Clogging Rate of Pressure Compensating Emitters in Irrigation with Rainbow Trout Fish Farm Effluent

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Abstract

One of the most fertilizing effluents for irrigation are those from fish farms. In drip irrigation systems, emitter clogging is the biggest problem of the effluent application. Therefore, the aim of this paper was to assess the clogging rate of a drip irrigation system using the effluent of a rainbow trout farm. A control treatment with the input fish farm freshwater and two more using fish farm effluent, with and without irrigation lateral drainage, were tested. Pressure compensating emitters Microflapper with nominal discharges of 4 and 8 L/h (M4, M8) and Netafim with discharges of 4, 8, and 12 L/h (N4, N8, and N12) were used. For each treatment, 42 irrigations events were carried out with a total of 336 h over a 4-month period. Each irrigation event lasted 8 h every 3 days. Clogging rate, Christiansen uniformity (CU) and emission uniformity (EU) coefficients were utilized for assessing the hydraulic performance of emitters. There was no emitter completely clogged during the experiment. However, as the clogging rate gradually increased, lateral discharges during the irrigation season decreased to a maximum of 57% of the initial value in some laterals. Evolution of the clogging rate was unstable, especially in the control treatment. N4 emitter show the best performance regardless of the quality of irrigation water. The clogging rates of M4 and N8 emitters were significantly ($p < 0.05$) higher when effluent was used. The N12 and M8 emitters had the highest sensitivity to clogging, without differences between treatments. Results show the dependence of clogging rate on emitter type and its discharge. The CU as well as EU for all emitters and treatments were higher than the allowable minimum. Lateral drainage had the greatest impact on the N12 and M8 emitters, which had the highest discharge. Moreover, some relationships between CU and clogging rate were obtained. It is generally possible to use the rainbow trout effluent in a drip irrigation system with pressure compensating emitters.

Keywords: Drip Irrigation, Microflapper Emitter, Netafim Emitter, Aquaculture Effluent, Emission Uniformity

1. Introduction

Nowadays, several types of treated effluent are considered as new and permanent sources for direct and indirect counterbalance of water resources shortage. For instance, the reuse of effluent as an alternative source of irrigation water in agriculture is widely employed (Nadav et al., 2013; González-Méndez et al., 2015). In this regard, integrating aquaculture with agricultural systems is an efficient and practical way to improve food production, protect the environment, and enhance food security (Karapanagiotidis et al., 2010; Kawarazuka, 2010; Zajdband, 2011).

Despite beneficial nutrients such as phosphorus and nitrogen (Gurung, 2012; Mustapha et al., 2013), the effluent from fish farms poses several risks to human health and the environment (Bakar et al., 2015; Becerra-Castro et al., 2015). As such, its application in agriculture requires specific management strategies, being one of the most important management the election of an appropriate irrigation technology. Drip irrigation is the best method for effluent irrigation (Bucks et al., 1979; World Health Organization, 2006). Nevertheless, the most important challenge of the drip irrigation system is emitter clogging, which is exacerbated by the effluent conditions (Bucks et al., 1979; Ravina et al., 1992).

Emitter clogging would lead to reducing the uniformity of water emission as well as to reduce production productivity. Emitter clogging could have physical (such as sand, silt and clay particles), biological (bacteria and algae), chemical (deposition of various substances) origins or a combination of them (Bucks et al., 1979). The main cause of emitter clogging when using effluents are usually suspended solids and microorganisms, especially bacteria and sludge (Adin and Sacks, 1991; Tajrishy et al., 1994; Taylor et al, 1995; Hills and Brenes, 2001). Furthermore, some chemical compounds, especially calcium carbonate deposition, are sometimes the cause of emitter clogging (Nakayama and Bucks, 1981; Hills et al., 1989; Liu and Huang, 2009; Eroglu et al., 2012; Eid et al., 2014; Lili et al., 2016). Emitter clogging can also be due to the formation and growth of biofilms in the emitter wall (Taylor et al., 1995; Ravina et al., 1997; Duran-Ros et al., 2009; Yan et al., 2010; Li et al., 2012a, 2013).

Several studies have been conducted on emitter clogging using treated urban and industrial effluents (Capra and Scicolone, 2007; Li and Chen, 2009; Li et al., 2012b; Tarchitzky et al., 2013; Tripathi et al., 2014; Al-Jassim et al., 2015) but no study has been conducted on the use of fish farms effluent in drip irrigation systems. The suspended solids of fish farm effluent are mostly organic, since there are algae, sludge, and fish food residues (Manbari et al., 2019). However, the effect of fish farm effluents on emitter clogging is still not reported.

This study aims to investigate the hydraulic performance of two different pressure compensating emitters in drip irrigation using rainbow trout effluent. To accomplish this aim, the input water to fish farm was also employed as the control treatment. As a management approach, the effect of lateral pipe drainage at the end of each irrigation was also investigated.

2. Materials and Methods

2.1. Experimental setup

The experiment was carried out in the Abidar rainbow trout farm in Sanandaj, northwest of Iran. Input water into the farm was first introduced into fish ponds measuring 15 m length and 4 m width. Then this effluent was conveyed to other fish ponds of the same size where bigger fish grew. Eventually, the final effluent was discharged to a field for its use as irrigation water. Average water flow velocity at ponds was 2–3 cm/s, below the recommended maximum flow velocity in fish ponds, which is set at 5 cm/s (Klontz, 1991). Therefore, the fish ponds played a role of sedimentation ponds, although particle settling might be slightly disturbed by the movement of the fishes. Table 1 reports the characteristics of the input water as well as the effluent used in this study. Samples of freshwater and effluents were taken by triplicate 8 times in 3 different days and physical, chemical and biological characteristics were determined following standard methods (Adams, 2017; Rice et al., 2005).

Three treatments were assessed in the experiment. In treatment 1, input farm freshwater was used as the control. In treatments 2 and 3, farm outlet effluent was used. In treatment 3, by the end of each irrigation event, laterals and manifold pipes were drained (Figure 1). The drip irrigation system for all three treatments had the same elements. Each system contained an electro pump, filtration system (hydro- cyclone, sand filter (3-8 mm grain size) and screen filter (125-149 µm filtration level), a 50 mm diameter polyethylene manifold pipe and five 16 mm diameter polyethylene laterals with 50 m length. Each lateral had 12 loop branches. In each treatment, 5 different types of pressure compensating emitters with discharges of 4, 8 and 12 L/h were used (Table 2). There were 240 emitters per treatment. Each lateral had only one type of emitter. The discharge of each loop and lateral was set at 24 L/h and 288 L/h, respectively. Therefore, the number of emitters for each loop was 6, 3 and 2, respectively, for emitters with discharges of 4, 8 and 12 L/h. The proposed system layout was in accordance with common drip irrigation designs implemented in Iran.

Table 1. Average and standard deviation of physical, chemical and biological characteristics of input water and outlet effluent of the rainbow trout fish farm and emitter clogging risk

Water Quality Parameters	Water source		Risk of Clogging (Pitts et al, 1990; Ayers and Westcot, 1994; Couture, 2004)	
	Freshwater (control)	Trout farm effluent	Freshwater (control)	Trout farm effluent
Physical				
Suspended solids (mg/L)	234.8 ± 166.3	206.5 ± 27.4	**High**	**High**
Chemical				
pH	8.0 ± 0.2	8.0 ± 0.2	**Moderate**	**Moderate**
Dissolved solids (mg/L)	220.7 ± 49.9	223.5 ± 47.0	**Low**	**Low**
Manganese (mg/L)	<0.1 ± 0.0	<0.1 ± 0.0	**Low**	**Low**
Iron (mg/L)	<0.2 ± 0.0	<0.2 ± 0.0	**Low**	**Low**

Hydrogen sulfide (mg/L)	<0.2 ± 0.0	<0.2 ± 0.0	**Low**	**Low**
Magnesium (mg/L)	10.6 ± 9.2	11.2 ± 7.5	**Low**	**Low**
Total hardness (mg/L)	164.6 ± 50.8	163.1 ± 36.8	**Moderate**	**Moderate**
Bicarbonate (mg/L)	173.3 ± 36.3	183.7 ± 33.5	**Moderate**	**Moderate**
Nitrate (mg/L)	12.4 ± 4.4	49.4 ± 6.3	**Moderate**	**High**
Salinity (dS/m)	0.3 ± 0.0	0.3 ±0.0	**Low**	**Low**
Sodium absorption ratio $(meq/L)^{0.5}$	0.1 ± 0.0	0.1 ± 0.0	**Low**	**Low**
Wilcox Classification	C2S1	C2S1		
Biological				
Number of heterotrophic bacteria (Per mL)	2028.0 ± 1207.3	5235.5 ± 921.8	**Low**	**Low**

Table 2. Characteristics of the emitters used in the present study

Emitter brand	Connection type	Pressure range (kPa)	Nominal discharge (L/h)	Code	Manufacturing coefficient of variation	Other specifications
Micro Flapper	Online	98.1-343.2	4	M4	0.025	Pressure compensating emitters and self-drained
Micro Flapper		98.1-343.2	8	M8	0.035	
Netafim		68.6-392.3	4	N4	<0.05	
Netafim		68.6-392.3	8	N8	<0.05	
Netafim		68.6-392.3	12	N12	<0.05	

2-2 Experimental procedure

Irrigation events lasted 8 h while the irrigation interval was 3 days, being both chosen according to the local conditions. At the end of each irrigation event, the gate valve of the manifold pipe and the end of laterals of treatment 3 were opened to drain the residual effluent present in the laterals. A total of 42 irrigation events were carried out for 336 h over four months. The number of irrigation events is based on typical orchard irrigation pattern in the area. In each irrigation event, the volume of emitter discharge of each loop was measured. Moreover, the number of clogged emitters was also counted in each irrigation.

2-3 Data analysis and evaluation indicators

The emitter clogging data were analyzed using SAS (SAS Institute, Cary, North Carolina, USA) software in the form of composite analysis design. At the end of the experiment, a factorial experiment (3*5) was performed based on the randomized complete block design (RCBD). Also, the comparison of means was analyzed using one-way analysis of variance and Duncan test, at 95% confidence level. To evaluate the hydraulic performance of emitters, the indicators of Clogging Rate (Wei et al., 2008) and Christiansen Uniformity Coefficient (1941) for each irrigation and Seasonal Emission Uniformity Coefficient (Keller and Karmeli, 1974; Capra and

Scicolone, 1998) were used. The relationships related to the mentioned hydraulic indicators and their descriptive classification are provided in Table 3. Also the following statistical parameters were used to evaluate the accuracy of the proposed relationships between hydraulic indicators:

$$MARE = \frac{100}{n}\left(\sum_{i=1}^{n}\frac{HI_{i(cal)} - HI_{i(\exp)}}{HI_{i(\exp)}}\right) \tag{1}$$

$$ME = Max\left(MARE\right) \tag{2}$$

$$RMSE = \sqrt{\frac{1}{n}\left(\sum_{i=1}^{n}\left(HI_{i(cal)} - HI_{i(\exp)}\right)^{2}\right)} \tag{3}$$

where MARE, ME and RMSE are the Mean Absolute of Relative Error, the Maximum relative Error, and the Root Mean Square Error, respectively. $HI_{i(\exp)}$ and $HI_{i(cal)}$ are the experimental and computed values of the hydraulic indices terms, respectively.

Some clogged drippers from different treatments were cut out by laser with an accuracy of 0.5 mm and were photographed in macro mode using a digital camera. Also, the clogging substances were analyzed following standard methods (Adams 2017; Rice et al. 2005).

Table 3. Hydraulic evaluation indicators used and their descriptive classification

Hydraulic Index	**Equation**	**Parameters**	**Classification (Capra and Scicolone, 1998; Wei et al., 2008)**		
			Low	**Mean**	**High**
Clogging Rate	$Cr = 100\left\|1 - \frac{\bar{q}}{q_{\upsilon}}\right\|$ $\bar{q} = \frac{\sum_{i=1}^{n} q_i}{n}$	Cr **: Clogging rate (%)** CU **: Christiansen uniformity coefficient (%)** EU_S **: Emission uniformity coefficient during the whole irrigation season (%)** $\bar{q}$ **: Average loop discharge (L/h)** q_{υ} **: Nominal loop discharge (L/h)** q_i **: Discharge of *i*th loop (L/h)** ***i*: Number of loop** ***n*: Total number of loops** $q_{(\min 1/4)_S}$ **: Average lateral discharge of the lower quartile during the whole irrigation season (L/h)** $\bar{q}_S$ **: Average lateral discharge during the whole irrigation season (L/h)**	**---**	**---**	**>25**
Christiansen Uniformity Coefficient	$CU = 100\left\|1 - \frac{\sum_{i=1}^{n}\|q_i - \bar{q}\|}{\sum_{i=1}^{n} q_i}\right\|$		**<70**	**70-81**	**>81**
Seasonal Emission Uniformity Coefficient	$EU_S = 100\left(\frac{q_{(\min 1/4)S}}{\bar{q}_S}\right)$		**<71**	**71-89**	**>89**

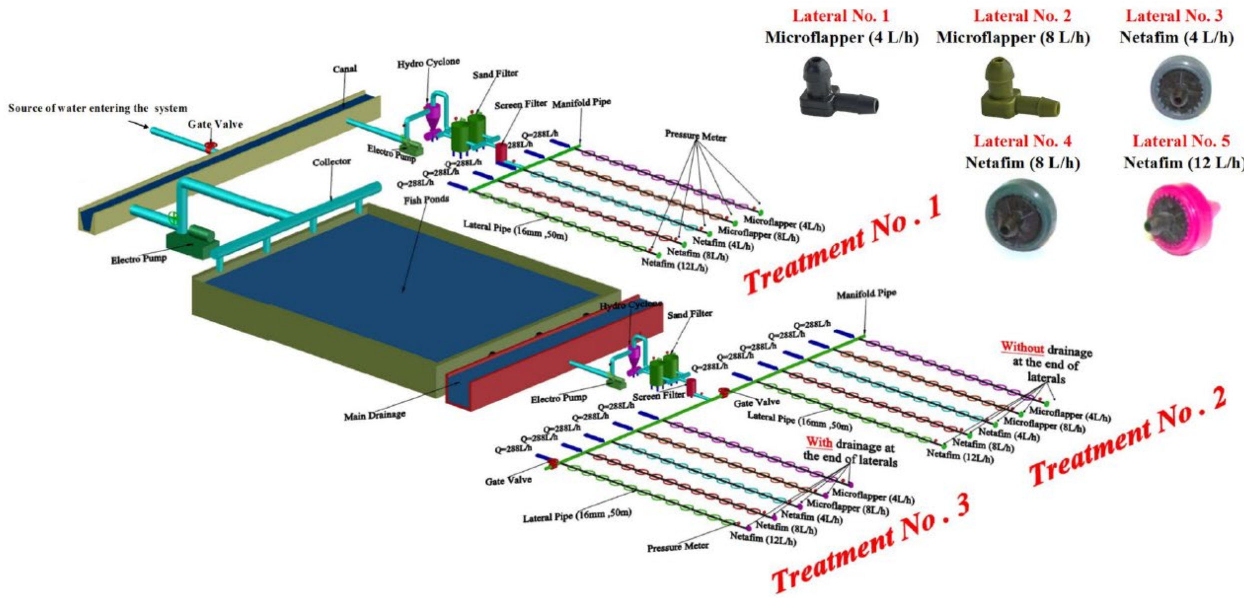

Figure 1: Specifications of drip irrigation system and treatments

3. Results and Discussion

3.1 Emitter Clogging Rate (C_r)

Figure 2 shows the trend of emitters clogging rate during the 42 irrigation events. Complete clogging was not observed in any emitter. For all the three treatments, the clogging rate increased with time for all the emitters, although there were some decreases. This instability could be due to the temporary clogging of the emitter and the effect of its self-cleaning system (Rowan et al., 2013). The N4 emitter had the least instability. Besides, these unsteadinesses were more noticeable in the control treatment than in effluent treatments. Many researchers (Bralts et al., 1981; Ravina et al., 1992; Boman, 1995; Puig-Bargués et al., 2005; Wei et al., 2008; Puig-Bargués et al., 2010; Li et al., 2019), have reported that when using effluents in some emitters, several factors such as corrosion of elastic membrane, adhesion of particles to membrane and entrapment between elastic parts, presence of microbial colonies in emitter and decomposition of clogging factors, increase the emitter discharge and reduce clogging rate. Manbari et al. (2019) also reported that the most suspended solids of fish farms effluent were organic particles, which can be easily deformed and therefore they can be released from the emitter if they are not strongly attached. As a result, one of the other reasons for the increase in control treatment instabilities over effluent may be due to differences in the type of suspended solids.

Figure 3 illustrates the average clogging rate of the 4 last-irrigation events for the different emitters and treatments. Due to the important changes of clogging rate in each irrigation event, computing the average of the 4 last irrigation events was considered to be more representative of the clogging status at the end of the experiment than using only values from the last event. For the control treatment, the clogging rate of the N4, N8 and M4 emitters was lower than the critical limit, with no significant differences ($p > 0.05$). In this treatment, the clogging rate of N12 and M8 emitters ranged from 30% to 35%. For the effluent treatments, N4 emitter had the lowest the clogging rate, which was below the critical limit. For these treatments, the clogging rates of other emitters were in the range of 30% to 43%, with no significant differences ($p > 0.05$). Although drainage at the end of laterals reduced the clogging rate in all emitters (except N4), differences were not significant ($p > 0.05$). Drainage at the end of laterals helps removing the remaining suspended solids and prevents the accumulation of these materials in the lateral (Puig-Bargués et al., 2010; Li et al., 2015, 2019). This management strategy had the greatest impact on high-discharge emitters. In this sense, clogging hazard is increased in pressure compensating emitters with higher discharge. These results contradict those from Ravina et al. (1997), who found smaller clogging hazard for higher discharge emitters. However, emitter discharge is not the only variable that affects clogging since emitter geometry (Pei et al., 2014) and water release system also play also a role. Baeza and Contreras (2020) found that pressure compensating emitters performed worst with more polluted effluents. Gamri et al. (2014) also found that pressure compensating emitters were more prone to clog. In the studies carried out by Gamri et al. (2014), Pei et al. (2014) and Baeza and Contreras (2020), emitter discharges were all below 5 L/h. Nevertheless, in the present work, the 8 L/h emitters discharged more water and, thus, more particles entered and could accumulate in the region between the membrane and emitter outlet, which is directly related to clogging (Pinto et al., 2017).

For the M8 and N12 emitters, the clogging rate for the control and effluent treatments were not significantly different ($p > 0.05$) and was above the critical limit. In other words, these emitters were more susceptible to clogging than the other emitters. For M4 and N8 emitters, the clogging rate of control was significantly smaller ($p < 0.05$) than effluent treatments, indicating that the clogging depended on irrigation water quality. For N4 emitter, the clogging rate of control treatment was not significantly different ($p > 0.05$) than that of the effluent treatment No. 2, but it was significantly smaller ($p < 0.05$) than the effluent treatment No. 3. Thus, N4 emitter clogging rate was independent of the quality of irrigation water, which is noticeably below from the critical limit in all conditions. However, this was the only emitter where lateral drainage increased emitter clogging rate, despite having a not significant effect regarding no drainage treatment. In general, the performance of Netafim emitters was better than Microflapper ones, in which by increasing the nominal discharge, the potential of emitter clogging when using effluent increased compared to freshwater, which is consistent with the studies of Liu and Huang (2009). Many researchers have also reported the dependence of the clogging rate on the emitter type (Taylor, 1992; Duran-Ros et al., 2009; Pei et al., 2014) and the optimal performance of Netafim pressure compensating emitters (Ebrahimi et al., 2012). The composition of clogging substance found at emitter outlet (Figure 4) was mainly physicochemical and contained 23 and 25% calcium carbonate in the emitters of control and effluent treatments, respectively. The remaining materials in the emitters of control and effluent treatments were mineral and organic, respectively.

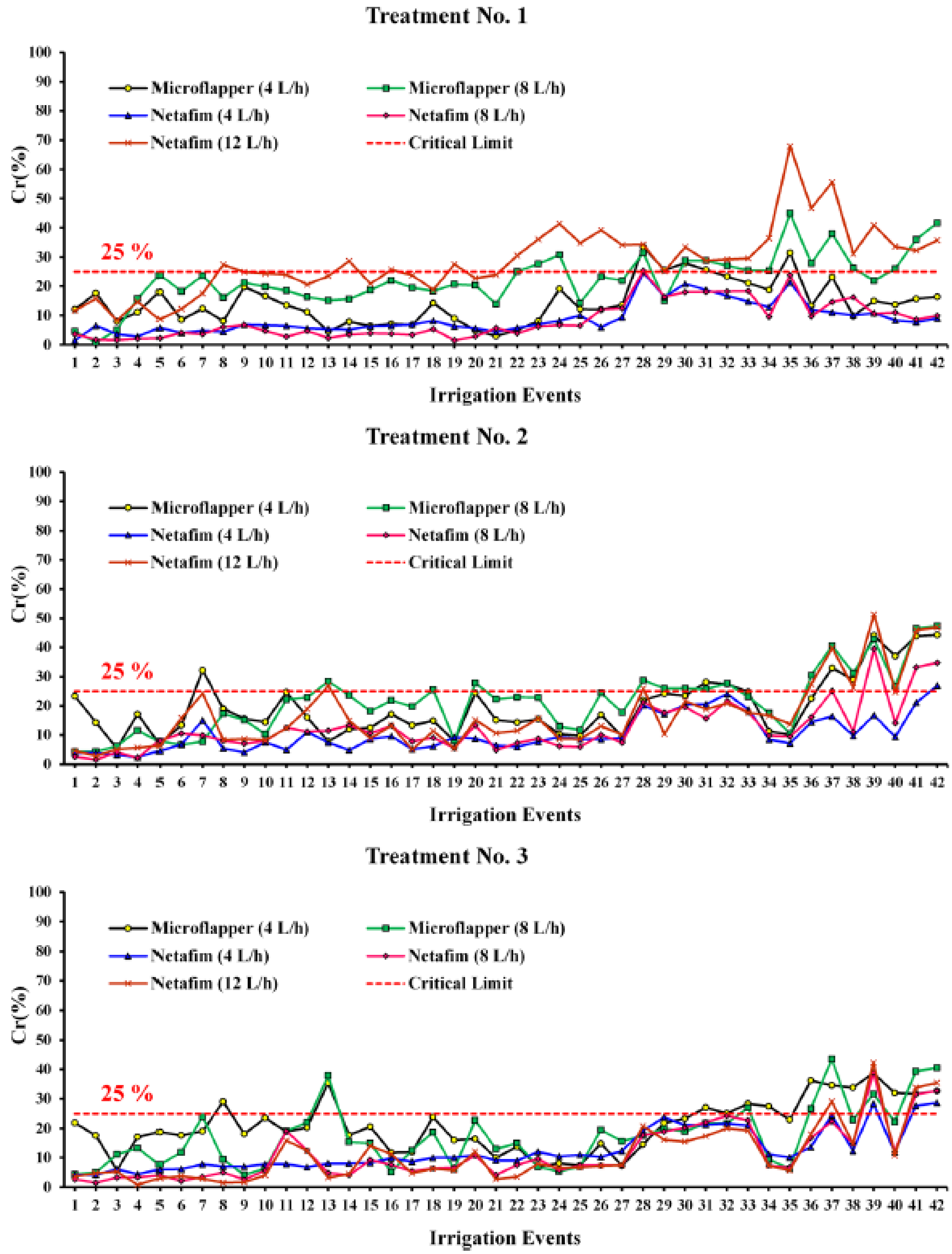

Figure 2. Evolution of emitter clogging rate for control (treatment No. 1), effluent without (treatment No. 2) and with (treatment No. 3) lateral drainage

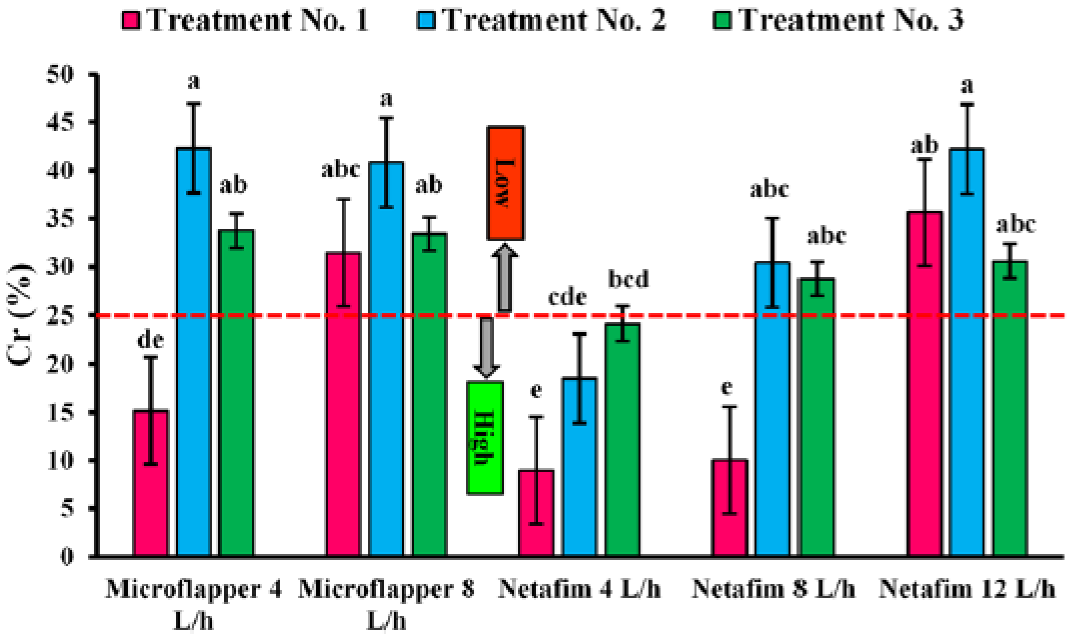

Figure 3. Average and standard error bars for emitter clogging rate (Cr) for the 4 last irrigation events for the different emitters and treatments (columns having at least one letter in common are not significantly different at 5% level)

Figure 4. Samples of clogging of Microflapper and Netafim emitters

3.2 Christiansen Uniformity Coefficient (CU)

Figure 5 shows the changes in the Christensen uniformity (CU) coefficient for the emitters studied along the 42 irrigation events carried out. For the effluent treatments, CU were above 70% and had slight fluctuations, but for the control treatment, CU for N12 and M8 emitters was oscillatory. In some irrigation events, CU was lower than the allowable threshold (70%, Table 3). The trend of CU changes was consistent with that shown for emitters clogging rates (Figure 2). During 42 irrigation events, the N4 and N8 emitters had higher CU than the other emitters studied ($86.4 \le CU_{N4} \le 98.6$ and $80 \le CU_{N8} \le 99$).

The CU coefficient describes the flow uniformity in the drip irrigation system, which does not always reflect the clogging state of the emitters (Xianbin et al., 2008). High CU denote that there are fewer differences between emitter discharges and, consequently, their clogging is more uniform (Adin and Sacks, 1991; Ravina et al., 1992; Xianbin et al., 2008; Duran-Ros et al., 2009; Pei et al., 2014; Feng et al., 2017). The desired values of the CU of the emitters through the experiment confirm that the clogging rate of the emitters was quite uniform.

Figure 6 depicts the mean of CU of the 4 last irrigation events by treatment. In the control treatment, the CU coefficient for the N4, N8 and M4 showed high uniformity while, for the rest of the emitters, uniformity was moderate, which agrees with clogging rate results. For the effluent treatment without lateral drainage (treatment No. 2), the best CU was obtained by N4 emitter (91.82%), whereas the worst one was that of N12 emitter (72.96%), which had significantly ($p < 0.05$) smaller CU regarding the other emitters, except for itself and M8 at control treatment. The lateral drainage showed to be most effective on the N12 and M8 emitters since CU significantly ($p < 0.05$) increased after this maintenance practice was carried out. Results show that drainage helped avoiding clogging, although it is not always effective (Liu and Huang, 2009; Puig-Bargués et al., 2010). Thus, the effect of the lateral drainage was greater on those emitters with a higher discharge. For 4 L/h discharge emitters, lateral drainage tended to slightly reduce CU regarding effluent treatment, although there were not significant differences. However, for these emitters, CU was significantly higher ($p < 0.05$) for the control treatment, which shows that effluent increased clogging and reduced CU.

Figure 7 illustrates the relationship between Christiansen uniformity coefficient and emitter clogging rate. The MARE of treatments 1, 2, and 3 were 4.27, 4.04 and 3.04 %, respectively, which indicates the appropriate accuracy of the proposed relations. Also, in Fig. 6, the values of ME and RMSE are listed separately for each the treatment. Several studies have confirmed the linearity of the relationship between the studied hydraulic indexes (Li and Chen, 2009; Feng et al., 2017; Li et al., 2015; Pei et al., 2014).

3.3 Seasonal Emission Uniformity Coefficient (EUs)

By gradually increasing emitters clogging rate, discharge of laterals decreased along the 42 irrigation events. At the beginning of irrigation season, discharge of lateral was 288 L/h, but in some laterals the mean discharge reached 57% of the initial value in the last 4 irrigation events. The changes of lateral discharges through the experiments are related to the reduction of the uniformity of water emission discussed in the previous section. In this regard, Figure 8 illustrates the water emission uniformity coefficient of the whole irrigation season computed as shown in

Table 3. The EUs coefficients for all the emitters were in the moderate area since they were between 71 and 89%. This indicates that not only there was a high uniformity in the each emitter and loop clogging, but the frequent clogging and unclogging of the emitters occurred uniformly during the 42 irrigation events. N4 emitter with effluent treatments showed the highest EUs across the experiment. Moreover, lateral drainage had the greatest effect on EUs for N12 emitter.

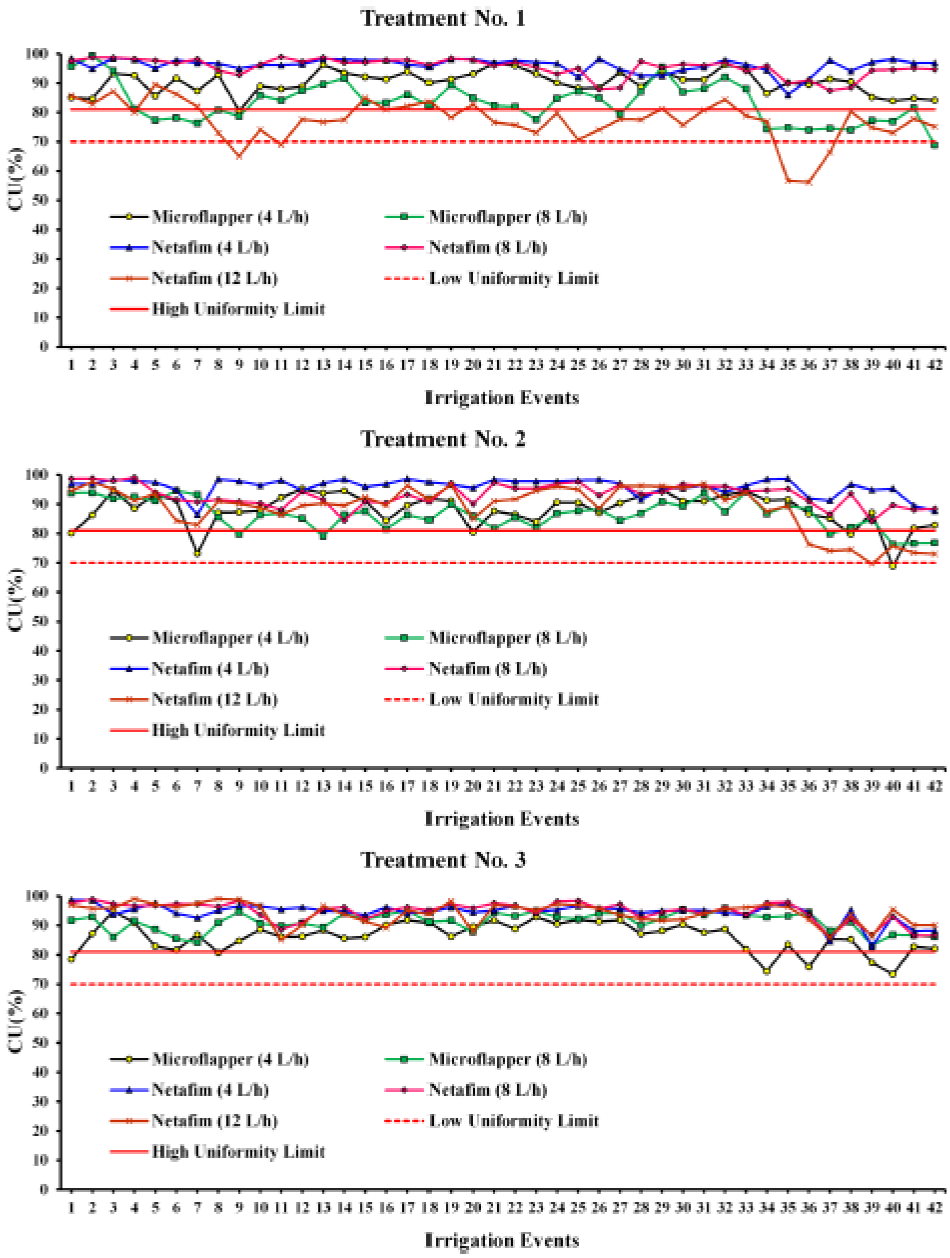

Figure 5: Evolution of Christensen uniformity coefficient (CU) for each irrigation event in control (treatment No. 1), effluent without (treatment No. 2) and with (treatment No. 3) lateral drainage.

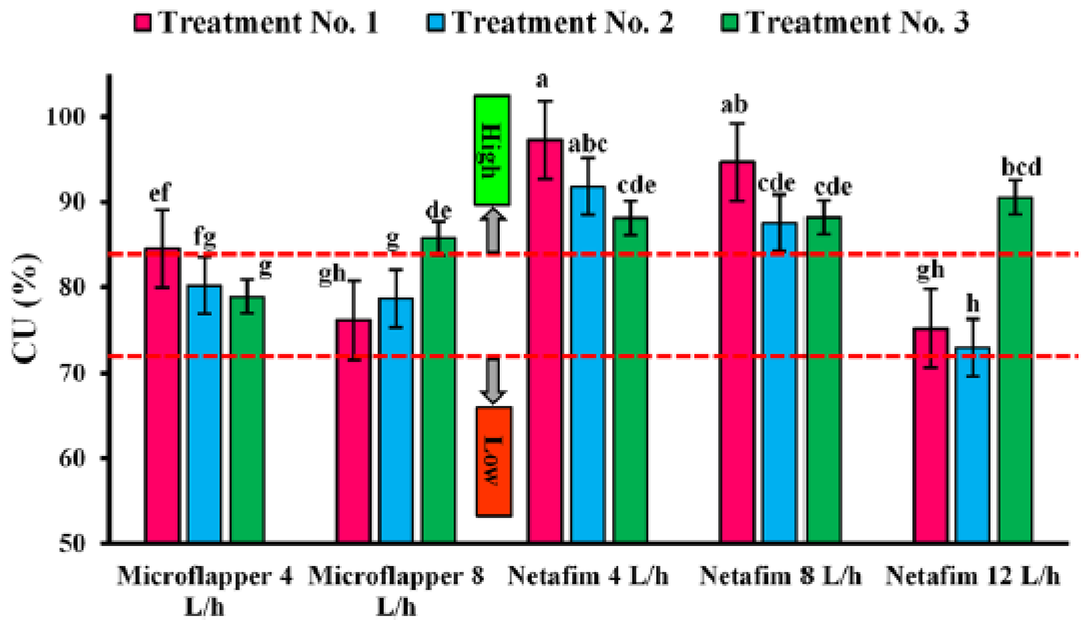

Figure 6: Average and standard error bars of Christiansen uniformity (CU) coefficient for the last 4 irrigation events and different treatments (columns having at least one letter in common are not significantly different at 5% level)

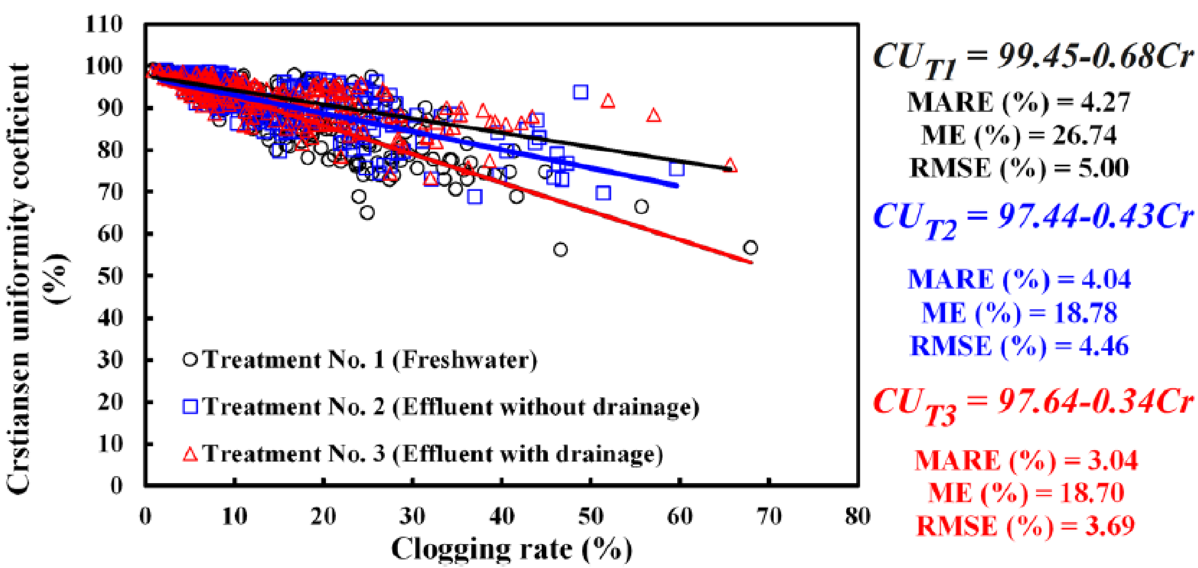

Figure 7- Relationship between Christiansen uniformity coefficient and emitter the clogging rate by type of treatment studied

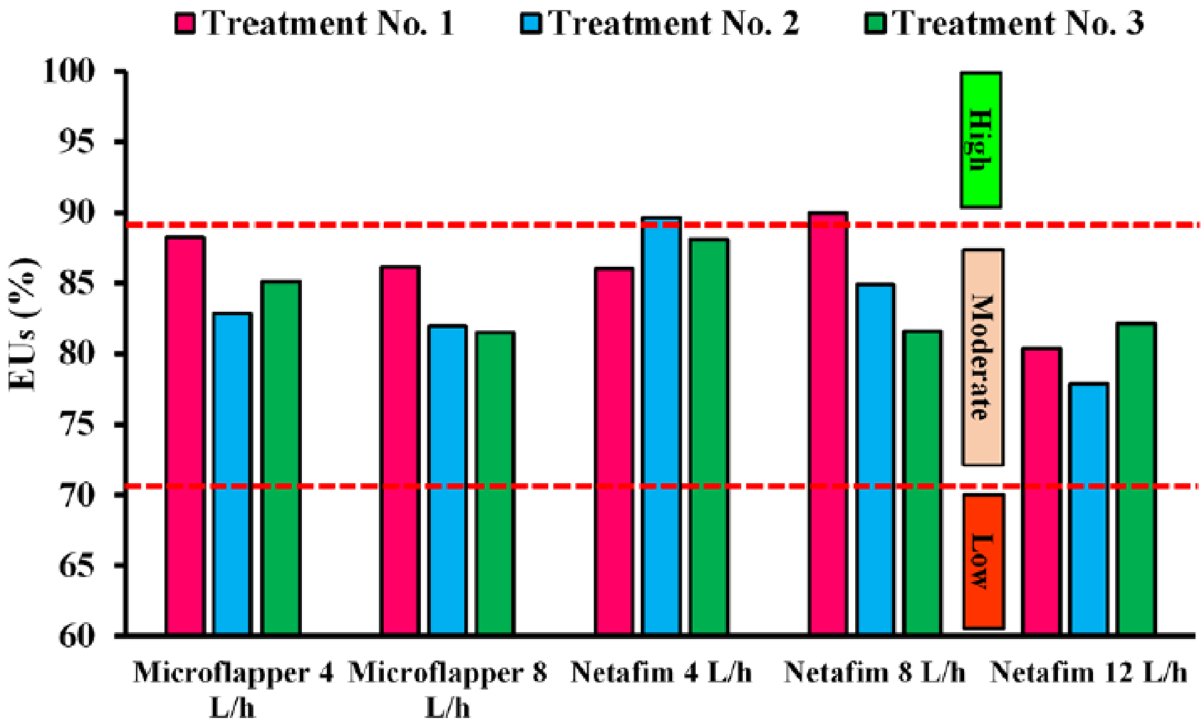

Figure 8. Seasonal emission uniformity coefficient (EUs) throughout the irrigation season by type of treatment

4. Conclusion

According to the results, no emitters completely clogged were observed when using rainbow trout effluents in a drip irrigation system. The clogging rates of all emitters were unstable but incremental across the experiment, with different trends depending on the emitter. The maximum clogging rate reached 43% for emitters M8 and N12, being these emitters the most sensitive to clogging. The clogging rate of the N4 emitter in both control and effluent treatments was less than critical limit, indicating that it was not dependent on the quality of irrigation water. The clogging rate of M4 and N8 emitters were notably dependent on the quality of irrigation water. The CU and EUs were higher than the minimum allowable for all emitters in all three treatments. Results show that is possible to utilize the rainbow trout fish effluent in a drip irrigation system since clogging levels are reasonable. The emitter clogging rate depends on the emitter type and emitter discharge. In this study, the Nefatim emitter had a better performance than the Microflapper emitter. In addition, by increasing the emitter discharge, the potential of clogging of the tested emitters increases. As a management strategy, the lateral drainage at the end of each irrigation had the greatest impact on high-discharge emitters.

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