Effect of Type of emitter self-cleaning mechanism and its structure on the Performance of Drip Irrigation System Using Effluent of Rainbow Trout Fish

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Abstract

The anti-clogging ability of the emitters depends on their automatic self -cleaning mechanism, the structure and geometry of the flow path, and the type of material carried by irrigation water. Suspended solids in fish farm effluents are mostly organic with a low volumetric mass and high compressibility. In the present study, three types of pressure-compensating emitters, two discharges with three flushing mechanisms of emitter were evaluated. The three emitter flushing mechanisms were: 1) continuous self-cleaning with silicone diaphragm, 2) on-off self-cleaning with silicone diaphragm, and 3) continuous self-cleaning with silicone rubber path. Four drip irrigation units for irrigation with fresh water (control) and effluent of a rainbow trout fish farm were designed and implemented. Two of these units were for control treatment (with and without filtration system) and the other two for effluent treatment (with and without filtration system). A total of 270 pressure compensating emitters of Microflapper, Netafim and Corona brands with discharge of 4 and 8 l h^{-1} through 24 irrigation events lasting 192 operating hours were evaluated over a period of 10 weeks. The indices of Relative Discharge (Dra), the Christiansen Uniformity Coefficient (CU) and Season Relative Discharge Coefficient of Variation (CV $(Dra)_S$) were used. During the irrigation season, the changes in Dra and CU fluctuated, especially for the Microflapper emitter. The maximum percentage of completely clogged emitters was 83.3% and the lowest Dra was 14% with Microflapper emitters using not filtered effluent. The Dra for these emitters with effluent treatments under no filtration decreased significantly ($p<0.05$) compared to control treatment. Without filtration, the type of water, irrigation periods, emitter type and discharge and their interaction affected the relative discharge significantly ($p<0.05$). No completely clogged emitters were found under filtration conditions. For both control and effluent treatments, filtration significantly ($p<0.05$) increased Dra of 4 and 8 l h^{-1} Microflapper and 8 l h^{-1}Netafim emitters. Effluent filtration improved Dra of Microflapper emitters by an average of 41%. The 4 l h^{-1} Netafim emitter performed best in all conditions independently of irrigation water and filtration system, without significant ($p<0.05$) differences between them. Overall, the performance of Netafim and Corona emitters was similar and better than Microflapper, which showed the independence of the relative discharge of the emitter to the type of self-cleaning mechanism and its dependence on the type of structure from its self-cleaning mechanism. For each brand, the performance of the emitters with lower discharge (4 l h^{-1}) was better than the higher discharge (with significant difference in some cases).

Keywords: Aquaculture effluent, Clogging, Emission uniformity, Pressure compensating emitter, Relative discharge

1. Introduction

Drip irrigation is a safe and environmentally friendly way to use low quality water (Han et al., 2018). However, emitter clogging is one of the main problems of this irrigation system (Pei et al., 2014; Zhou et al., 2016) since it leads to a reduction in water emission uniformity and system shutdown (Wei et al., 2008; Liu et al., 2019). Proper filtration system, flushing and drainage of laterals, acid treatment and chlorination have been suggested as methods to reduce emitter clogging (Puig-Bargués et al., 2010; Enciso-Medina et al., 2011; Song et al., 2017; Manbari et al., 2020). Another simple and effective solution is the selection of emitters resistant to clogging (Zhou et al., 2017). The anti-clogging ability of the emitter depends on the type of emitter, the structure and the geometric parameters of the flow path (Bucks et al., 1979; Mu et al., 2005; Wang, 2007a, 2007b). Emitters with short and wide flow paths are more resistant to clogging (Adin and Sacks, 1991; Camp, 1998; Yao et al., 2003). Moreover, the geometric form of the flow path (shape, angle, height and distances between the protrusions) also affects the clogging degree of the emitters (Wang et al., 2003). The depth of flow path of an emitter affects its resistance to clogging, as it not only changes the distribution of the inlet flow rate to the emitter, but also alters the material transfer process (Zhou et al., 2014). Also, the self -cleaning mechanism of some emitters improves their resistance to clogging since the flow path is automatically cleaned and those trapped particles are flushed out. These self-cleaning emitters could have a continuous flushing or an on-off flushing. In the first group, the flushing operation is performed all the time during the emitter operation, while in the second group, only when the emitter starts (on) and ends (off) its operation, i.e. two flushings per irrigation event. In self-cleaning emitters, the flow path is generally made of flexible material or part of it is made of rubber material. So, these emitters are often pressure -compensating.

Effluents of fish farms can be important for agriculture due to their nutritional potential (Gurung, 2012; Mustapha et al., 2013). The suspended solids of fish farm effluents are mostly organic, and their concentration can be less than the water entering the farm due to deposition in the ponds used in aquaculture (Manbari et al., 2020). The volumetric mass of these materials is between 1.03 to 1.19 g cm^{-3} (Tchobanoglous and Schroeder, 1985; Chen et al., 1993; Patterson and Watts, 2003), which is less than half the volumetric mass density of sand (2.65 g cm^{-3}) (Crites and Tchobanoglous, 1998; Tchobanoglous et al., 2003). Suspended solids of fish farm effluents also have a high compressibility, which is effective in preventing emitter clogging (Maroufpoor et al. 2020). However, more information is needed about the operation of drip irrigation equipment when this type of effluents are used.

In the present study, the hydraulic performance of 3 types of pressure-compensating emitters with different self-cleaning mechanisms, working with and without filtration system and using rainbow trout farm fish effluents was studied. The main purpose of the present study was to identify the best emitter self-cleaning mechanism and structure which allow an appropriate operation of drip irrigation systems under the aforementioned conditions.

2. Materials and Methods

2.1. Fish farm effluent

The present study was conducted on Abidar rainbow trout fish farm (Sanandaj, northwestern Iran), which has a raceway and a water multi-pass system type. Input water into the farm was first introduced into fish ponds (first to ponds with small fishes, then to ponds with larger fishes). Eventually, the final effluent was discharged. The maximum water flow velocity inside the fish ponds was lower than the critical level recommended by Klontz (1991) ($V_{\max} = 2.5\,cm\,s^{-1} < 5.0\,cm\,s^{-1}$). Some specifications of the water entering the fish farm and the effluent used are listed in Table 1.

2.2. Drip irrigation system

Four drip irrigation units similar to those common in Iran were implemented. Each unit consisted of 2 or 3 laterals with an outlet diameter of 16 mm. Each lateral was 15 m long and had 6 loop branches with one emitter brand. Netafim, Corona and Microflapper pressure-compensating emitters were used (Table 2). Netafim and Corona pressure-compensating emitters had a silicone diaphragm. The flow path of these emitters followed a labyrinth and their self-cleaning mechanism was continuous and on-off, respectively. The labyrinth had wide width and large depth, which wide cross-section improved clogging resistance. Microflapper emitter used a liquid silicone rubber diaphragm as part of the flow path. The flow path expanded in case of blockage and flushed off trapped sediments. Figure 1 shows images of the emitters used and their geometric structure. The geometric structures of the Netafim and Corona emitters were very similar, but that of Microflapper emitter was quite different. Six 4 l h^{-1} emitters were used in the 3 first loops and 3 emitters of 8 l h^{-1} were used in the 3 last loops. The initial discharge of each loop branch was 24 l h^{-1} and the discharge of each lateral was 144 l h^{-1}. In units 1 and 2, input farm freshwater was used as control treatment and in units 3 and 4, fish farm effluent was used as the effluent treatment (Figures 2 and 3). Units 1 and 3 lacked a filtration system, but units 2 and 4 had a filtration system consisting in a hydro cyclone, sand filter with two sand layers of 3-5 and 5-8 mm, and 125 µm screen filter. Backwashings took place when pressure drop reached 68 and 78 kPa for screen and sand filter, respectively, according to Bucks et al. (1979). Despite screen filter usually reached this pressure loss and needed to be cleaned after almost each irrigation event, sand filter pressure loss was never close to backwashing threshold during the experiment.

The operating pressure of the irrigation units was 200 to 300 kPa. Irrigation events lasted 8 h and were carried out each 3 days. During 10 weeks, 24 irrigation events were performed which took 192 h. The discharge of each loop branch was measured by volumetric method and the number of completely clogged emitters were recorded.

Table 1. Average and standard deviation of physical, chemical and biological parameters of inlet 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^{-1})	202.1± 169.6	200.7 ± 26.6	**High**	**High**
Chemical				
pH	7.9 ± 0.1	7.9 ± 0.1	**Moderate**	**Moderate**
Dissolved solids (mg L^{-1})	207.6 ± 45.6	212.9 ± 42.4	**Low**	**Low**
Manganese (mg L^{-1})	<0.1 ± 0.0	<0.1 ± 0.0	**Low**	**Low**
Iron (mg L^{-1})	<0.2 ± 0.0	<0.2 ± 0.0	**Low**	**Low**
Hydrogen sulfide (mg L^{-1})	<0.2 ± 0.0	<0.2 ± 0.0	**Low**	**Low**
Magnesium (mg L^{-1})	6.5 ± 8.6	5.8 ± 6.5	**Low**	**Low**
Total hardness (mg L^{-1})	140.9 ± 47.5	140.3 ± 28.9	**Moderate**	**Moderate**
Bicarbonate (mg L^{-1})	172.4 ± 28.0	192.3 ± 14.0	**Moderate**	**Moderate**
Nitrate (mg L^{-1})	12.4 ± 4.4	49.4 ± 6.3	**Moderate**	**High**
Electrical conductivity (dS m^{-1})	0.3 ± 0.1	0.3 ±0.1	**Low**	**Low**
Sodium absorption ratio (meq $L^{-1})^{0.5}$	0.2 ± 0.0	0.1 ± 0.0	**Low**	**Low**
Wilcox Classification	C2S1	C2S1		
Biological				
Number of heterotrophic bacteria (Per mL)	1635.3 ± 1083.1	4472.7 ± 601.9	**Low**	**Low**

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

Emitter brand	Code	Connection type	Pressure range (kPa)	Nominal discharge (l h^{-1})	Manufacturing coefficient of variation	Flow path dimensions With-Depth- Length (mm)	Self-cleaning mechanism	Flow path specifications
Micro Flapper	M4	Online	98.1-343.2	4	0.025	-	Continuous	Liquid silicone rubber
Micro Flapper	M8		98.1-343.2	8	0.035	-		
Netafim	N4		68.6-392.3	4	<0.050	1.3×1.4×60.0	Continuous	Labyrinth
Netafim	N8		68.6-392.3	8	<0.050	1.6×1.6×17.0		
Corona	C4		34.3-411.9	4	0.021	1.1×1.2×39.6	On-off	Labyrinth
Corona	C8		34.3-411.9	8	0.021	1.3×1.2×31.7		

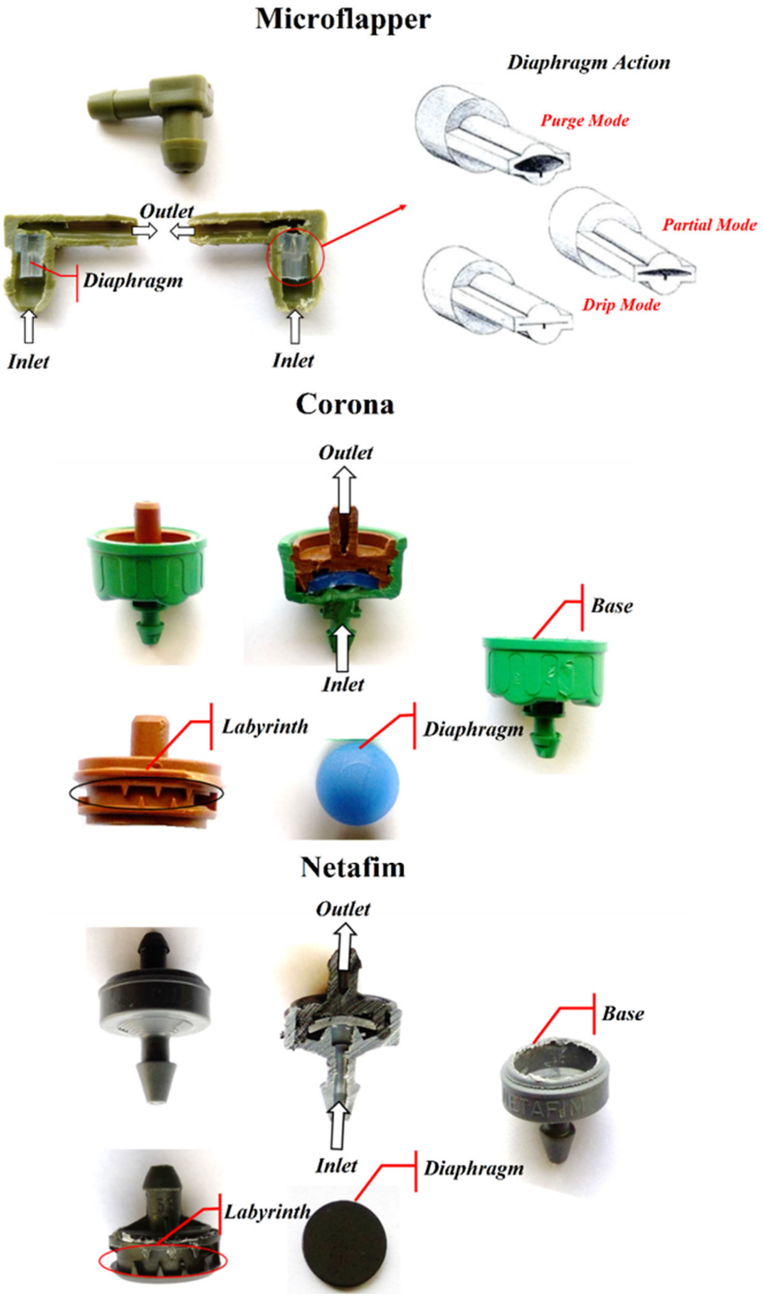


Figure 1. View and geometric structure of self-cleaning mechanism of the emitters used

2.3. Evaluation indices

Data analysis was performed using SPSS software (Ver. 26, IBM, Armonk, NY, USA). A composite analysis design and factorial experiment based on randomized complete block design was carried out. The following indices were used to assess the hydraulic performance of the emitters:

- ❖ Relative discharge (*Dra*, %) in each irrigation event was calculated for each emitter using Equation 1 (Capra and Scicolone, 1998):

$$Dra = \frac{\sum_{i=1}^{n} q_i}{} \times 100 \qquad \begin{cases} < 61 & Low \\ 61-79 & Moderate \end{cases} \tag{1}$$

where q_i is the discharge measured for each loop branch (l h^{-1}); q_{ini} is the initial discharge of each loop branch (l h^{-1}); and n is the number of loop branches with the same emitter (n = 3).

- ❖ The Christiansen Uniformity Coefficient (*CU*, %) for each emitter type was determined following Equation 2 (Christiansen, 1941):

$$CU = \left| 1 - \frac{\sum_{i=1}^{n} \left| q_i - \overline{q} \right|}{} \right| \times 100 \qquad \begin{cases} < 70 & Low \\ 70-81 & Moderate \end{cases} \tag{2}$$

where $\overline{q}$ is the average discharge of loop branch with the same emitter (L h^{-1}).

- ❖ The relative discharge coefficient of variation (*CV(Dra)s*) over the whole of irrigation season was calculated using Equation 3:

$$CV(Dra)_s = \sqrt{\frac{\sum_{i=1}^{m} \left(Dra_i - \overline{Dra} \right)^2}{}} \qquad \begin{cases} < 11 & Low \\ 11-29 & Moderate \end{cases} \tag{3}$$

being Dra_i the relative discharge of each irrigation event (%); $\overline{Dra}$ the average relative discharge throughout the season (%) and m is the number of irrigation events.

The comparison of means was analyzed using one-way analysis of variance and Duncan test, at 95% confidence level. Analysis of variance of the studied factors (discharge, treatment, emitter, irrigation periods and filtration) and their interactions on the relative discharge of the emitter was studied. In addition, to evaluate the interaction of different parameters on the relative discharge, 6 irrigation periods, and each period, including 4 irrigation events were considered.

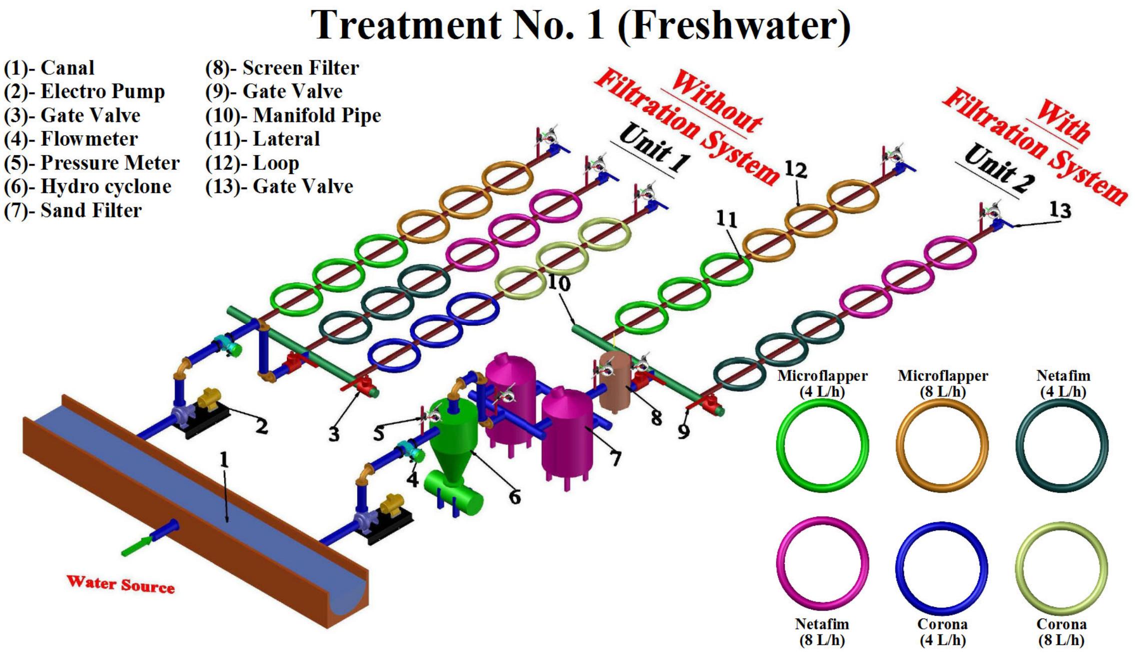


Figure 2. Layout of control treatments, unit 1 (without filtration system) and unit 2 (with filtration system).

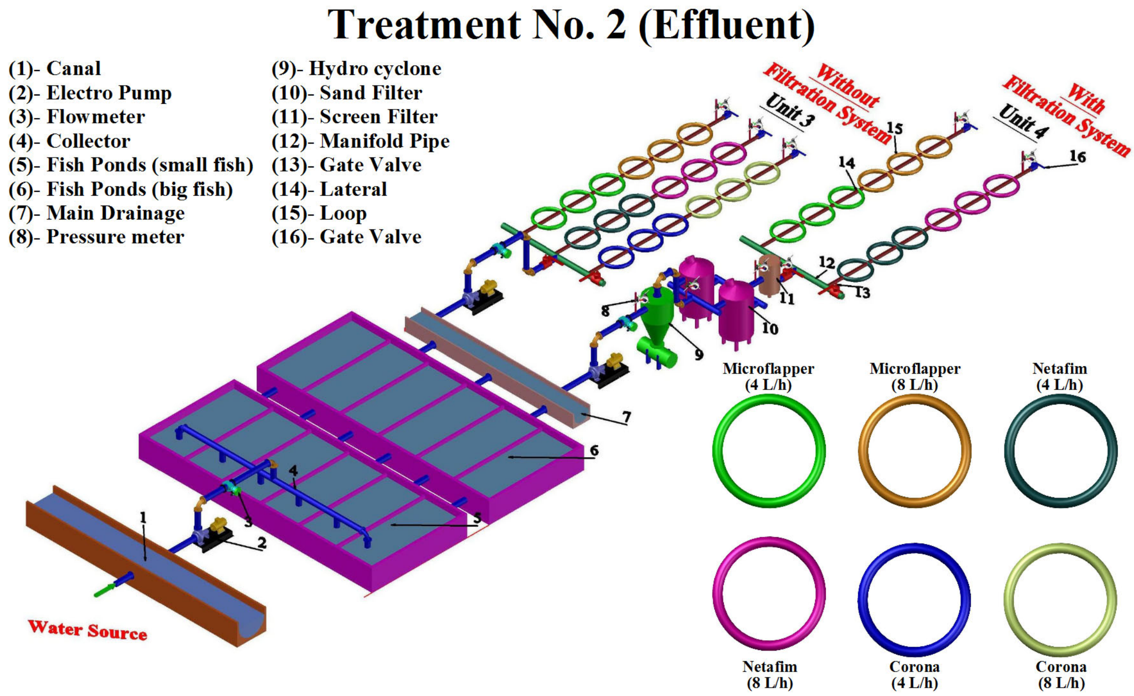


Figure 3. Layout of effluent treatments, unit 3 (without filtration system) and unit 4 (with filtration system).

3. Results and Discussion

3-1 Relative discharge of emitters (Dra)

3.1.1. Control treatments

Figure 4 shows the change of Dra in the control treatment with and without filtration system (irrigation units 1 and 2) for the different emitters. The 4 l h^{-1} Netafim (N4) emitter performed well without needing a filtration system since their Dra values were high (Dra>79%) throughout the whole irrigation season. The 8 l h^{-1} Netafim (N8) emitter showed high Dra until the 22nd irrigation event, then Dra decreased down to 72%. Corona emitters also performed similar to Netafim ones, but the 8 l h^{-1} Corona (C8) showed the worst Dra values after 17 irrigation events. In the absence of a filtration system, the performance of the 4 l h^{-1} and 8 l h^{-1} Microflapper emitters (M4 and M8, respectively) from the 17th irrigation event onwards showed Dra below 61% since their relative discharge decreased due to clogging. When the filtration system was used, Dra of M4 and M8 emitters increased by an average of 13.2% and 16.9%, respectively, compared to those emitters that worked without filtered canal water. Their Dra was above 80% but with a clear tendency to decrease in the last irrigation events (Figure 4-b). Figure 5 shows the number and percentage of completely clogged emitters for each irrigation event without filtration system (unit 1). The highest number of completely clogged emitters was found with M4 and M8 (Figure 5-a), reaching maximum values of 61.1% for M4 and 77.8% for M8. When fresh water was filtered, no emitter was completely clogged during the irrigation season.

3.1.2 .Effluent treatments

Figure 6 shows the evolution of Dra when using the effluent of the fish farm, with and without filtration system (irrigation units 3 and 4). For M4 and M8 emitters without filtration system, Dra averaged 42.2% and 39.1%, respectively, but improved up to an average of 80.3% and 83.6% when effluent was filtered. Netafim and Corona emitters, similar to the control treatment, had a good and stable performance when the effluent was used, regardless of the filtration system, having Dra>79% throughout the irrigation season. Figure 7 shows the number and percentage of completely clogged emitters for each irrigation event in the absence of a filtration system. The maximum percentage of completely clogged emitters was observed for M4 (83.3%) and M8 (77.8%). Netafim and Corona emitters only became completely clogged at the last irrigation, but their percentage was below 10%. When the effluent was filtered, no emitter was completely clogged. Although not using a filtration system could reduce installation and operational cost, the reduction of emitter discharge and the increase of clogged emitters for both freshwater and effluents makes this option not feasible for securing a proper drip irrigation system performance, as several authors pointed out (Bucks et al., 1979; Pitts et al., 1990; Ravina et al., 1992; Puig-Bargués et al., 2005).

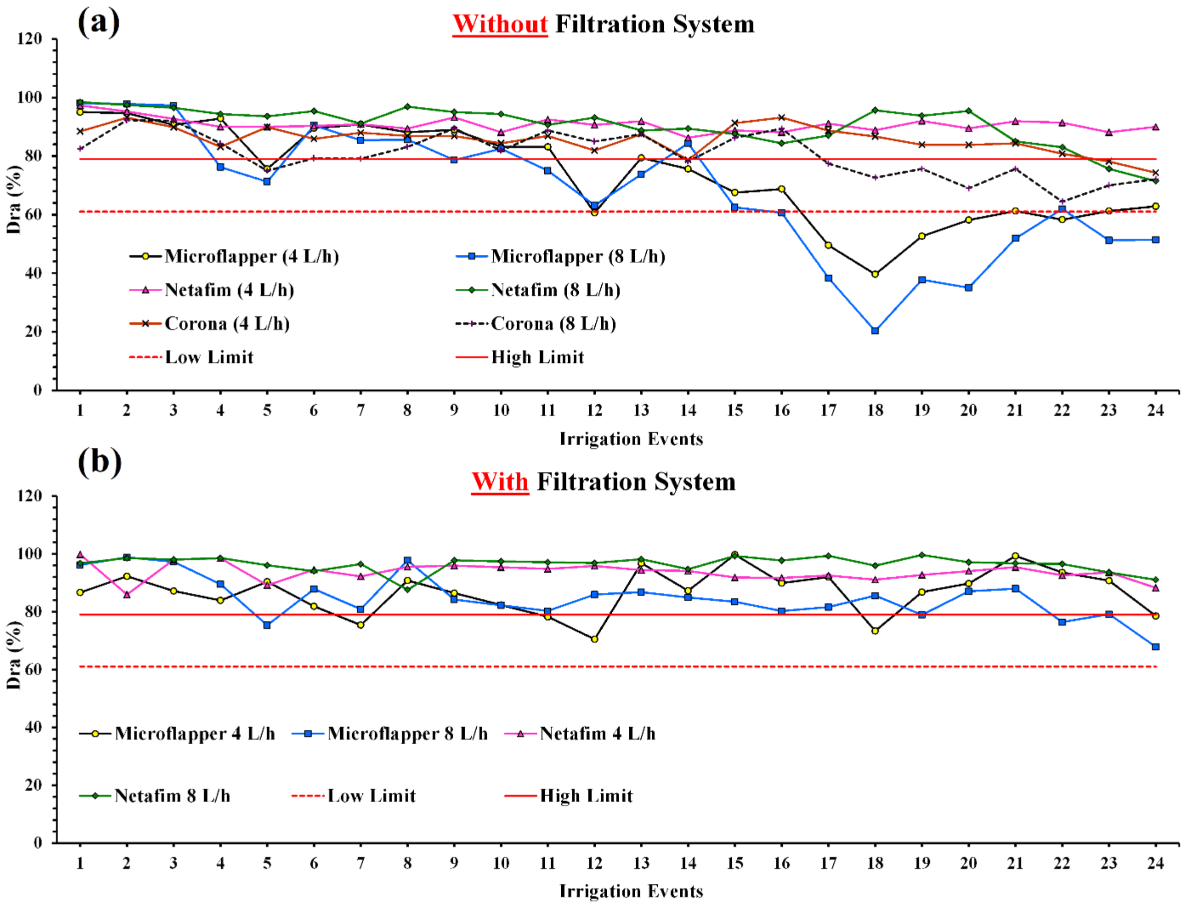


Figure 4. Relative discharge (Dra) in control treatments, for 24 irrigation events: a) without filtration system (unit 1) b) with filtration system (unit 2).

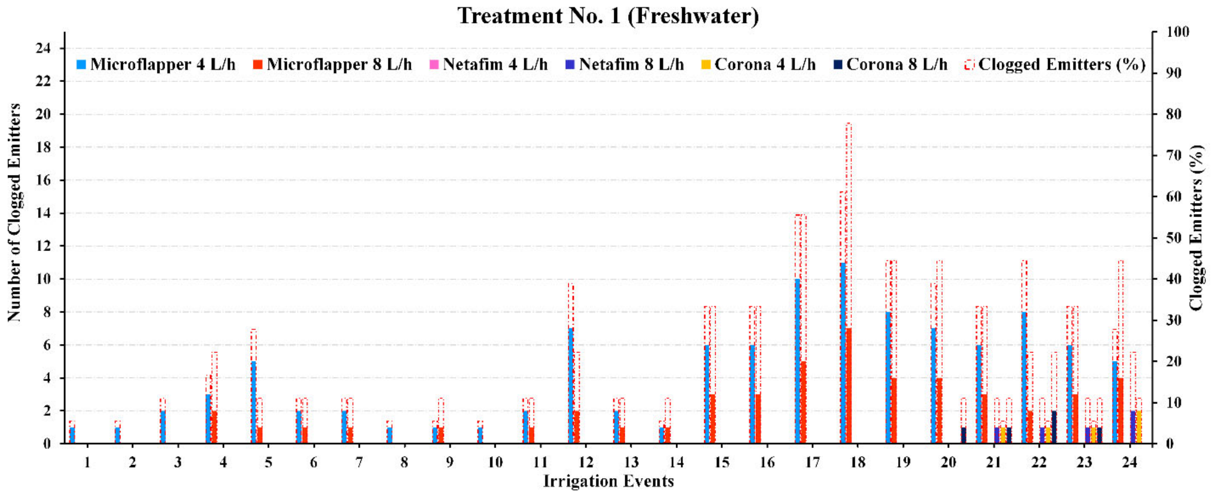


Figure 5. Number and percentage of emitters completely clogged in each irrigation event without a filtration system for the control treatment.

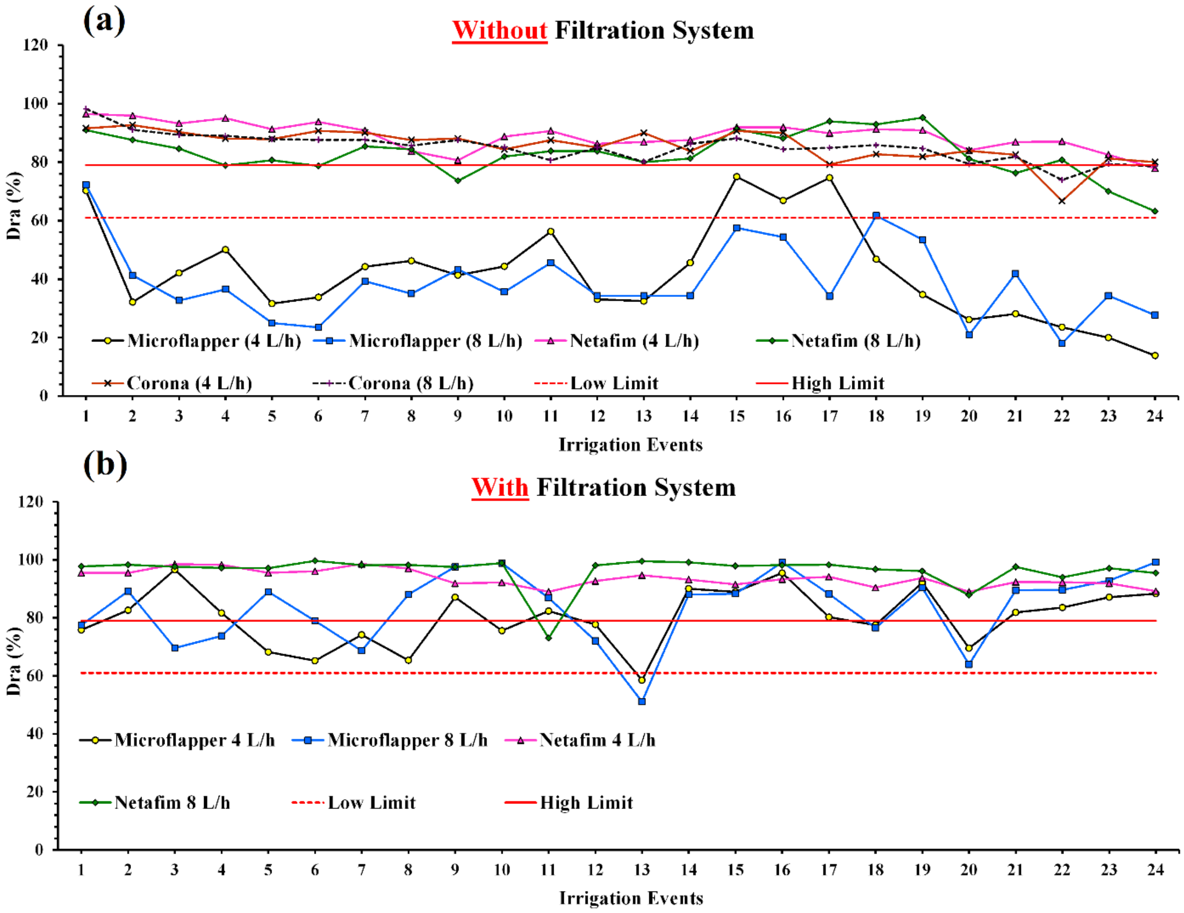


Figure 6. Relative discharge changes (Dra) in effluent treatments, for 24 irrigation events: a) without filtration system (unit 3) b) with filtration system (unit 4).

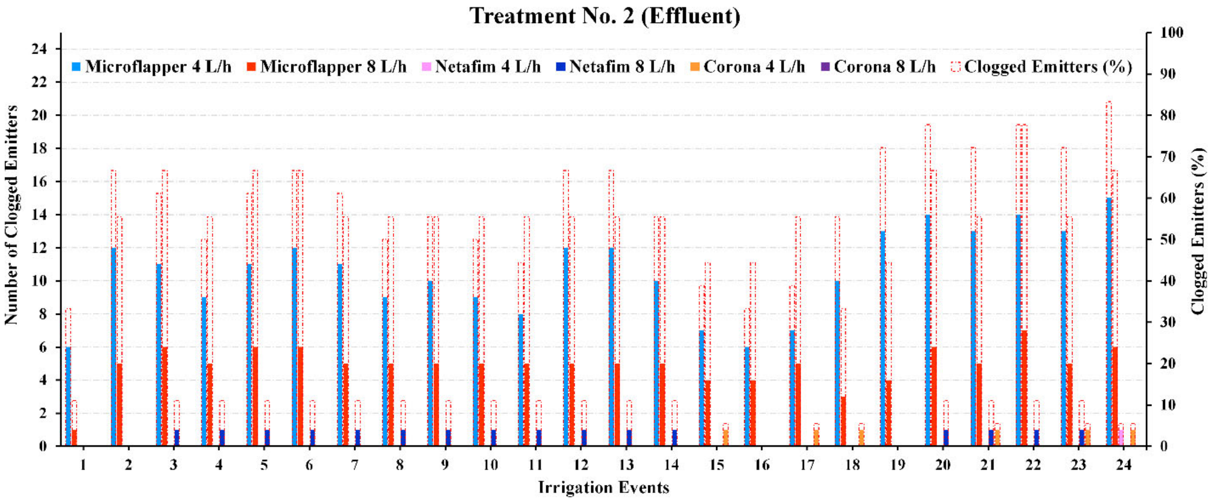


Figure 7. Number and percentage of emitters completely clogged in each irrigation event, without a filtration system, for the effluent treatment.

3.1.3 End of irrigation season

Figure 8 shows the Dra average for the last 3 irrigation events (i.e. between 176 and 192 h of irrigation) for the different emitters and treatments. The N4 emitter had the best performance regardless of the type of water and the presence or absence of the filtration system. For all the experimental conditions, N4 Dra were above 79% without significant differences among them ($82.4 \le Dra_{N4} \le 91.5$). So, N4 performance was not affected by the quality of irrigation water, which agrees with Maroufpoor et al. (2020). For both control and effluent treatments, the filtration system had the greatest effect on M4, M8, and N8 emitters since it increased their Dra significantly ($p<0.05$). In addition, Corona emitters had a good performance and were in the moderate area ($68.7 \le Dra_{C4-C8} \le 77.7$) regardless of the type of water used and without filtration.

The Dra of M4 and M8 Microflapper emitters in effluent treatment and without filtration was significantly ($p<0.05$) smaller (19.1% for M4 and 26.7% for M8) compared to the control treatment (60.8% for M4 and 54.9% for M8). However, for the other tested emitters, no significant differences ($p>0.05$) between the control and the effluent treatment were found. Moreover, with the filtration system, Dra of the different emitters was very similar, being higher than 61% for both control and effluent treatments. The Dra of M8 emitter was significantly ($p>0.05$) higher with effluents than the control treatment under filtration condition due to the corrosion of elastic membrane, particle entrapment between elastic parts (Bralts et al., 1981; Ravina et al., 1992; Wei et al., 2008; Puig-Bargués et al., 2010; Li et al., 2019; Manbari et al., 2020) or microbial colonies

(Puig-Bargués et al., 2005). In addition, the performance of emitters with 4 l h^{-1} discharge was better than emitters with 8 l h^{-1} for each brand, with significant difference in some cases. Although higher discharge emitters are usually less prone to clogging (Ravina et al., 1992) in some cases they have shown more clogging (Maroufpoor et al., 2020), which may be due to emitter geometry (Pei et al., 2014), water release system and particle load and characteristics (Pinto et al., 2017) have an important effect. In general, the performance of Netafim and Corona emitters was better than Microflapper emitter showing the dependence of the Dra on the type of structure of its self-cleaning mechanism, not on the type of its mechanism.

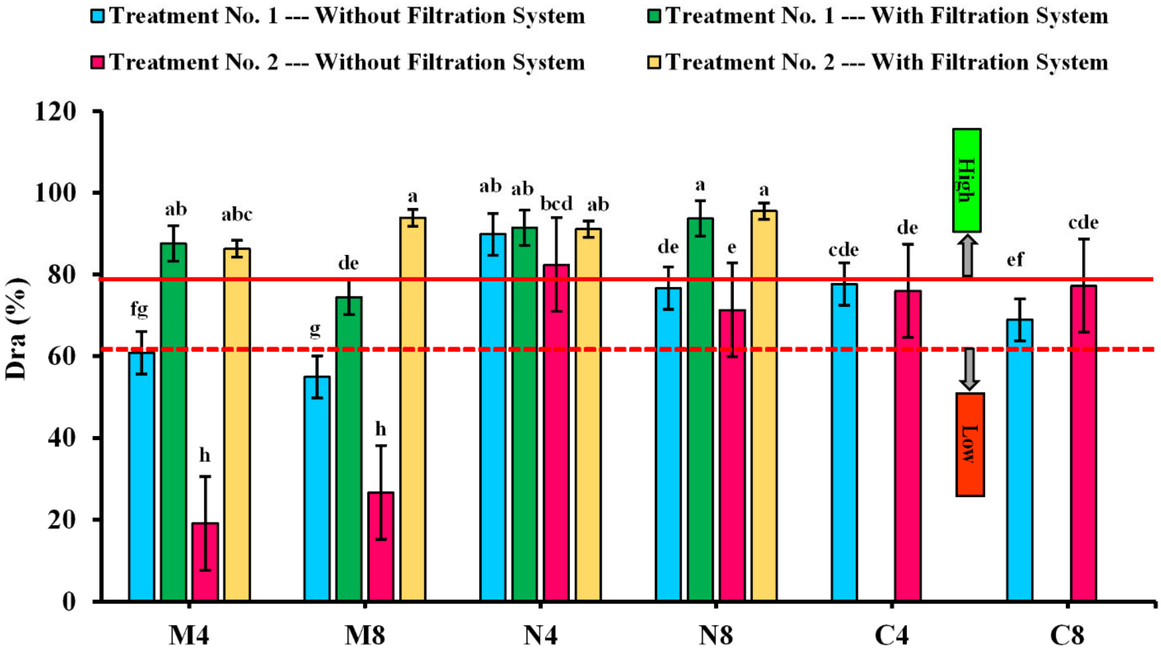


Figure 8- Average of relative discharge (Dra) for the last 3 irrigation events for the different emitters in control and effluent treatments, and with and without filtration system. Columns having at least one letter in common are not significantly different at 5% level.

Table 3 shows the results of variance analysis of the effect of different parameters (type of emitter, discharge of emitter, type of water, filtration system and irrigation periods (4 irrigation events in a row)) and their interactions on the relative discharge (Dra). The results show that except for the emitter discharge, the changes of all parameters and their interactions on the Dra were significant ($p<0.05$). Figure 9 shows the effect of treatment, emitter type and irrigation periods on the relative discharge of emitter in the presence or absence of the filtration system. According to Figure 9-a, Netafim and Corona emitters had acceptable Dra $Dra \geq 61\%$) regardless of the quality of water used in the whole irrigation season without using the filtration system. In these emitters, there were no significant differences ($p>0.05$) between Dra of irrigation periods except for the first and last periods. The lowest Dra was observed in Microflapper emitters with using the effluent ($25.9\% \le Dra_{M,T2} \le 50.1\%$). A descending trend was observed for Dra of the Microflapper emitters with using fresh water over time and these changes entered the critical area ($Dra<61\%$) during the irrigation periods 5 and 6. In this emitter, there was a significant difference ($p<0.05$) between the relative discharge of most irrigation periods for both control and effluent treatments.

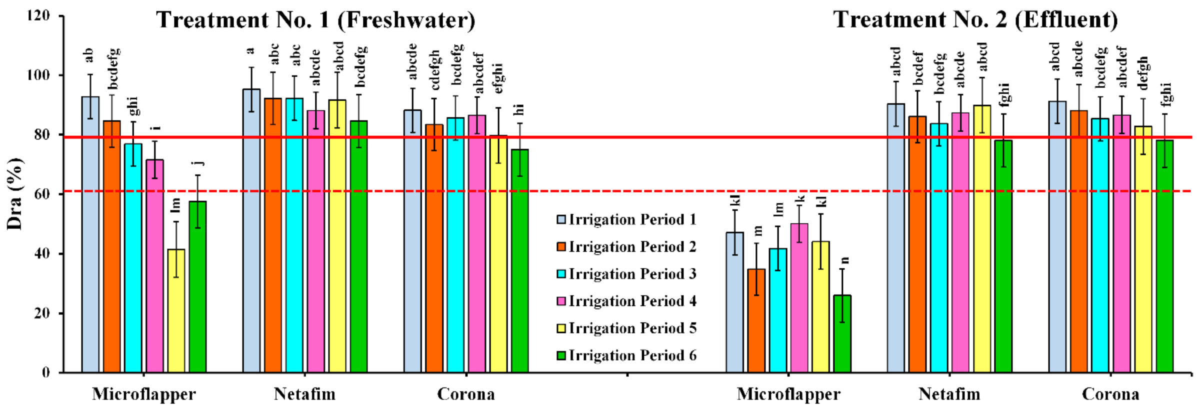
Under the conditions of using the filtration system, Dra of the Microflapper emitter in all irrigation periods (except for one case) was above 79% compared to non-filtration conditions, improving significantly ($p<0.05$) for both control and effluent treatments (Figure 9-b). The Netafim emitters performed best regardless of the filtration system and the quality of the water used, being their Dra>79% throughout the season, showing no significant differences ($p<0.05$) between irrigation periods.

Table 3. Results of analysis of variance of the studied factors and their interactions.

Source of change	**Degree of freedom**	**Mean square**	**F**	**P_r**
Discharge	1	$2.41\cdot10^2$	0.75	0.39
Emitter	2	$2.33\cdot10^2$	103.24	0.00
Treatment	1	$6.45\cdot10^3$	20.83	0.00
Irrigation Period	5	$1.23\cdot10^3$	3.92	0.00
Filtration	1	$2.06\cdot10^4$	73.56	0.00
Discharge * Emitter	5	$9.41\cdot10^3$	41.51	0.00
Discharge * Treatment	3	$2.25\cdot10^3$	7.24	0.00
Discharge * Irrigation Period	11	$5.92\cdot10^2$	1.87	0.04
Discharge * Filtration	3	$7.21\cdot10^3$	25.83	0.00
Emitter * Treatment	5	$1.22\cdot10^4$	61.87	0.00
Emitter * Irrigation Period	17	$3.22\cdot10^3$	14.91	0.00
Emitter * Filtration	4	$2.17\cdot10^4$	152.85	0.00
Treatment * Irrigation Period	11	$1.30\cdot10^3$	4.36	0.00
Treatment * Filtration	3	$9.77\cdot10^3$	37.16	0.00
Irrigation Period * Filtration	11	$2.73\cdot10^3$	10.28	0.00
Discharge * Emitter * Treatment	11	$5.62\cdot10^3$	28.37	0.00
Discharge * Emitter * Irrigation Period	35	$1.59\cdot10^3$	7.18	0.00
Discharge * Emitter * Filtration	9	$9.78\cdot10^3$	69.20	0.00
Discharge * Irrigation Period * Filtration	23	$1.36\cdot10^3$	5.04	0.00
Discharge * Treatment * Irrigation Period	23	$6.76\cdot10^2$	2.22	0.00
Discharge * Treatment * Filtration	7	$4.34\cdot10^3$	16.53	0.00
Emitter * Treatment * Irrigation Period	35	$2.11\cdot10^3$	11.65	0.00
Emitter * Treatment * Filtration	9	$1.22\cdot10^4$	128.36	0.00

Emitter * Irrigation Period * Filtration	29	$3.47\cdot10^3$	28.92	0.00
Treatment * Irrigation Period * Filtration	23	$1.82\cdot10^3$	7.38	0.00
Discharge * Emitter * Treatment * Irrigation Period	71	$1.08\cdot10^3$	5.65	0.00
Discharge * Emitter * Treatment * Filtration	19	$5.86\cdot10^3$	62.72	0.00
Discharge * Emitter * Irrigation Period * Filtration	59	$1.74\cdot10^3$	14.23	0.00
Discharge * Treatment * Irrigation Period * Filtration	47	$9.43\cdot10^2$	3.70	0.00
Emitter * Treatment * Irrigation Period * Filtration	59	$2.24\cdot10^3$	41.66	0.00
Discharge * Emitter * Treatment * Irrigation Period * Filtration	119	$1.15\cdot10^3$	22.98	0.00

(a) Without Filtration System



(b) With Filtration System

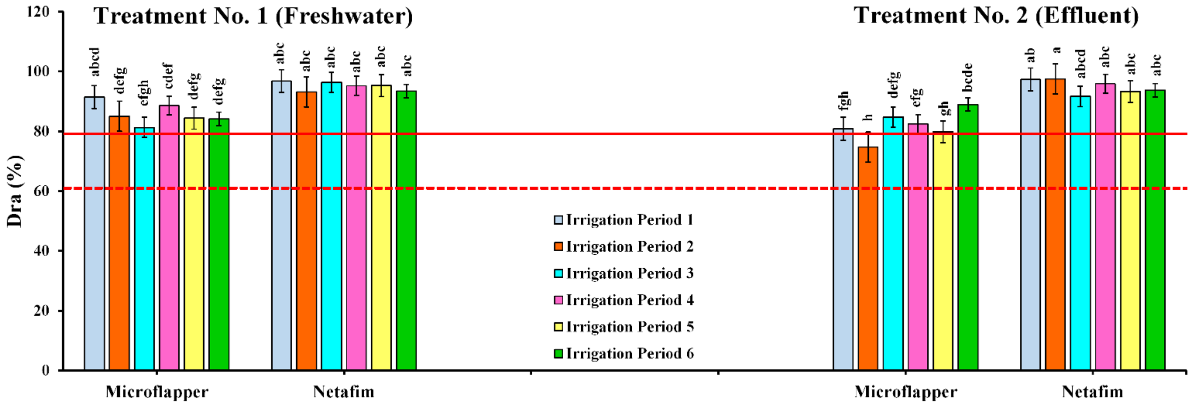


Figure 9. Effect of treatment, type of emitter and irrigation periods on the relative discharge (±standard error): a) without filtration system, and b) with filtration system. Columns having at least one letter in common are not significantly different at 5% level.

3.2. Christiansen uniformity coefficient (CU)

3.2.1. Control treatments

Figure 10 shows the evolution of CU for 24 irrigation events for each type of emitter with and without filtration system (units 1 and 2). The CU of all emitters was above 81% and had the least instability except for Microflapper (M4 and M8) and regardless of the presence or absence of filtration system. Without filtration system, M4 and M8 emitters showed oscillating CU between irrigation events, reaching values below the allowable limit ($CU \leq 70\%$) due to partially and completely clogged emitters. This the change in trend was similar to that of the Dra change trend. With the filtration system, CU of Microflapper emitters improved and their instability was mostly eliminated, except in a couple of irrigation events for M8.

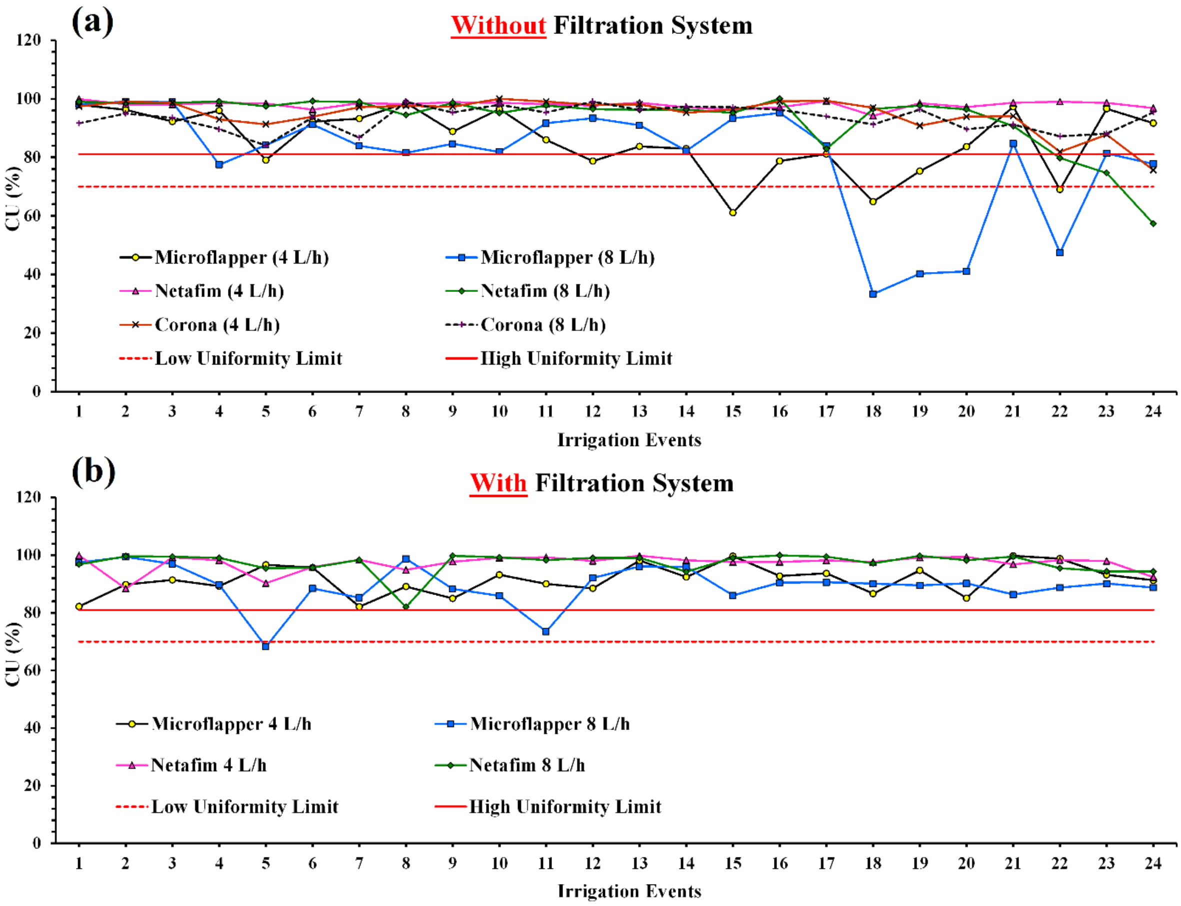


Figure 10. Evolution of the Christiansen uniformity coefficient (CU) of emitters studied in the control treatments for 24 irrigation events: a) without filtration system (unit 1), and b) with filtration system (unit 2).

3.2.2. Effluent treatments

Figure 11 shows how CU evolved for the emitters studied with and without filtration system when using fish farm effluent (units 3 and 4). Microflapper emitters (M4 and M8) performed poorly without a filtration system, which was similar to control treatment. Conversely, when the effluent was filtered, CU increased significantly ($p<0.05$) (on average, 17.9% for M4 and 31.3% for M8) and its instability improved. On the other hand, Netafim and Corona emitters performed in the same way in all irrigation events regardless of the filtration system ($79.5 \le CU_{Netafim} \le 100.0$ and)., respectively $68.7 \le CU_{Corona} \le 100.0$

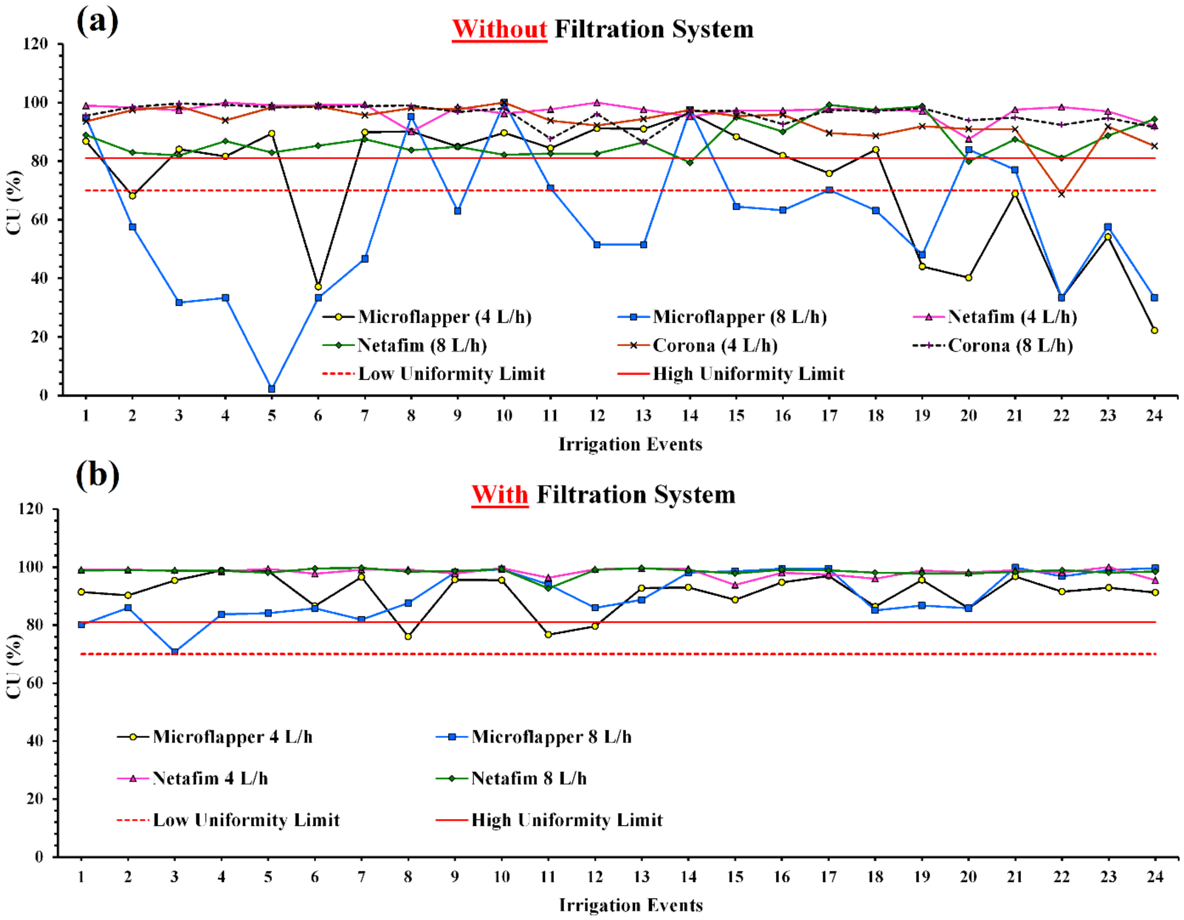


Figure 11. Evolution of the Christiansen uniformity coefficient (CU) of emitters studied in the effluent treatments for 24 irrigation events: a) without filtration system (unit 3), and b) with filtration system (unit 4).

3.2.3 End of irrigation season

Figure 12 shows the average CU values of the last 3 irrigation events for different emitters. Similar to the results obtained in Section 3.1.3, the N4 emitter performed well in all conditions regardless of the type of water used and the presence or absence of a filtration system and showed high CU values without significant differences between treatments (p>0.05) ($82.5 \le CU_{N4} \le 91.4$). The highest impact of the filtration system was found with M8 and N8 emitters in the control treatment, since they had CU significantly smaller (p<0.05) when water was not filtered. In the effluent treatment, the filtration system improved CU of the Microflapper emitters by an average of 67.2% and transferred it from the low-performance area to the high-performance area. Corona emitters also performed similar to Netafim ones and were in the high-performance area regardless of the use of the filtration system and the type of water used.

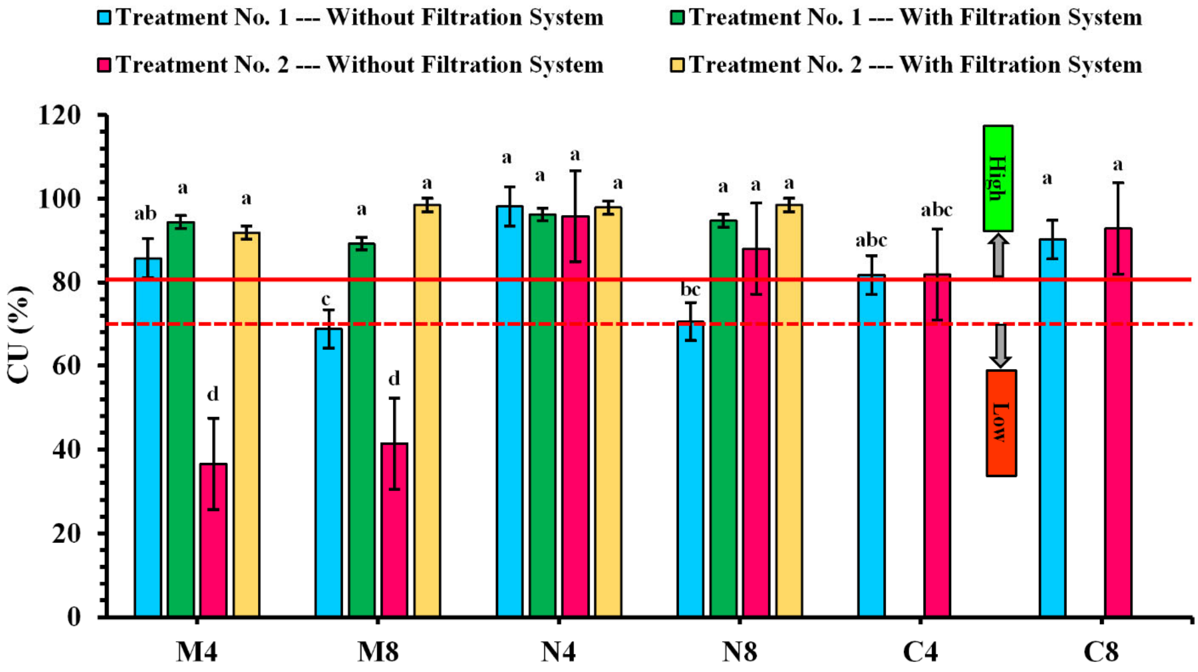


Figure 12 - Average of Christiansen Uniformity Coefficient (CU) of the 3 last irrigation events at the end of the season for emitters in control and effluent treatments with and without filtration system. Columns having at least one letter in common are not significantly different at 5% level.

3.3. Season relative discharge coefficient of variation (CV (Dra)$_S$)

Figure 13 shows the trend of CV (Dra)$_S$ for two water and the two filtration treatments depending on the type of emitters. Netafim emitters had a low CV (Dra)$_S$ regardless of the quality of the water and the use of the filtration system (lower than 11%). On the other hand, the effect of the filtration system was more evident on the performance of M4 and M8 Microflapper emitters since its CV (Dra)$_S$ was reduced from high and moderate values to low ones ($CV_{(Dra)S} \le 11$).

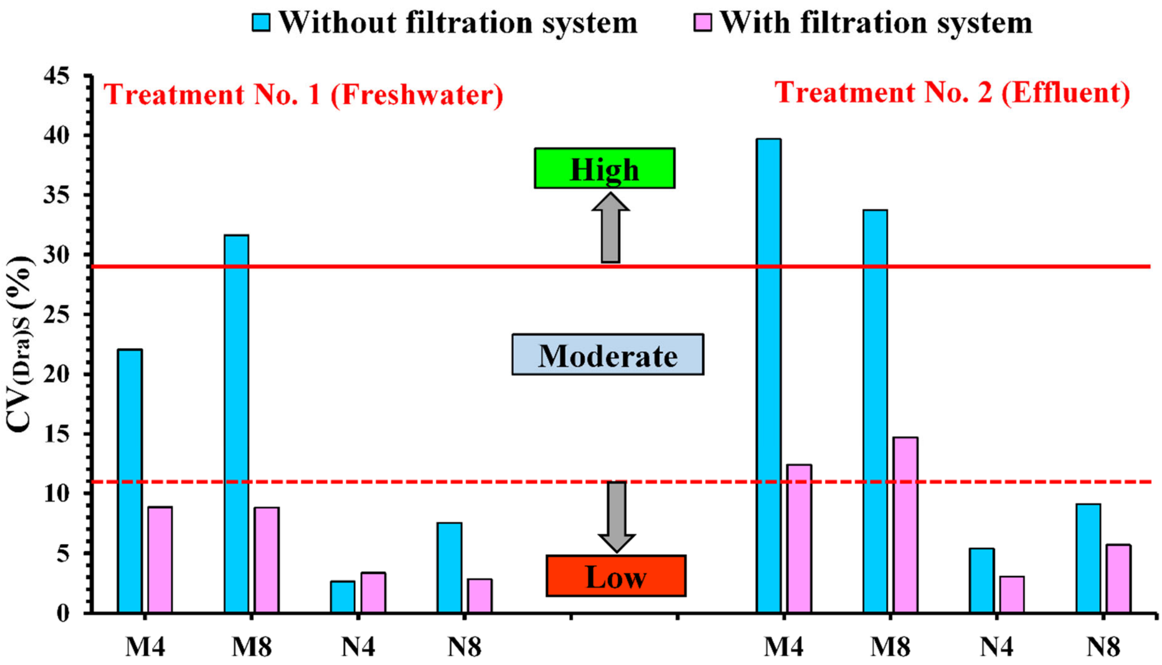


Figure 13. Relative discharge coefficient of variation for different emitters in the two treatments studied with and without filtration system.

4. Conclusions

The trend of relative discharge (Dra) and the Christiansen uniformity coefficient (CU) of the emitters was fluctuating and unstable in both control and effluent treatments. Microflapper emitters were the most unstable ($20.3\% \le Dra_{Freshwater} \le 98.4\%$ and $13.8\% \le Dra_{Effluent} \le 98.2\%$). There were significant differences (p<0.05) in Dra of most irrigation periods (i.e. four irrigation events in a row) for both the control and effluent treatments, and with and without filtration system. The maximum number of completely clogged emitters in an irrigation event in the absence of filtration was 61.1% for M4, 77.8% for M8 in the control treatment and 83.3% for M4 and 77.8% for M8 in effluent treatment.

In the absence of filtration system regardless of the quality of water, the performance of Netafim and Corona emitters was in the allowable area since $Dra \ge 61\%$. For Netafim and Corona emitters, there were no significant differences (p>0.05) between Dra of irrigation periods except for the first and last 4 irrigation events. These emitters became clogged only at the end of the season (completely clogged less than 10%). Under filtration conditions, the performance of the emitters studied in both control and effluent treatments were very close to each other and above

$Dra \geq 61\%$. In none of the treatments, there were no emitters under filtration conditions with complete clogging.

Changes in the emitter type, the emitter discharge, the water type, filtration system, irrigation periods and their interactions were significant ($p<0.05$) on the Dra index. In general, Netafim and Corona pressure-compensating emitters with a continuously and on-off self-cleaning mechanism, respectively, and also with the structure of labyrinth and silicone diaphragm, had the best performance in terms of hydraulic characteristics regardless of the quality of the water used and the filtration system, and their use is recommended for irrigation with effluent of rainbow trout fish farms.

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Competing Interests

All authors certify that they have no affiliations with or involvement in any of the companies with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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