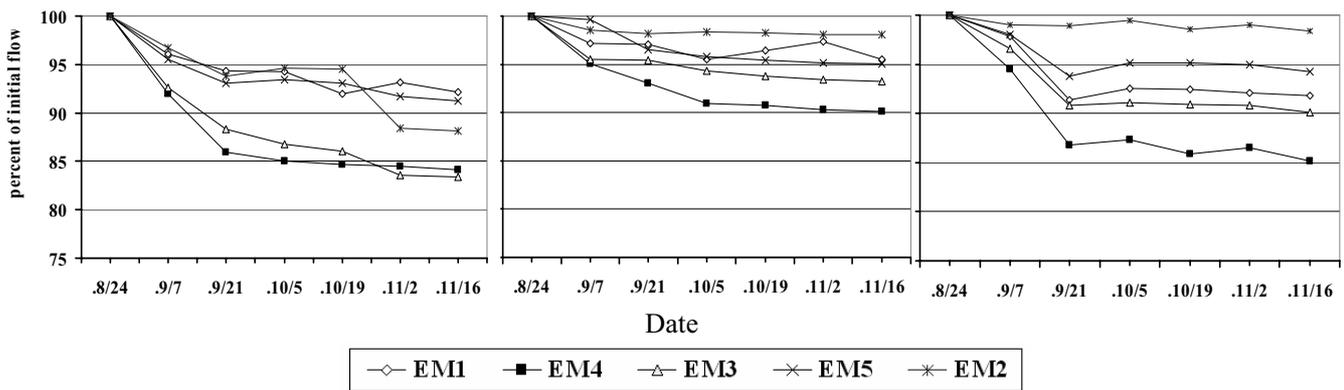


Figure 4. Variations of flow rate for different emitters

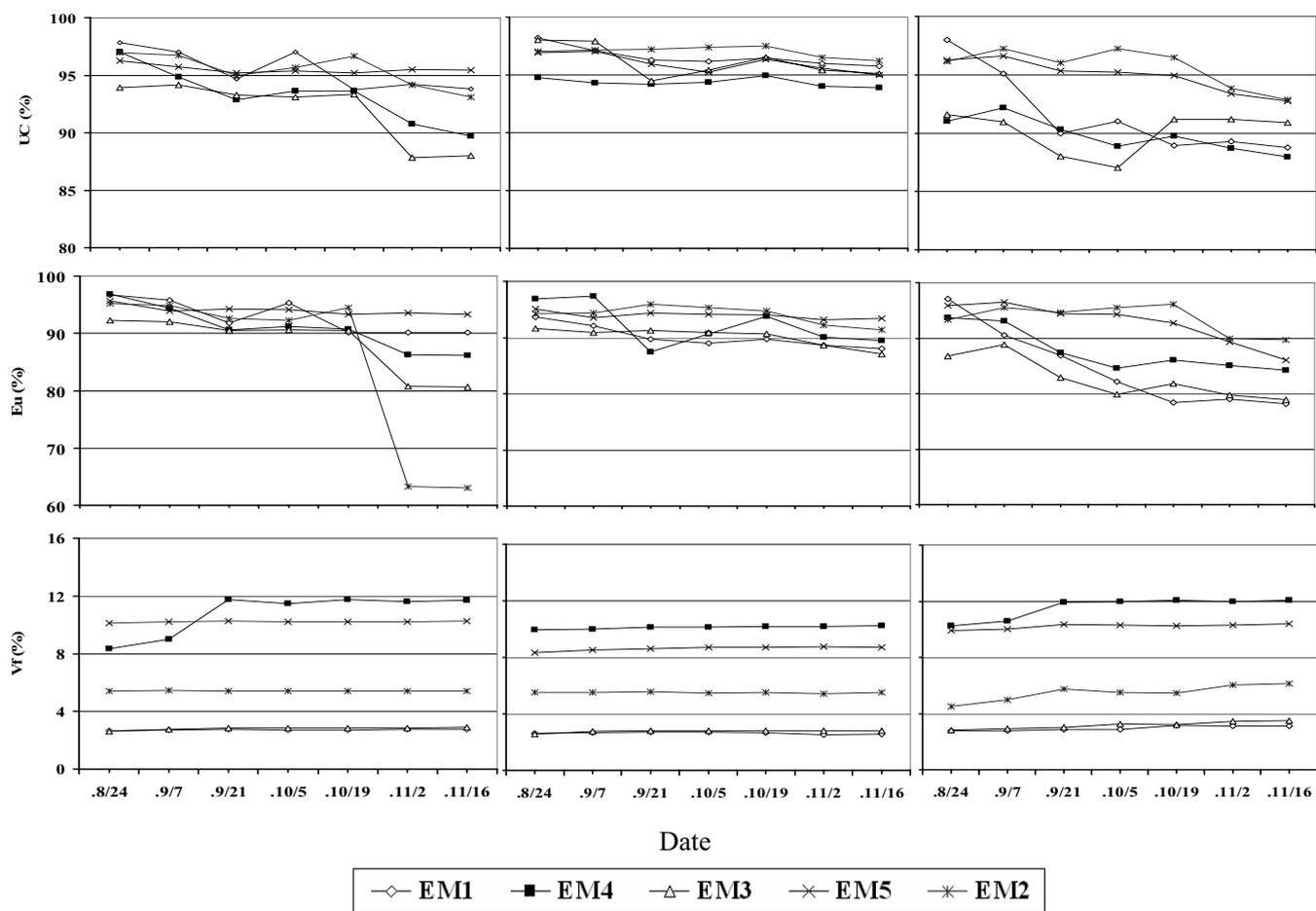


Figure 5. Variation of Uc, Eu and Vf in different subunits irrigated with well, acidic and magnetic water