Field evaluation of the performance of different irrigation emitter types using treated wastewater

Naji K. Al-Mefleh, Ibrahim Bashabsheh, Samer Talozi and Taha A. Al-Issa

ABSTRACT

Experimental tests are carried out to evaluate the impact of treated wastewater (TWW) on the discharge of five different types of emitters which are commonly used. Two water qualities, fresh water (FW) and treated wastewater, and five types of emitters, GR, Nein (NE), Edin (ED), Corona (CO), and Rain Bird (RB) are tested. The values of chemical properties for FW show mostly low clogging potential on emitter performance. The clogging potential for TWW varied from low to medium. The exception was for pH where there was severe clogging potential for both water types. The performance of emitters was tested by measuring the emitter discharge and estimating the average emitter discharge (Q_{avg}), coefficient of variation (CV), emission uniformity coefficient (EU), and Christiansen uniformity coefficient (CU). The average discharges for different types of emitters were analyzed and compared at $P \leq 0.05$. The CO and RB emitter types did not show any signs of clogging whereas the GR, NE, and ED emitter types showed signs of clogging. The results of CV, EU, and CU values showed that the performances of emitter types GR, NE, ED were classified as low or moderate clogging potential. In contrast, the CO and RB emitters were classified as moderate or high clogging potential.

Key words | drip irrigation, emitter clogging, emitter types, treated wastewater, water quality

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ABBREVIATIONS

CO	Corona emitter
CU	Christiansen uniformity coefficient
CV	coefficient of variation
ED	Edin emitter
EU	emission uniformity coefficient
FW	fresh water
GR	GR emitter
NE	Nein emitter
Q_{avg}	average discharge
RB	Rain Bird emitter
TWW	treated wastewater

INTRODUCTION

In many parts of the world, agriculture is still considered the main user of water and it is becoming more challenging to meet the water demand in agriculture especially with fresh water (FW). For reducing the demand on FW in agriculture, treated wastewater (TWW) is used as another source of irrigation. TWW is suitable to be used in drip irrigation more than other methods of irrigation because it minimizes the health risks for farmers and product consumers (Capra & Scicolone 2004). Drip irrigation with TWW may offer an efficient way to deal with water shortages for agricultural crops (Capra & Scicolone 2006). It has the advantage of high water content in the root zone but its performance depends on water quality because it may cause emitter clogging (Bouya *et al.* 2007). Emitter clogging is a serious problem in drip irrigation where different types of emitters are available in the market. The factory performance characteristics of these emitters are usually evaluated using clean water. Clogging reduces emission

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uniformity (EU) which, in turn, affects drip irrigation efficiency. The field distribution uniformity depends on manufacturing variation, pressure, temperature, clogging, and material fatigue (Ozekici & Sneed 1995; Capra & Scicolone 2004, 2006). Uniformity decreases as the length of lateral increases (Mansour *et al.* 2010). It is necessary to choose the emitters that show an acceptable performance, particularly under reclaimed water (Ravina *et al.* 1997). Emitter clogging decreases the water distribution efficiency, which leads to a reduction in water use efficiency and crop production. Clogging of emitters is the most difficult problem encountered in the operation of drip irrigation systems. It is not easy to detect, clean, or replace clogged emitters. Emitters can be clogged by particles in the water supply, precipitates, or bacterial slimes resulting from dissolved calcium or other salts in the water supply (Keller & Bliesner 1990). The availability of biological clogging agents (algae and protozoa) in irrigation water will increase the percentage of clogging emitters, leading to the reduction of the average discharge as well (Dehghanisanij *et al.* 2004). This reduction depends on emitter characteristics and water operating pressure. It has been indicated that antagonistic microorganisims can be utilized for the treatment of clogging in drip irrigation systems (Sahin *et al.* 2005). The flow rate of $CaCO_3$-clogged emitters increased in drip lines that were treated with bacterial suspensions (Eroglu *et al.* 2012). Using the reclaimed wastewater treated by biological aerated filter for drip irrigation system is more suitable than wastewater treated with fluidized-bed reactor (Li *et al.* 2012).

For the same kind of emitters, when the total suspended solids and organic matter content increases, the percentage of totally clogged emitters is expected to increase; however, the mean emitted discharge, the EU coefficient, and the operating time of the filters between cleaning operations are expected to decrease (Capra & Scicolone 2004, 2006). The emitter performance characteristics are affected by water quality, emitter type, and time of operation (Lui & Huang 2009). However, it was found that the coefficient of variation (CV) and percentage of clogging for the TWW were greater than those values for fresh water. Also, the values of EU and coefficient uniformity (CU) for TWW treatments were lower than those for the fresh water. The authors also indicated that chemical precipitation was the main reason for emitter clogging due to high pH and ion concentration in TWW. Furthermore, they indicated that the online emitters showed better anti-clogging than the inline emitters for irrigation with TWW.

The causes of clogging vary from one location to another (Nakayama & Bucks 1991). Therefore, the performance of emitters needs to be evaluated under field conditions where wastewater is used.

Many studies (Capra & Scicolone 2006; Bouya *et al.* 2007; Lui & Huang 2009) have examined the impact of TWW on the performance of emitters under TWW. However, no research has been conducted on the impact of TWW on the performance of the emitters currently used by farmers. The irrigation water around the study area comes from Al-Ramtha water treatment plant (Jordan), and was not mixed with any other water resources. The main objective of this study is to evaluate the impact of TWW on the discharge of different types of emitters.

MATERIALS AND METHODS

Experimental site

Field experiments were conducted near a water treatment plant located 7 km north of Ramtha (32 ° 35′ north latitude and 35 ° 59′ east longitude) and an elevation of 490 m above sea level. The experiments were conducted during the summer and spring seasons of 2008 and 2009. The inlet of Ramtha wastewater treatment plant was 100% domestic wastewater and it was a secondary mechanical treatment process that employed the activated sludge-extended aeration method of treatment.

Water resources and qualities

FW and TWW were used to test the performance characteristics of different emitters. FW came from local municipal tube wells, usually used for drinking purposes. The main parameters of water qualities tested were the pH, SAR, EC, TSS, Ca, Mg, TDS, Na, K, Fe, Cl, Mn, CO_3, HCO_3,

Table 1 | Chemical and biological analysis of FW and the TWW

		Fresh water		Treated wastewater	
Parameter	**Units**	**# of readings**	**Mean[a,b]**	**# of readings**	**Mean[a,b]**
pH		7	8.19 (0.38) (severe)	5	8.02 (0.28) (severe)
EC[c]	dS/m	7	1.20 (0.17)	5	2.72 (0.34)
SAR[d]		6	2.68 (0.38)	5	10.78 (3.56)
TSS[e]	ppm	5	6.4 (9.2) (low)	5	51.8 (15.0) (low)
TDS[f]	ppm	7	933.85 (91.00) (medium)	6	1554 (181) (medium)
Fe	ppm	3	0.11 (0.01) (medium)	3	0.2 (0.08) (severe)
Mn	ppm	3	0.01 (0.006) (low)	3	0.04 (0.01) (low)
Ca	ppm	7	70.17 (9.09)	5	68.32 (8.04)
Mg	ppm	7	44.09 (9.90)	5	39.91 (3.59)
Na	ppm	7	133.76 (50.27)	5	455.77 (152.08)
K	ppm	7	14.04 (9.48)	5	48.28 (7.12)
Cl	ppm	6	211.44 (34.89)	5	652.75 (182.66)
CO_3	ppm	4	5.63 (2.25)	4	4.88 (3.09)
HCO_3	ppm	4	76.25 (13.87)	4	117.43 (13.29)
SO_4	ppm	4	212.04 (127.40)	4	326.64 (238.12)
NO_3	ppm	7	21.57 (16.25)	5	13.60 (8.07)
B	ppm	5	0.05 (0.05)	4	0.125 (0.08)
P	ppm	7	0 (0.00)	5	0.11 (0.17)
BOD_5	ppm	4	12.0 (13.11)	4	41.05 (25.93)
COD	ppm	4	28.25 (27.73)	4	62.75 (64.59)
FC (*E. coli*)	MPN/100 ml	2	2 (0.00)	2	20.00 (0.00)

[a] Standard deviation.
[b] Clogging potential (Bucks *et al.* 1979; Nakayama & Bucks 1991).
[c] Electrical conductivity.
[d] Sodium adsorption ratios.
[e] Total suspended solids.
[f] Total dissolved solids.

SO_4, NO_3, B, P, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and FC (*Escherichia coli*). The chemical and biological parameters for FW and TTW are presented in Table 1.

The FW was passed through the screen filter then the disk filter. The TWW was passed through the sand filter followed by screen and disk filters. The sand filter consisted of a layer of gravel with a diameter of 8 to 16 mm and another layer with a diameter of 1 to 8 mm. The screen filter consisted of a diameter of 1.6 mm and the disk filter had 250 mesh/in^2. The cleaning was based on the losses of pressure between the inlet and outlet for each filter.

Emitters

Five types of emitters were tested using FW and TWW. These types were the GR, Nein (NE), Edin (ED), Corona (CO), and Rain Bird (RB). These emitters were commonly used by farmers in Jordan, and were manufactured by different factories. The specifications of these emitters are summarized in Table 2.

Experimental layout

The experiment layout consisted of three replicates (blocks). In each block, the five different emitters and

Table 2 | Specifications of manufacturing emitters

Emitter type	Specifications
GR emitters	In-line emitters, pressure compensated 4 L/h, 150 kPa, self-flushing, area cross-section
Nein emitters (NE)	On-line emitter, pressure compensated 4 L/h, 150 kPa, un-self-flushing, area cross-section
Eden emitters (ED)	On-line emitter, pressure compensated 3.8 L/h, 150–400 kPa bar, self-flushing, area cross-section
Corona emitters (CO)	On-line emitter, pressure compensated 4.0 L/h, 150 kPa bar, self-flushing, area cross-section
Rain Bird emitters (RB)	On-line emitter, pressure compensated 3.8 L/h, 150 kPa bar, self-flushing, area cross-section

the two water types were tested. Emitters were installed 50 cm apart on a 10-m long lateral (a total of 20 emitters for each lateral and 60 emitters of each emitter type were divided into three blocks). Thus, each block contained 10 laterals. Consequently, each lateral tested one type of emitter with one type of water. The lateral lines were raised using rigid iron rods at a height of 20 cm above soil surface. Under each emitter, water pots with a capacity of 2 l were located to collect the discharge of emitters.

The irrigation system consisted of two tanks (each with a capacity of 2 m^3), a pump, valves, filters, pressure gauges, a flow meter, lateral pipes (20 mm diameter) as shown in the schematic diagram of the experiment in Figure 1.

Estimating initial emitter's characteristics

Using FW only, emitter discharge values were measured in the field at two operating pressures (100 and 200 kPa) for new emitters as a first trial under field conditions. Measurements were used to estimate the initial values ($_i$) of coefficient of variation (CV_i), the discharge exponent (X_i), and the discharge coefficient (Kd_i). An operating pressure of 138 kPa was used for conducting the rest of the experiments, which included the two water types and five emitter types.

For the new emitters, the discharge exponent (X_i) was estimated using Equation (1), and the discharge coefficient (Kd_i) was estimated using Equation (2)

$$X_i = \frac{\log\left(\frac{Q_{\mathrm{avg1}}}{Q_{\mathrm{avg2}}}\right)}{\log\left(\frac{H_{\mathrm{avg1}}}{H_{\mathrm{avg2}}}\right)} \tag{1}$$

where $Q_{avg\mathit{1}}$ is the average discharge at operating pressure (H_{avg1}) of 200kPa, $Q_{avg\mathit{2}}$ is the average discharge at operating pressure (H_{avg2}) of 100 kPa

$$K_{d_i} = \left(\frac{Q_{\mathrm{avg}}}{H_{\mathrm{avg}}^{0.5}}\right) \tag{2}$$

The main parameters used to evaluate an emitter's performance are the mean discharge of the emitters (Q_{avg}) in each lateral, the CV, the EU coefficient, and Christiansen uniformity coefficient (CU). Average

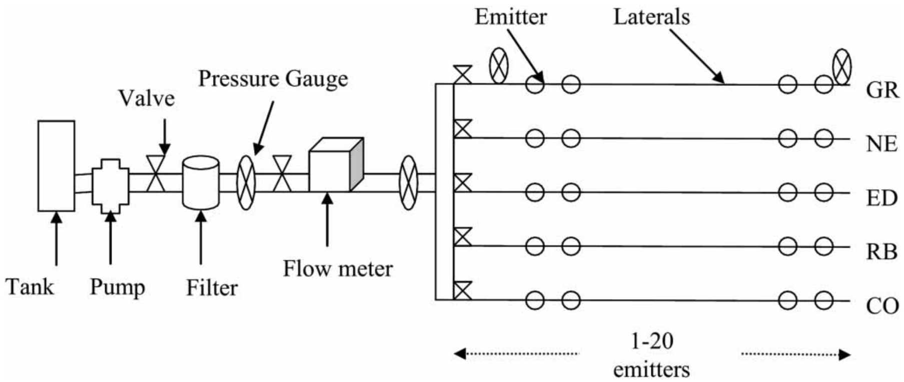

Figure 1 | Schematic diagram of the irrigation system for testing different emitters (GR, NE, ED, CO, and RB).

Table 3 | Initial testing characteristics of emitters with fresh water during the first trial

Emitter types	Coefficient of variation (CV_i%)	Discharge exponent (X_i)	Discharge coefficient (Kd_i)	Manufacturer discharge (L/h)	Initial mean discharge (L/h)
GR	0.21	0.14	2.85	4.0	4.4
NE	0.23	0.47	0.81	4.0	3.5
ED	0.09	0.03	3.32	3.8	3.6
CO	0.05	0.16	2.06	4.0	3.8
RB	0.19	0.02	4.02	3.8	4.3

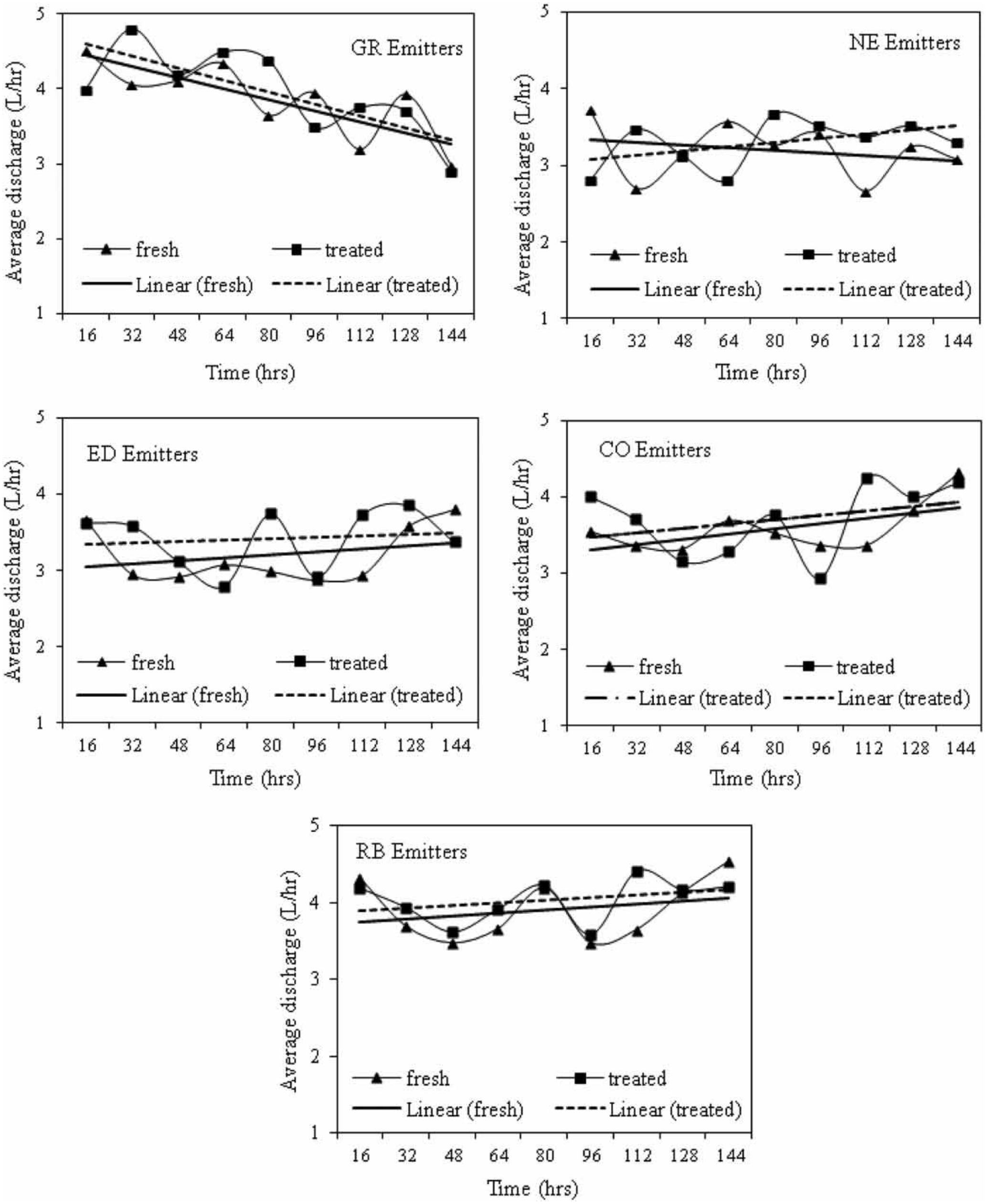

Figure 2 | The average discharge (L/h) for five emitter types under FW and TWW.

discharge was estimated by dividing the summation of individual discharge in each lateral line on the number of emitters. The CV was calculated by dividing the standard deviation for the emitters in each lateral line on the average discharge of emitters. The EU was estimated by dividing the mean discharge of the lower quarter in each lateral line on the average discharge as well.

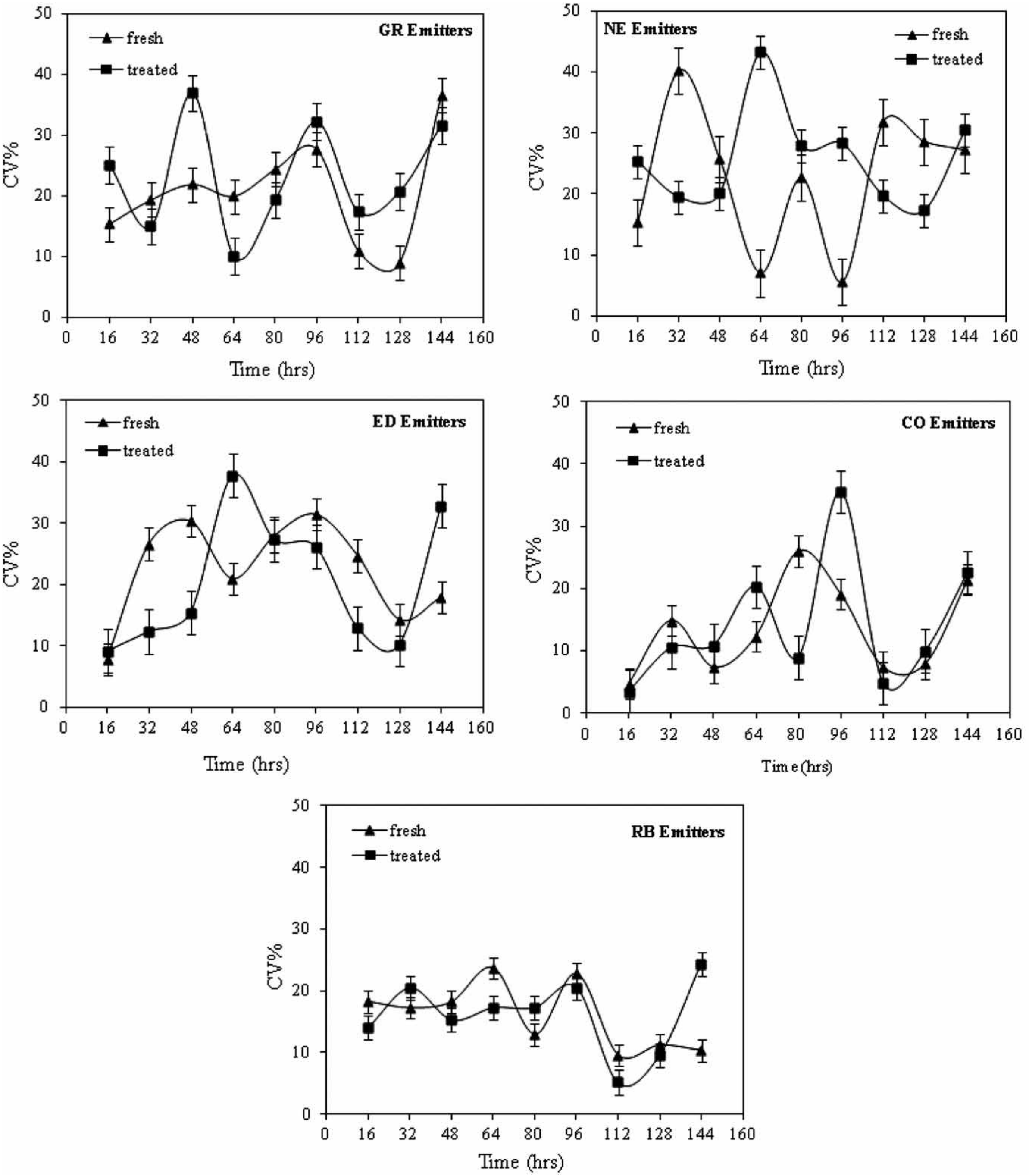

Figure 3 | The coefficient of variation (CV%) for five emitter types under FW and TWW.

The CU was calculated using Equation (3)

$$CU = \left(1 - \frac{\sum_{i=1}^{n} |q_i - Q_{avg}|}{nQ_{avg}}\right) \times 100 \tag{3}$$

where q_i is the individual emitter discharge in liters (l), Q_{avg} is the average discharge of observations, n is number of observations.

Field measurements

From each lateral, 10 out of 20 emitters were tested. Every other emitter on the lateral was selected. Emitter discharge of 10 minutes was collected using a graduated cylinder and converted to liters per hour. Every week, the system was run for 2 hours every other day with 1 day off per week. After 16 hours of operation time, a set of emitter discharge readings was measured. In total, nine sets of readings were recorded. The head loss along the lateral was maintained within 10% of the inlet head pressure. Laterals were flushed every 2 weeks for 5 minutes each time; after conducting the testing, the collected data were subjected to analysis of variance (ANOVA) using SAS software (SAS 2002). Means were separated using Fisher's least significant difference at 0.05 probability level.

RESULTS AND DISCUSSION

Water quality

The chemical and biological water quality parameters for fresh (FW) and TWW are presented in Table 1. According to their classification, the present study found that pH value for FW (8.19) was higher than that for TWW (8.02), while both of them had severe potential on the emitter clogging. The values of TDS for FW and TWW have medium clogging potential on emitter performance and the values of Fe in FW have low clogging potential compared with Fe values in TWW. Based on these values, the clogging potentials of the emitters were varied between low and moderate. The values of Mn in FW and TWW have a little clogging potential on emitter performance.

The impact of pH on clogging potential was classified as <7.0 (slight), 7–8 (medium), and >8.0 (severe) (Nakayama & Bucks 1991). The potential of biological oxygen demands (BOD_5) on emitter clogging were classified as <15 ppm (low), 15–40 ppm (medium), and >40 ppm (severe) (Capra & Scicolone 2004). In this study, the potential value of the concentration of BOD_5 for FW on emitter clogging is 12.0 ppm (low) and for TWW is 41.1 ppm (severe). Increasing the suspended solids and organic matter (which are related to BOD_5) would lead to an increase in the percentage of clogged emitters and a decrease in the emitter discharge and EU (Capra & Scicolone 2004). Also, the salt concentration in the water did not cause emitter clogging because the EC values of the FW (1.2 dS/m) and TWW (2.27 dS/m) are low.

Initial characteristics of new emitters

The characteristics of variation coefficient (CV_i), discharge exponent (X_i), and discharge coefficient (Kd_i) for new emitters were estimated and are presented in Table 3.

Table 4 | Classification of test results for the different emitter types under FW and TWW according to the CV classification (Bralts 1986)

	Well: CV = 0–10%		**Moderate: CV = 11–29%**		**Poor: CV > 30%**	
Emitter type	**FW**	**TWW**	**FW**	**TWW**	**FW**	**TWW**
GR	1	1	7	5	1	3
NE	2	0	5	7	2	2
ED	1	2	6	5	2	2
CO	4	5	5	3	0	1
RB	2	2	7	7	0	1

Table 5 | Classification of test results for the different emitter types under FW and TWW according to the CV classification (ASAE EP405.1. 2003)

	Well: CV < 10%		**Moderate: CV = 10–20%**		**Poor: CV > 20%**	
Emitter type	**FW**	**TWW**	**FW**	**TWW**	**FW**	**TWW**
GR	1	1	4	3	4	5
NE	2	0	1	4	6	5
ED	1	2	2	3	6	4
CO	4	4	3	3	2	2
RB	2	2	5	6	2	1

The CV values were classified as <5% (excellent) 5–7% (average) 7–11% (marginal), 11–15% (poor), and >15% (unacceptable) (Ozekici & Sneed 1995). The study found that the CV_i values for GR, NE, and RB were 21, 23, and 19%, respectively. The CV_i values for ED and CO were 9 and 5%, respectively. According to another study (Bralts 1986), the GR, NE, and RB emitters were classified as having a good performance, while the ED and CO have a moderate performance. The X_i value characterized the flow regime and operating pressure and this varies from 0 to 1. When X_i is less than 0.5 for tested emitters, less discharge will be affected by pressure variation and the emitters are characterized as compensated emitters. When X_i is greater than 0.5, the discharge is affected by pressure

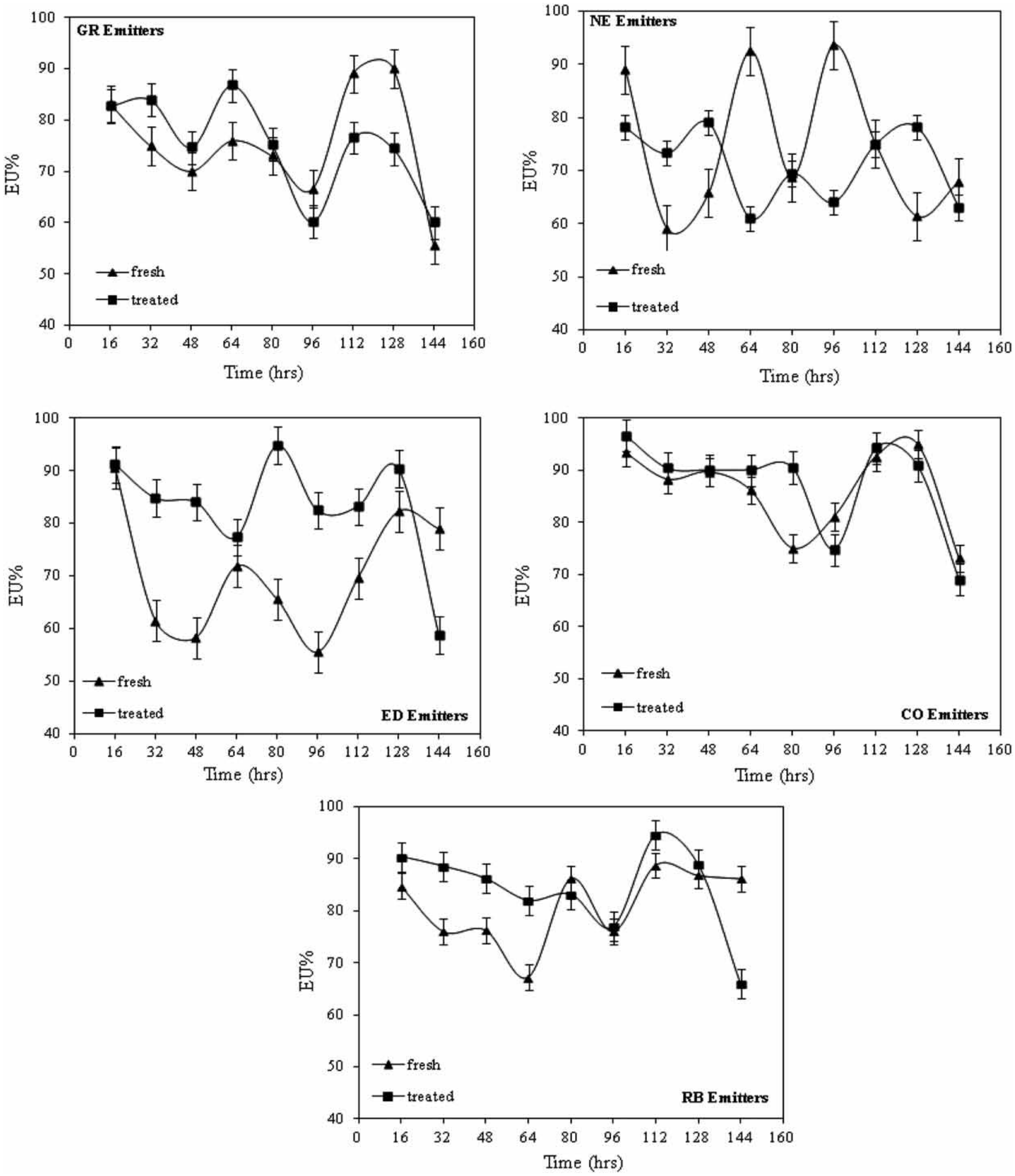

Figure 4 | The emission uniformity (EU) for five emitter types under FW and TWW.

variation and the emitters are characterized as uncompensated emitters. Where $X_i = 0$ is for fully compensated emitters. The X_i values for ED and RB emitters are less sensitive to pressure variation since their X_i values are closer to zero while the sensitivity to pressure variation for GR, CO, and NE emitters increased from zero, respectively.

Average discharge

The average discharge over time for the five emitters types with both the FW and TWW are presented in Figure 2. The main effect of water quality on the emitter discharge was not significant ($P = 0.05$). The main effect of interaction for the water quality, time of operation, and emitter type on average discharge was significant at the level of 0.05 probabilities. Generally, the average discharge varies with emitter discharge, water quality, and operational times (Lui and Huang 2009).

For FW and TWW, the trend line between the average discharge and times of operation (hours) for GR emitters decreases with an operational time of 144 hours. For the FW and TWW, the average discharge of GR emitters varied from 4.06 to 2.97 L/h and from 4.80 to 2.90 L/h, respectively. The average discharge of GR emitters at FW and TWW water type was higher than the manufacturing discharge (4 L/h) from the beginning of operational time until 64 to 80 hours. Then, it started to drop down below 4 L/h until it reached around 2.90 L/h at the end of the operational time of 144 hours.

For the NE and ED emitter types, the average discharge was below the manufacturing discharge (4 L/h). The average discharge of NE emitters varied from 3.73 to 2.66 L/h and 3.67 to 2.81 L/h for FW and TWW, respectively. The average discharge of ED emitters varied from 3.80 to 2.88 L/h and from 3.85 to 2.79 L/h for FW and TWW, respectively. The maximum average discharge of CO emitters was 4.31 L/h and the minimum was 3.31 L/h for the FW. For the TWW, the maximum average discharge of CO emitters was 4.25 L/h and the minimum was 2.94 L/h. The values of average discharge for the CO emitter type were below the manufacturing discharge (4 L/h) up to 96 hours of operational times, then increased to reach about 4.25 L/h at the end of the operation time for both the FW and TWW. For CO emitters, the average discharge for four out of nine times tests (with operational time of 16 hours) for FW was higher than the corresponding time tests for TWW.

The average discharge of RB emitters varied from 4.55 to 3.47 L/h and from 4.41 to 3.59 L/h for FW and TWW, respectively. The overall mean discharge of the RB emitters was around 4 L/h. It was found that average discharge at RB was closer to the manufacturing discharge, followed by the CO under both FW and TWW. The general trend line of emitter discharge for both water qualities (FW and TWW) decreased with increasing the operational time. For NE emitters for TWW, the trend line shows an increase as the operational time increased, but for FW, the trend line decreases as the operational time increases. For ED, CO, and RB emitters under both water qualities, the trend line increased slightly as the operational time increased. The CO and RB emitter types did not show any sign of clogging while the GR, NE, and ED emitter types showed signs of clogging. It was noticed that the NE and ED emitter types needed continuous cleaning for both FW and TWW during operation. It was evident with increasing operational time that the average emitter discharge decreases and the number of clogged emitters increases.

Coefficient of variation

Figure 3 shows the CV of the emitter discharges for the different emitter types. The CV values of emitters under FW varied from 9 to 37% (GR), 6 to 40% (NE), 8 to 31% (ED), 5 to 26% (CO), and 10 to 24% (RB). The CV values for the GR, NE, and ED were high and for the CO and RB were low. For the TWW, the CVs varied from 10 to 37% (GR), 17 to 43% (NE), 9 to 38% (ED), 3 to 35% (CO), and 5 to 24% (RB).

Table 6 | Classification of test results for the different emitter types under FW and TWW according to the EU classification (Keller & Bliesner 1990)

	Low: EU < 60%		**Moderate: EU = 60–75%**		**High: EU > 75%**	
Emitter type	**FW**	**TWW**	**FW**	**TWW**	**FW**	**TWW**
GR	1	2	4	3	4	4
NE	0	0	5	6	3	3
ED	2	1	4	0	3	8
CO	0	0	2	1	7	7
RB	0	0	1	1	8	8

In general, the CV values for each emitter of CO and RB for FW treatments were close to those values for TWW during an interval of 16 hour tests. The numbers of the time tests for CV values for TWW were lower than those for FW with an exceptional situation for the ED emitter. The CV values were classified as 0–10%, 11–29%, and greater than 30% to have good, moderate, and poor performance of emitters, respectively (Bralts 1986). According to this classification of CVs, the values of CVs for the emitter types GR, NE, and ED were classified as having a poor performance while the values of CVs for CO and

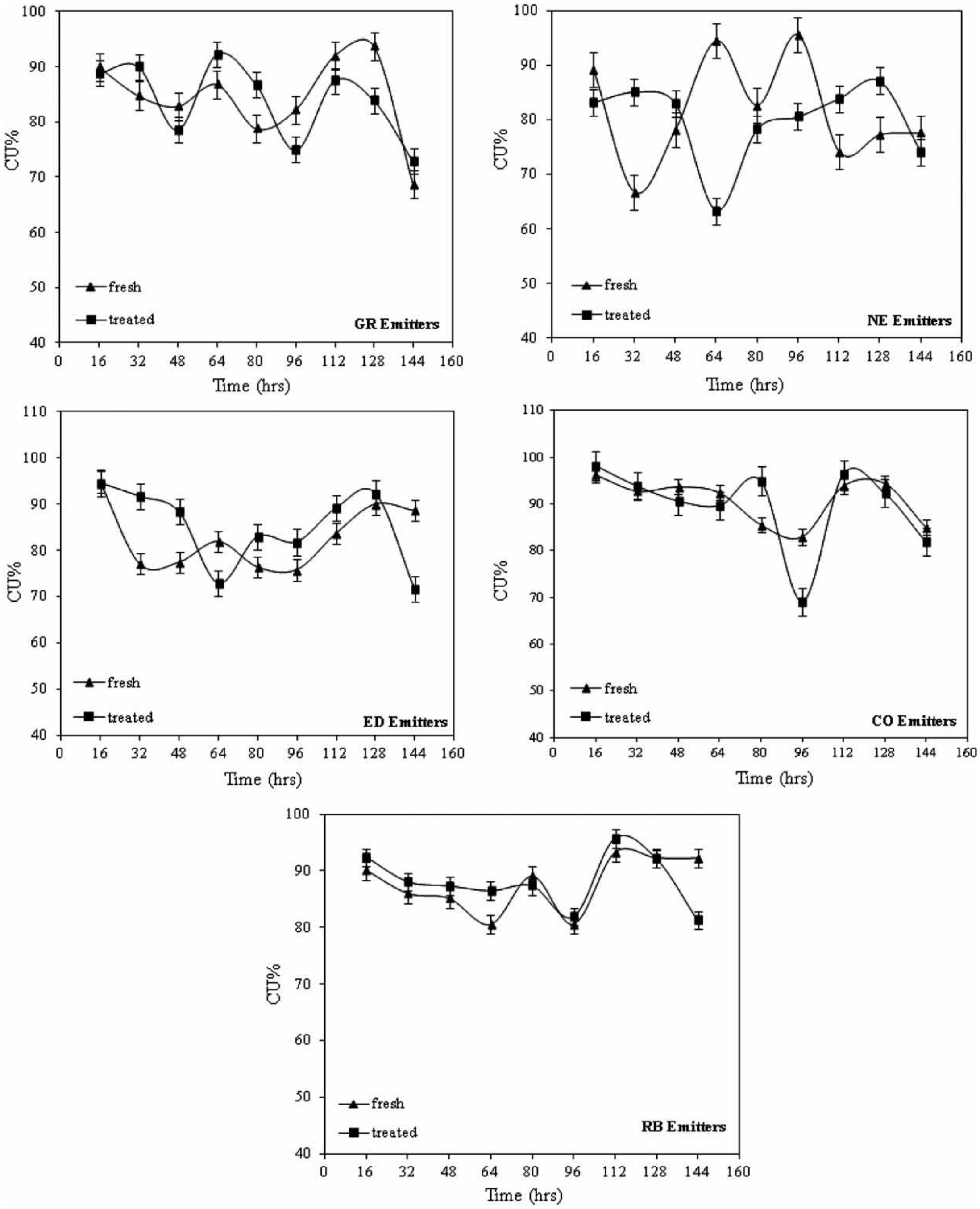

Figure 5 | The coefficient uniformity (CU) for five emitter types under FW and TWW.

RB emitters fall in the category of well or moderate class. Another classification (ASAE EP405.1. 2003) for CV values for a line source considered that <10% is good, 10–20% is moderate, and >20% is poor. Most of the tests for the CV values for GR, NE, and ED fall in the category of moderate or poor class. While CO and RB emitters were classified as good or moderate performance. Results of CV values for this study were compared to other classifications (Bralts 1986; ASAE EP405.1. 2003) (Tables 4 and 5). By comparing the CV values for each type of emitter, the number of tests for FW and TWW are closer to each other. The majority of the tests fall into the medium classification.

EU coefficient

The estimated EUs for the five emitter types under FW and TWW are shown in Figure 4. EU of emitters for FW varied from 90 to 55%, 92–58%, 90–58%, 95–73%, and 88–65% for GR, NE, ED, CO, and RB, respectively. For, TWW, EU values varied from 88 to 62%, 80–62%, 95–62%, 97–70%, 96–68%, for GR, NE, ED, CO, and RB, respectively. EU less than 60% is considered relatively low and a value that exceeds 75% value is recommended (Keller & Bliesner 1990). Another study (ASAE EP405.1. 2003) indicated that EU between 80 and 90% for a line source is recommended.

It was found that the EU for the GR, NE, and ED varied from low to moderate while the EU values for CO and RB varied from moderate to high. These results indicate that the last two emitter types are more recommended for use with TWW. Most of the tests for the EU values for GR, NE, and ED fall in the category of moderate and high (Table 6), whereas most of the tests for CO and RB fall in the category of high performance. This study found that the EU performances for CO and RB emitters were high, and are recommended more than GR, NE, and ED emitters. The number of time tests for EU values under TWW was higher than those under FW for GR, ED, CO, and RB emitters with an exceptional case for the NE.

Coefficient uniformity

The estimated CU values for the five emitter types for FW and TWW are shown in Figure 5. For FW, CU values of emitters varied from 94 to 68%, 96–67%, 95–77%, 96–85%, and 93–81% for GR, NE, ED, CO, and RB, respectively. They varied under TWW from 92 to 73%, 87–63%, 95–72%, 95–70%, and 95–80% for GR, NE, ED, COR, and RB, respectively. If the CU is less than 75%, the CU is considered relatively low while a value greater than 84% is recommended (Keller & Bliesner 1990). This study found that the CU values for the GR, NE, and ED varied from a moderate-to-high performance uniformity (Table 7). These CU values for emitters (GR, NE, and ED) are acceptable since the numbers of time tests out of nine time tests were greater than 75%. The CU values for CO varied from moderate to high and the CU values for RB mostly fall in the category of a high uniformity of performance. These results indicated that the CO and RB emitter types are more recommended than other emitters. The numbers of time tests for CU values for TWW were higher than those at FW for ED and RB emitters with the exception of the GR NE, and CO emitters.

CONCLUSIONS

The results showed that the effect of water type on the emitter discharge of each emitter type was not significant. The operational time and emitter type have a significant effect on the emitter discharge. The values of pH for FW and TWW were greater than 8; they have severed clogging potential on emitter discharge. The values of TSS, Fe, and Mn for FW have a little clogging potential. The values of TSS, TDS, and Fe for TWW have a medium clogging potential on emitter performance.

Table 7 | Classification of test results for the different emitter types under FW and TWW according to the EU classification (Keller & Bliesner 1990)

	Low: CU < 75%		Moderate: CU = 75–84%		High: CU > 84%	
Emitter type	**FW**	**TWW**	**FW**	**TWW**	**FW**	**TWW**
GR	1	1	2	3	6	5
NE	2	2	4	5	3	2
ED	0	2	5	2	3	5
CO	0	1	5	2	3	5
RB	0	0	2	2	7	7

Average discharge for each emitter type has not always declined from the beginning to the end of the operational time. The NE and ED emitters registered an average discharge below the manufacturing discharge while the average discharges of CO and RB emitters were closer to the manufacturing discharge. Most of the CV values for the average discharge of emitters for GR, NE, and ED emitters were higher than the values for CO and RB emitters; whereas most of the values of EU and CU for GR, NE, and ED emitters were lower than those for CO and RB emitters. Flushing the drip irrigation system is recommended during operational time to reduce the clogging of emitters. Overall, the classification of the GR, NE, and ED emitters can be described as having a moderate-to-low performance, respectively, and for the CO and RB emitters as having a moderate-to-high performance.

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REFERENCES

ASAE EP405.1. 2003 *Design and Installation of Microirrigation Systems: Standards*. Society for Engineering in Agricultural, Food, and Biological Systems, St Joseph, MI, USA.

Bouya, A. O., Yamamoto, T., Fujiyama, H. & Miyamoto, K. 2007 Assessment of emitter discharge in microirrigation system as affected by polluted water. *Irrig. Drain. Syst.* **21**, 97–107.

Bralts, F. V. 1986 Field performance and evaluation. In: *Trickle Irrigation for Crop Production: Design, Operation and Management* (F. S. Nakayama & D. A. Bucks, eds). Elsevier, Amsterdam, The Netherlands, pp. 216–240.

Buck, D. A., Nakayama, F. S. & Gilbert, R. G. 1979 Trickle irrigation water quality and preventative maintenance. *Agri. Water Manage.* **2**, 149–162.

Capra, A. & Scicolone, B. 2004 Emitter and filter tests for wastewater reuse by drip irrigation. *Agri. Water Manage.* **68**, 135–149.

Capra, A. & Scicolone, B. 2006 Recycling of poor quality urban wastewater by drip irrigation systems. *J. Clean. Product.* **15** (16), 1529–1534.

Dehghanisanij, H., Yamamoto, T., Rasiah, V., Utsunomiya, J. & Inoue, M. 2004 Impact of biological clogging agents on filter and emitter discharge characteristics of microirrigation system. *Irrig. Drain.* **53**, 363–373.

Eroglu, S., Sahin, U., Tunc, T. & Sahin, F. 2012 Bacterial application increased the flow rate of $CaCO_3$-clogged emitters of drip irrigation system. *J. Environ. Manage.* **98**, 37–42.

Keller, J. & Bliesner, R. D. 1990 *Sprinkle and Trickle Irrigation*. John Wiley and Sons, Inc., New York, USA.

Li, Y. K., Lui, Y. Z., Li, G. B., Xu, T. W., Lui, H. S., Ren, S. M., Yan, D. Z. & Yang, P. L. 2012 Surface topographic characteristics of suspended particulates in reclaimed wastewater and effects on logging in labyrinth drip irrigation emitters. *Irrig. Sci.* **30**, 43–56.

Lui, H. J. & Huang, G. H. 2009 Laboratory experiment on drip emitter clogging with fresh water and treated sewage effluent. *Agri. Water Manage.* **96**, 745–756.

Mansour, H. A. G., Tayel, M. Y., Abd El-Hady, M. A., Lightfoot, D. A. & El-Gindy, A. M. 2010 Modification of water application uniformity among closed circuit trickle irrigation systems. *J. Earth Environ. Sci.* **1** (1), 1–9.

Nakayama, F. S. & Bucks, D. A. 1991 Water quality in drip/trickle irrigation: a review. *Irrig. Sci.* **12**, 187–192.

Ozekici, B. & Sneed, R. E. 1995 Manufacturing variation various trickle irrigation on line emitters. *Appl. Eng. Agri.* **11**, 235–240.

Ravina, I., Pas, E., Sofer, Z., Marcu, A., Schischa, A., Sagi, G., Yechialy, Z. & Lev, Y. 1997 Control of clogging in drip irrigation with stored treated municipal sewage effluent. *Agri. Water Manage.* **33**, 127–137.

Sahin, U., Anapali, O., Donmez, M. F. & Sahin, F. 2005 Biological treatment of clogged emitters in a drip irrigation system. *J. Environ. Manage.* **76**, 338–341.

SAS Institute 2002 *The SAS System for Windows 8.2*. SAS Institute, Cary, NC, USA.

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