Effects of fertigation on emitter clogging and soil infiltration rate

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Abstract: A field experiment was conducted to study the effect of fertigation components on emission uniformity, emitter clogging and soil infiltration rate. The effects of two types of emitters (pressure and non-pressure compensating) with two discharges (2 and 4 L h^{-1}) and six fertilization treatments were undertaken. For all fertilization treatments, the emission uniformity significantly (p<0.05) decreased while emitters clogging ratio increased with more fertigations, which were periodically applied throughout the 180-day season. The 4 L h^{-1} discharge emitters resulted in less clogging than the 2 L h^{-1} emitters. Clogging problems observed with the pressure compensating (PC) emitters was less than those non-pressure compensating emitters. The maximum clogging ratios (29.42% and 28.72% at the end of 180 days season) were recorded for the plots that received ammonium sulfate and humic acid+ ammonium sulfate fertigation, respectively, with 2 L h^{-1} non-pressure compensating emitters.Finally, humic acid treatment showed a clear reduction in infiltration rate from 876 mm h^{-1} to 408 mm h^{-1}.
Keywords: drip irrigation; fertigation; clogging ratio; infiltration rate

Citation: Mostafa, H., A. Moursy, M. El-Ansary, and M. Hatata. 2021. Effects of fertigation on emitter clogging and soil infiltration rate. Agricultural Engineering International: CIGR Journal, 23(1):92-99.

1 Introduction

Drip irrigation systems have many potential benefits relative to other irrigation technologies, some of which are linked to low water application levels, high performance and greater water savings (Mostafa and Thörmann, 2013). Emitter clogging, which is directly related to water quality and its physical, chemical or biological pollutants, is one of the most important drawbacks of drip irrigation (Mostafa and Derbala, 2013). In this respect, the efficiency of the water source for the design and maintenance of micro irrigation is important to evaluate. Zhu and Cui (2005) reported that clogging by emitters was one of the key factors determining whether drip irrigation systems can be successful.

Adin (1987) found that the clogging of dripper may be due to physical, chemical and biological factors. De Troch (1988) showed that two or more of those reasons for clogging that occur simultaneously. Dripper clogging may be due to their extremely tiny water passages and poor flow rate (Dasberg and Bresler, 1986). Hebbar et al. (2004) found regular fertilizers appear to clog the dripper in general. Ravina et al. (1997) reported that, at the end of the drip laterals, more dripper clogging was observed than at the beginning possibly due to lack of head pressure. Uniform distribution of irrigation water is very critical for achieving uniform application of water and fertilizer. Bozkurt and Zekiei (2006) have shown that different treatments with fertilizers have a major impact on clogging of the dripper. Calcium-and sulphur-containing fertilizers caused higher clogging compared to the other elements. Chang (2008) recorded that as water flow slows down in the irrigation system and/or changes in the chemical history of the water, chemical precipitates and/or microbial flocks and slimes begin to shape and develop, thereby causing emitter clogging.

Received date: 2020-01-21 **Accepted date:** 2020-05-08

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The application of humic substances in soils with a variety of texture grades and mineral suites has been shown to increase aggregation (Quilty and Cattle, 2011). The soil's cation exchange capacity is also impacted by the use of humic substances. Humus typically accounts for 50% to 90% of mineral surface soil cation-absorbing strength. Like clays, humus colloids carry nutrient cations, i.e. potassium, calcium, magnesium, in an easily exchangeable shape, where they can be used by plants but are not leached too readily from the profile by percolating waters (Ichino and Kasuya, 1998; Hama et al., 2011; Lillo et al., 2013). Aggregation encourages high infiltration rates, which reduce runoff and erosion (Brady and Weil, 2008).

The main objective of this work was to investigate the effect of fertigation components and emitter type on emitter clogging and soil infiltration rate.

2 Materials and methods

2.1 Experimental site

A field experiment was carried out at the farm of Soils and Water Research Department, Nuclear Research Center, Atomic Energy Authority, Inshas, Egypt. Soil physical and chemical analyses indicated that soil texture of the experimental area was sand with pH of 7.97, organic matter of 0.3 g kg^{-1}, $CaCO_3$ of 10 g kg^{-1}, and C: N ratio of 34.3. Properties of irrigation water are summarized in Table 1.

Table 1 Average values of the main quality parameters of the irrigation water

pH	Electrical conductivity EC (dS m^{-1})	Sodium adsorption ratio SAR	Soluble ions (mmol$_c$ L^{-1})						
			Cations				Anions		
			Mg^{2+}	Ca^{2+}	K^+	Na^+	HCO_3^-	SO_4^{2-}	CL^-
7.53	0.38	2.8	0.51	1.32	0.22	2.13	0.33	1.54	2.31

2.2 Experiment layout

The experiment layout consisted of electrical centrifugal pumping unit of 18 m^3 h^{-1} discharge under 200 kPa operating pressure lifting the water from an open channel and deliver it to a 50 mm diameter poly ethylene (PE) main pipe through a control head involving media and screen filters, 19 mm Venturi fertilizer injector, valves and pressure gauges. Four drip irrigation plots with 16 mm diameter PE laterals served as four different irrigation (emitters) treatments. Each plot included 18 laterals 20 m long spaced 0.5 m. Each lateral had on-line emitters at 0.5 m apart along the lateral line. Inside each plot, the 18 laterals were used to apply the arrangement of 6 fertilizer treatments with three replicates.

The fertilizer rates of nitrogen and humic acid were 240 and 1.2 kg ha^{-1}, respectively, as recommended by the Egyptian Ministry of Agriculture and Land Reclamation (Pipars, 2009). No crops were grown in the field during the study, but the fertilizer and water requirements for garlic crop were applied throughout the estimated growing season.

The amounts of fertilizers were divided into three doses, which were injected during 2 h, i.e. during 50% of the irrigation time throughout the growing season. All the three doses were applied at three equal intervals. The injection rate was 0.18 m^3 h^{-1} with an irrigation flow rate of 0.32 m^3 h^{-1}. So, the nitrogen fertilizer concentrations in the irrigation water alone and mixed with humic acid were 0.22 and 0.11 kg m^{-3}, respectively.

2.3 Treatments

The main treatments included four irrigation treatments, i.e. two types of emitters with two discharge rates as follows:

Non-pressure compensating emitters (NEIN-ETF) (D_1): 2 L h^{-1} (D_1q_1) and 4 l.h^{-1} (D_1q_2).

(2) Pressure compensating emitters (NEIN-PC) (D_2): 2 L h^{-1} (D_2q_1) and 4 L h^{-1} (D_2q_2).

2.4 Sub- treatments

There were six treatments of fertilizer: (1) without fertilizer as control (F_0); (2) humic acid (H); (3) ammonium nitrate (N); (4) ammonium sulphate (S); (5) %50 humic acid + %50 ammonium nitrate (H+N); and (6) %50 humic acid + %50 ammonium sulphate (H+s).

2.5 Emission uniformity (EU)

Emitter flow rate was measured by collecting discharge of 18 emitters (six emitters at the beginning, six at the middle and six at the end of laterals) in catch cans during 15 min for each treatment. EU was determined as a function of the relation between average discharge emitted by the 25% of the emitters with lowest flow l.h^{-1}

(q_{lq}) and the mean flow emitted by all the control emitters l.h^{-1} (q_a). The emission uniformity coefficient (Eu %) was computed using Capra and Tamburino (1995) Equation 1:

$$Eu = \frac{q_{lq}}{q_a} \times 100 \tag{1}$$

2.6 Emitters clogging

Emitters from each lateral were chosen to be evaluated by calculating their clogging ratio at the beginning and at the end of the growing season. Clogging ratio was calculated according to El-Berry et al. (2003) using the following equations**:**

$$E = \frac{q_u}{q_n} \times 100 \tag{2}$$

$$CR = (1 - E) \times 100 \tag{3}$$

Where, E is the emitter discharge efficiency (%), q_u is the average emitter discharge at the end of the growing season (L h^{-1}), q_n is the average emitter discharge at the beginning of the growing season (L h^{-1}), and CR is the emitter clogging ratio (%).

2.7 Soil infiltration rate

Infiltration rate was measured using a constant head double ring infiltrometer with inner and outer ring diameters of 30 cm and 50 cm that was inserted to a depth of approximately 10 cm. The constant head was maintained with a Mariotte siphon and the volume of water required to maintain this head was measured on a one-minute interval. A detailed description of the infiltration apparatus is described by Gregory et al. (2005). The infiltration test was conducted for at least 2 h. However, infiltration rate was found to become constant typically within the first 10 min of the test.

The infiltration rate (instantaneous) I (mm min^{-1}) at any time was calculated as follows:

$$I = k \times t_o^{\,m-1} \tag{4}$$

Where, t_o is the opportunity time (min), K and m are empirical constants that depend on soil properties and its surface conditions (m <1).

Initial soil moisture content was measured before measuring the infiltration rate. The infiltration rate of the soil was measured using double ring method (Ankeny 1992; Reynolds et al. 2002) before irrigation for three locations along furrow with three repetitions for each location.

2.8 Statistical analysis

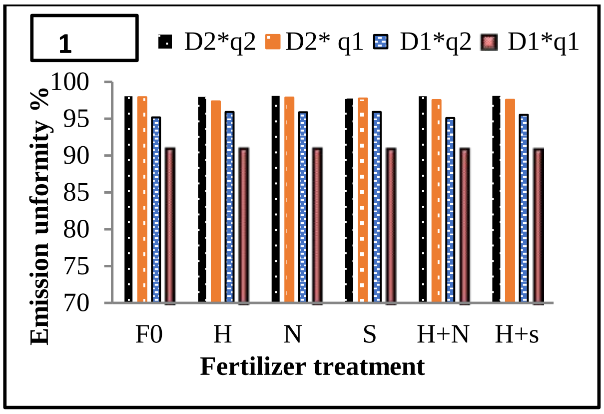
All data collected were statistically analyzed as a plot design with nine replications and means among treatments were compared using Least Significant Difference (LSD) at p<0.05 probability (Snedcor and Cochran, 1982).

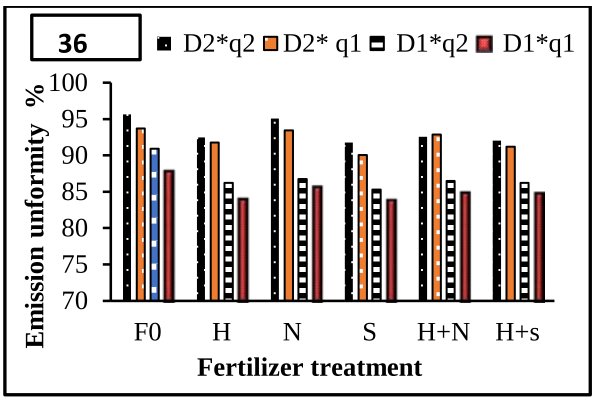
3 Results

3.1 Emission uniformity

3.1.1 Effect of emitter type on emission uniformity

Figure 1 shows that the emission uniformity (EU) determined at the beginning of the experiments were 90.94%, 95.16%, 97.91% and 98.05% for no fertilizer treatment (F_0) at D_1q_1, D_1q_2, D_2q_1 and D_2q_2, respectively. At the end of the season, EU were 84.62%, 90.14%, 92.90% and 94.67%, respectively, for the aforementioned treatments. So, EU for pressure compensating emitters (D_2q_1 and D_2q_2) was slightly reduced, while for non-pressure compensating emitters (D_1q_1 and D_1q_2), EU decreased significantly (p< 0.05) by the end of the season. Larger discharge emitters (4 L h^{-1}) show better EU than low discharge emitters (2 L h^{-1}).





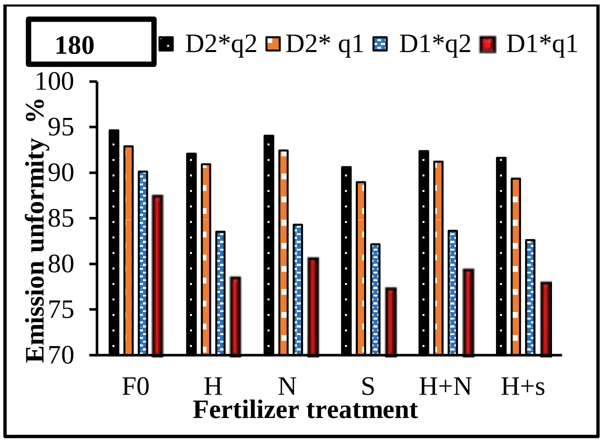


Figure 1 Emission uniformity (EU) % for non-pressure (D_1) and pressure (D_2) compensating emitters of 2 (q_1) and 4 L h^{-1} (q_2) discharge with different fertilizer treatments

3.1.2 Effect of fertigation components on EU

At the end of the experiment, EU averaged for all types of emitters were 92.55%, 89.96%, 91.23%, 89%, 90.29% and 89.54% for the fertilizer treatments of F_0, H, N, S, H+N, and H+s, respectively. It could be concluded that using humic fertilizer either separately or mixed with ammonium nitrate or sulfate reduced EU significantly ($p<$ 0.05) by about 3.55% compared with the no fertilizers treatment.

3.1.3 Interaction between fertilizers and emitter type on emission uniformity

The interaction effect of emitter type and fertilizers on EU showed significant differences. At the end of season, (after 180 days) the maximum values of average EU were 95.99% and 95.53% under D_2q_2 with the treatments of no fertilizer (F_0) and ammonium nitrate (N), respectively. Conversely, the minimum average values of EU were 84.58%, 84.92% and 85.31% for non-pressure compensating low discharge drippers (D_1q_1) with ammonium sulfate (S), humic + ammonium sulfate (H+s), and humic (H) fertilizer, respectively.

3.2 Clogging ratio of emitters

3.2.1 Effect of emitter type on clogging ratio

Data of clogging ratio of emitters are given in Figure 2 as affected by emitter type and discharge. Non-pressure compensating emitters (D_1) with 2 L h^{-1} discharge (q_1) increased significantly ($p<0.05$) the clogging ratio under all fertilizer treatments compared with the larger discharge (4 L h^{-1}) for the same emitter type (D_1q_2). Pressure compensating emitters (D_2) of both 2 and 4 L h^{-1} discharge resulted in less clogging ratio than non-pressure compensating emitters. In general, differences in clogging ratio among the emitters used were significant at 5% level.

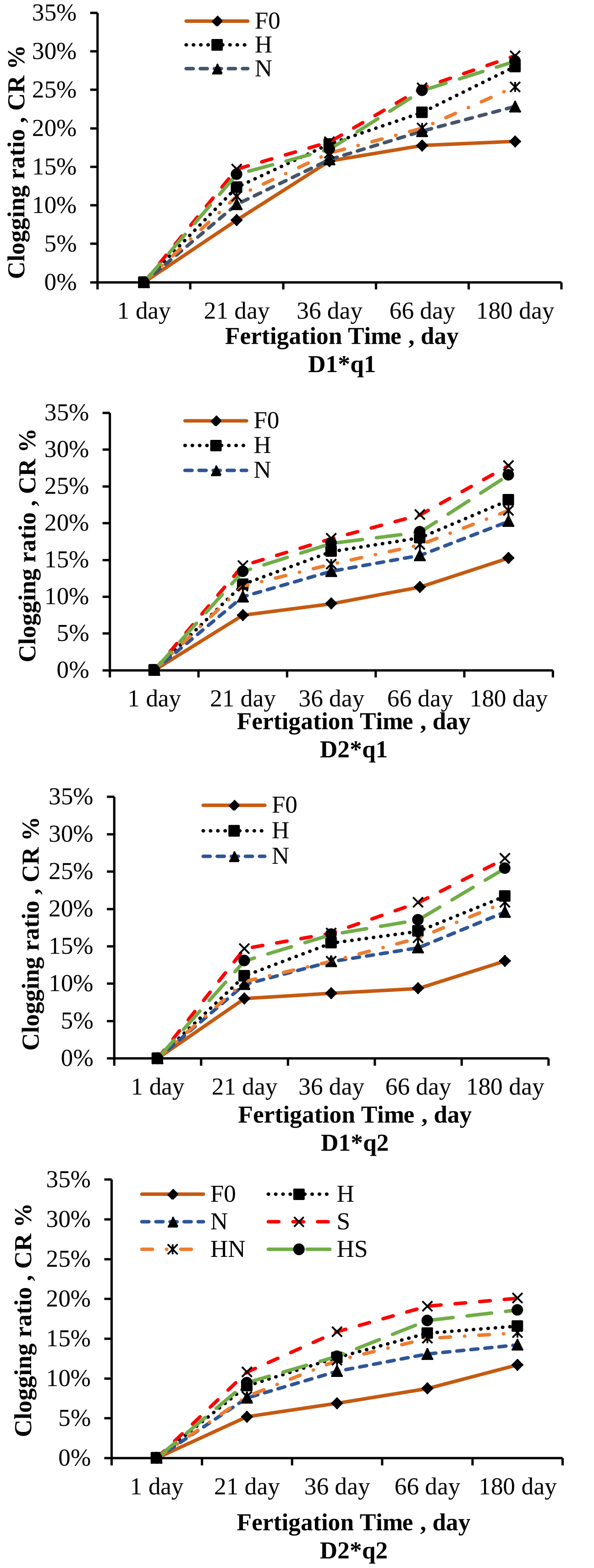


Figure 2 Effect of fertilizers components on clogging ratio (CR%) during the experiment

3.2.2 Effect of fertigation components on clogging ratio

Data of clogging ratio of emitters (Figure 2) show that the highest and lowest at clogging ratios were 21.91% and 7.93% with treatments of ammonium sulphate (S) and no fertilizer (F_0) under emitter treatments D_1q_1 and D_2q_2, respectively. Furthermore, emitters clogging significantly (p<0.05) increased due to application of humic acid and different nitrogen fertilizer sources applied with irrigation water. The highest values of average clogging ratios were 14.98%, 20.10%, 17.14%, 21.91%, 18.34% and 21.24% with F_0, H, N, S, H+N and H+S, respectively, for 2 L h^{-1} non-compensating emitter, while the least values were 7.93%, 13.49%, 11.44%, 16.46%, 12.70% and 14.52% with F_0, H, N, S, H+N and H+S, respectively, for 4 L h^{-1} pressure compensating emitter.

3.2.3 Effect of time on clogging ratio

Following up the changes of emitters clogging with time intervals up to 180 days as illustrated in Figure 2 indicates significant increase with time under all treatments. The clogging ratios with time intervals could be ranked as following: 180 days > 66 days > 36 days > 21 days > 1 days.

3.3 Interaction between emitters types and fertigation components on clogging ratio

The highest emitters clogging ratio was detected with 180 days as revealed by the treatment D_1q_1. The maximum average clogging ratio (25.45%) occurred at the end of the season with the 2 L h^{-1} non-pressure compensating emitter (D_1q_1) and the minimum average value (8.30%) was found with 4 L h^{-1} pressure compensating emitter (D_2q_2), respectively.

Differences in clogging ratio for both emitter types and discharges were significant at the 5% level. The fertilizers applied increased the clogging ratio at different degrees, but especially at the end of the season with the lowest discharge non-pressure compensating emitters (D_1q_1) compared with no fertilizer (F_0) and pressure-compensating emitters.

3.4 Effect of fertigation components on infiltration rates

Water infiltration rates (Tables 2 and 3) indicated significant variation with time process and combined additives of humic acid and nitrogen fertilizer treatment. There was no significant relationship between emitter types and discharges and infiltration rate on the testing soil for all treatments of fertilizer.

3.4.1 Effect of time on infiltration rates

Following up the changes in infiltration rate intervals time 0.167 up to 2 h as listed in Table 2 indicated significant (p<0.05) variation with time. In this respect, infiltration rate tended to decrease with time up to 120 mm of the end test. This holds true for all emitter types, emitter discharges and fertilization treatments. For example, with 2 L h^{-1} non-pressure compensating emitter, infiltration rate was 870 mm h^{-1} at 10 min, and then decreased with increasing time intervals up to 426 mm h^{-1} after 2 h.

3.4.2 Effect of fertilization on infiltration rates

The infiltration rates on the non-fertilization treatment (F_0) were generally high, with average rates varying from 870 to 426 mm h^{-1} (Tables 2 and 3). At the end of test the minimum measured infiltration rates were with humic acid and ammonium nitrate or ammonium sulphate mixed with humic acid. The average infiltration rates measured under the humic acid treatment were less than those for all emitter type and discharge treatments. The humic treatment at the end of the test showed a reduction in infiltration rate from 876 to 408 mm h^{-1}.

Table 2 Infiltration rates (mm h^{-1}) for 2 and 4 L h^{-1} non-pressure compensating emitters for the different fertilizer treatments

State	Discharge(Q)	Fertilizer treatment	Time (h)												Mean
			0.17	0.33	0.50	0.67	0.83	1.00	1.17	1.33	1.50	1.67	1.83	2.00	
Before starting the season	2 L h^{-1}	Control	864	546	528	510	504	462	438	432	426	426	426	426	498
		H	876	546	516	498	498	456	450	426	420	420	420	420	498
		N	870	594	546	510	492	450	444	432	426	426	426	426	504
		S	870	546	516	498	492	462	432	426	426	426	426	426	498
		H+N	876	576	564	552	504	474	456	450	438	432	432	432	516
		H+s	870	594	546	510	498	474	444	438	432	432	432	432	510

		Mean	870	570	534	516	498	462	444	432	426	426	426	426	-
		Control	870	546	528	510	504	456	444	438	432	426	426	426	498
		H	876	546	516	498	492	456	450	432	426	426	426	426	498
		N	870	546	510	498	492	456	438	432	426	426	426	426	498
	4 L h^{-1}	S	876	594	540	504	492	450	444	432	426	420	420	420	504
		H+N	870	546	546	516	498	456	444	438	432	432	432	432	504
		H+s	870	588	564	552	504	462	450	438	432	432	432	432	516
		Mean	870	564	534	516	498	456	444	438	432	426	426	426	-
After ending the season		Control	858	540	528	510	498	456	438	432	426	420	420	420	498
		H	816	486	480	456	438	426	420	414	408	408	408	408	462
		N	858	594	540	504	486	444	438	432	426	426	426	426	498
	2 L h^{-1}	S	852	546	510	498	492	450	438	432	426	426	426	426	492
		H+N	852	558	540	492	486	456	438	432	426	426	426	426	498
		H+s	846	546	510	498	492	450	444	432	426	426	426	426	492
		Mean	846	546	516	492	480	450	438	432	426	420	420	420	-
		Control	858	540	522	510	498	456	438	432	426	426	426	426	498
		H	780	480	456	450	438	432	426	426	420	420	420	420	462
		N	870	546	510	498	492	456	438	432	426	426	426	426	498
	4 L h^{-1}	S	870	594	540	504	492	450	438	426	426	420	420	420	498
		H+N	870	540	510	498	492	450	432	426	420	420	420	420	492
		H+s	870	588	540	504	486	450	438	426	420	420	420	420	498
		Mean	852	546	516	492	486	450	438	426	426	420	420	420	-

Table 3 Infiltration rates (mm h^{-1}) for 2 and 4 L h^{-1} pressure compensating emitters for the different fertilizer treatments

State	Discharge(Q)	Fertilizer treatment	Time (h)												Mean
			0.17	0.33	0.50	0.67	0.83	1.00	1.17	1.33	1.5	1.67	1.83	2.00	
Before starting the season	2 L h^{-1}	Control	864	546	528	510	504	456	438	432	426	420	420	420	498
		H	876	546	516	498	492	456	444	432	426	420	420	420	498
		N	870	594	540	504	492	450	444	426	420	420	420	420	498
		S	870	546	510	498	492	456	438	432	426	426	426	426	498
		H+N	870	588	552	498	492	456	444	438	432	432	432	432	504
		H+s	864	588	564	552	504	474	456	438	432	432	432	432	516
		Mean	870	570	534	510	498	456	444	432	426	426	426	426	-
	4 L h^{-1}	Control	870	546	528	510	504	456	438	432	426	426	426	426	498
		H	876	546	522	498	492	456	450	426	420	420	420	420	498
		N	870	594	546	504	492	450	444	432	426	426	426	426	504
		S	870	546	510	498	492	456	438	432	426	426	426	426	498
		H+N	870	546	546	504	498	462	444	438	432	432	432	432	504
		H+s	870	588	564	552	504	492	450	438	432	432	432	432	516
		Mean	870	564	534	510	498	462	444	432	426	426	426	426	-
After ending the season	2 L h^{-1}	Control	864	540	528	510	504	456	438	432	426	420	420	420	498
		H	810	510	504	492	480	450	432	426	420	420	420	420	480
		N	864	594	540	504	486	450	444	426	420	420	420	420	498
		S	870	540	510	498	492	450	432	426	426	426	426	426	492
		H+N	864	558	540	492	486	450	438	426	420	420	420	420	492
		H+s	852	546	540	498	486	450	444	432	426	420	420	420	492
		Mean	852	546	528	498	492	450	438	426	426	420	420	420	-
	4 L h^{-1}	Control	864	546	528	510	504	456	438	432	426	426	426	426	498
		H	780	492	486	456	450	438	432	426	420	420	420	420	468
		N	870	594	540	504	492	450	444	432	426	426	426	426	504
		S	870	546	510	492	492	456	438	432	426	426	426	426	492
		H+N	864	546	510	504	492	450	444	432	426	426	426	426	492
		H+s	864	588	540	492	486	444	438	426	420	420	420	420	498
		Mean	852	552	522	492	486	450	438	432	426	426	426	426	-

4 Discussion

The increase in emitters clogging ratio may be attributed to the precipitating effect of SO_4^{2-} in the applied ammonium sulfate fertilizer on both Ca^{2+} and Mg^{2+} found in irrigation water within the narrow opening of emitters after water evaporation as described by Li et al. (2016) and Abou-Khaled (1991). Also, iron reaction with humic organic is also important in emitters clogging with drip irrigation system. The complexes formed between iron and humates are more stable at high pH than at lower pH levels, because acids decrease pH and increasing availability of micro elements such as Fe, Mn, Zn and Cu. The results obtained agree well with those of Pipars (2009). On the other hand, the emitters with low discharge are more prone to clogging where more fertilizers could accumulate on the emitter opening (Mostafa, 2014; Airoldi, 2007).

Results show also that water infiltration into the sand is faster than to another soils because the infiltration rate depends on both soil texture and structure. Sand has a higher infiltration rate, and the addition of humic acid alone or mixed with ammonium sulphate or ammonium nitrate reduced the infiltration rate compared with ammonium sulphate or ammonium nitrate alone and control treatment (Eroglu, 2012). The addition of organic matter, such as humic substances, increases soil aggregation, water retention, infiltration rate, and water-holding capacity (Gregory et al., 2005). From a biological perspective, humic substances enhance soil fertility by impacting the composition of microbial populations (Calvo et al., 2014). Addition of humic substances has been shown to improve aggregation in soils with a range of texture grades and mineral suites (Quilty and Cattle, 2011).

5 Conclusions

In this study, EU significantly decreased due to the different nitrogen fertilizers applied to irrigation water up to an experiment carried out during 180 days. The maximum average EU were 95.99%, and 95.53 % respectively at $D_2q_2 \times F_0$, and $D_2q_2 \times N$. The minimum values of average EU % were 84.58%, 84.92% and 85.31% respectively at $D_1q_1 \times S$, $D_1q_1 \times H+S$ and $D_1q_1 \times H$, respectively.

Based on the results, emitters clogging ratio was lowest (8.30%) with 21 days and the highest (25.45%) was obtained at 180 days under treatment of $D_1 \times q_1$. The main effects of treatments used on clogging percent could be arranged in the following ascending order: $D_2q_2 < D_2q_1 < D_1q_2 < D_1q_1$.

Results indicated that there was no effect observed for emitter types or discharges on the soil infiltration rate under all fertilization treatments. Also, infiltration rate tended to decrease with increasing the time (i.e. the number of repeated irrigations) along the 180-day season. Humic acid treatment showed a clear reduction in infiltration rate from 876 to 408 mm h^{-1}.

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