Effect of a combined filtration system and drip irrigation laterals on quality of rainbow trout farm effluent

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Abstract

The main aim of this study was to investigate the qualitative changes of the rainbow trout effluent as water supply in a drip irrigation system. Two drip irrigation systems with a hydro-cyclone filter, sand filter and screen filter for using freshwater (control treatment) and fish farm effluent were tested in Kurdistan province (northwest of Iran) in 2017. In addition, the effect of lateral drainage at the end of each irrigation event was also studied. Two emitter types with different discharge flows were used for each treatment. In the 16 irrigation events carried out, samples were collected from the different water sources (dam, well, and river), filter outlets and lateral locations for measuring total suspended solids (TSS), particle size, pH, electrical conductivity, different compounds (Fe, Na, K, Ca, Mg, NO_3, PO_4, HCO_3) and the number of coliform bacteria. The results showed changes in the TSS and the number of coliform bacteria, but the remaining parameters had slight changes. In both control and effluent treatments, the filtration system significantly reduced TSS, having the screen filters the greatest effect on this decrease and hydro-cyclone and sand filter the least. In order to achieve higher removals, finer grains in sand filters. The filtration of both control and effluent treatments increased the number of bacteria. The highest number of bacteria in the control treatment was measured after the sand filter and in the effluent treatments after the screen filter

Keywords: Micro Irrigation; Water Reuse; Sand Filter; Screen Filter; Unconventional Water

1. Introduction

According to WWAP (2017), the global freshwater withdrawals are approximately 3,928 km^3 per year. About 44% of this water (i.e. 1,716 km^3 per year) is mainly consumed by agricultural land and through evaporation. The remaining 56% (2,212 km^3 per year) is released as municipal and industrial wastewaters and/or agricultural drainage. Reuse of wastewater in the agricultural sector can be very effective for alleviating water scarcity. On the other hand, the annual increment in global fish consumption (3.2 %) has been increasingly exacerbated by global population growth (1.6 %). In addition, the global fish production in the year 2016 reached 117 Mton/year, which means an increase of 11 % as compared with the year 2011 (FAO 2018).

The use of drip irrigation systems is one way to increase the productivity of the water resources due to its high water use efficiency (Martínez- Gimeno et al. 2018). However, one of the main problems related to drip irrigation is emitter clogging, which is mainly affected by water quality and the efficiency of the filtration system (Ravina et al. 1997; Capra and Scicolone 2004). Drip irrigation systems require a water treatment process such as filtration for preventing clogging. Hydro-cyclone, sand, screen and disc filters are common filter types used in drip irrigation systems. Several studies have been carried out on the pressure drop caused by various components of the filtration systems (Yurdem et al. 2008; Mesquita et al. 2012; Elbana et al. 2013; Bové et al. 2015; Zong et al. 2015), but less research (Puig-Bargués et al. 2005; Ribeiro et al. 2008; Tripathi et al. 2014; Wen-Yong et al. 2015) have been done on the efficiency of each filter type on the removal of organic and mineral matters from the water.

Tripathi et al. (2014) reported that the filtration efficiency of a combined sand-disc filter unit removing turbidity, total solids, calcium, magnesium, carbonate and coliform bacteria was greater than those achieved for these filters working alone. Wen-Yong et al. (2015) concluded that the removal efficiency of sand filters was in the range of 11.4% to 48%; but in a combined sand-disc filter this removal efficiency increased by 37% to 80.3%. However, the removal efficiency decreased with increasing the grain size of sand filter, as it was previously observed by Duran-Ros et al. (2009).

Ghaffari and Soltani (2016) showed that disc filters had a good efficiency in removing suspended and organic solid concentrations from 50 to 100 mg/l, but beyond 100 mg/l their performance was significantly reduced. Therefore, the use of sand filters is recommended before the disc filter. On the other hand, lateral flushing is a good maintenance practice that has shown its efficiency in removing the sediments that have accumulated within the laterals (Puig-Bargués et al. 2010) although does not avoid completely emitter clogging (Liu and Huang 2009; Li et al. 2015). However, in some areas, instead of flushing driplines at a given flushing velocity, lateral drainage is carried out by opening the dripline end as it is an easier and less costly maintenance practice.

To the authors' knowledge, there is not any published study on the use of wastewater from the fish farms in drip irrigation systems. The fish farm effluent contains many nutrients such as nitrogen and phosphorus that can be used by the plants (Gurung 2012; Mustapha et al. 2013). Moreover, the presence of organic matter in this type of the wastewater can improve the quality of the soil and reduce the cost of fertilization (Abdelraouf and Hoballah 2014; Becerra-Castro et al. 2015; Zajdband 2011). However, the presence of sludge particles, algae and non-consumable food waste by fish and the possibility of their accumulation in different parts of the filtration system may affect the drip irrigation system operation when fish farm effluents are used. On the other hand, the presence of sludge caused by the growth of bacteria may increase the probability of flocculation of sediment particles and, thus, emitter clogging.

The main objective of this study is to investigate the role of each component of the filtration system (hydro-cyclone, sand and screen filter) in improving or changing the quality of rainbow trout farm effluent. One of the other objectives of the present study is to compare the trend of changes in the basic parameters across the filtration system with the use of farm fish effluent and fresh water. Another goal of this study is to evaluate the interaction effects of filter type, type of emitter, and position of the emitter along the lateral on the concentration of suspended solids and the number of bacteria.

2. Materials and Methods

2.1. Experimental setup

Field experiments were carried out at the Abidar fish farm in Sanandaj (Kurdistan province, northwest of Iran), where rainbow trout (*Oncorhynchus mykiss*) is farmed. The water entering the fish farm was supplied from three different sources of Geshlagh Lake dam, Sirvan River, and a well.

The supplied water from the source fed 15 parallel fish ponds (each having a length of 15 m and a width of 4 m). The wastewater from the first pools immediately entered into 15 other ponds with the same dimensions where larger fish grew. The average flow velocity in these ponds was 2-3 cm/s, about half of 5 cm/s, which is the maximum flow velocity suggested in fish ponds (Klontz 1991). So, fish ponds provide a good opportunity for the formation of suspended solid particles and act like sedimentation pools. However, the activity of fishes increasing particle load should also be considered.

In this study, three different treatments were considered. The first treatment used fresh water entering the fish farm as the control treatment (Fig. 1). Freshwater sources varied across the experiment since water from Gheshlagh dam, Sirvan river, a well and a mixture of well and river water were used. In the second and third treatments (Fig. 1) the outlet effluent from the fish farm was used. Only in treatment 3, after each irrigation event with farm fish wastewater, the end of the laterals and manifold were opened until next irrigation and the pipes were drained (Fig. 1). In each of the three treatments, the water was filtered after pumping and then it was conveyed through a polyethylene pipe with external diameter of 50 mm to five lateral polyethylene pipes with an external diameter of 16 mm. The length of each lateral was 50 m, and there were 12 loops with emitters on each lateral placed at intervals of 4 m. This is a common drip irrigation system layout in the area. Five different emitter types (Table 1) with 4, 8 and 12 L/h flow discharges, respectively, were used in all the treatments. In each treatment, each lateral had only one type of the aforementioned emitters. The inflow discharge to each loop was 24 L/h. Considering the existence of 12 loops on each lateral, the total inflow to each dripline was kept at 288 L/h. So, the number of emitters per loop was 6, 3 and 2 for 4, 8, and 12 L/h discharge emitters, respectively. The characteristics of the different components of the used filtration system are presented in Table 2. The filtration system layout is common in the area for using freshwater. Sand filter had two filtration layers with 3-5 and 5-8 mm media size, respectively. Two or three silica sand layers with these media sizes are common in the area and they are intended to retain large particles with low density such as algae that have not been settled in farm fish ponds. Previous experiments using smaller sand media size (1-3 mm) showed important head losses across the filter that meant very short filtration cycles, which was not practical. The screen filter consisted of two cartridges with a filtration level of 125 μm and 149 μm, having the inlet cartridge the smallest diameter. In order to obtain the maximum efficiency, the manufacturer company of the screen filters used in this study recommended maximum flow discharge through the filter to be 135 L/s/m^2 of screen open area.

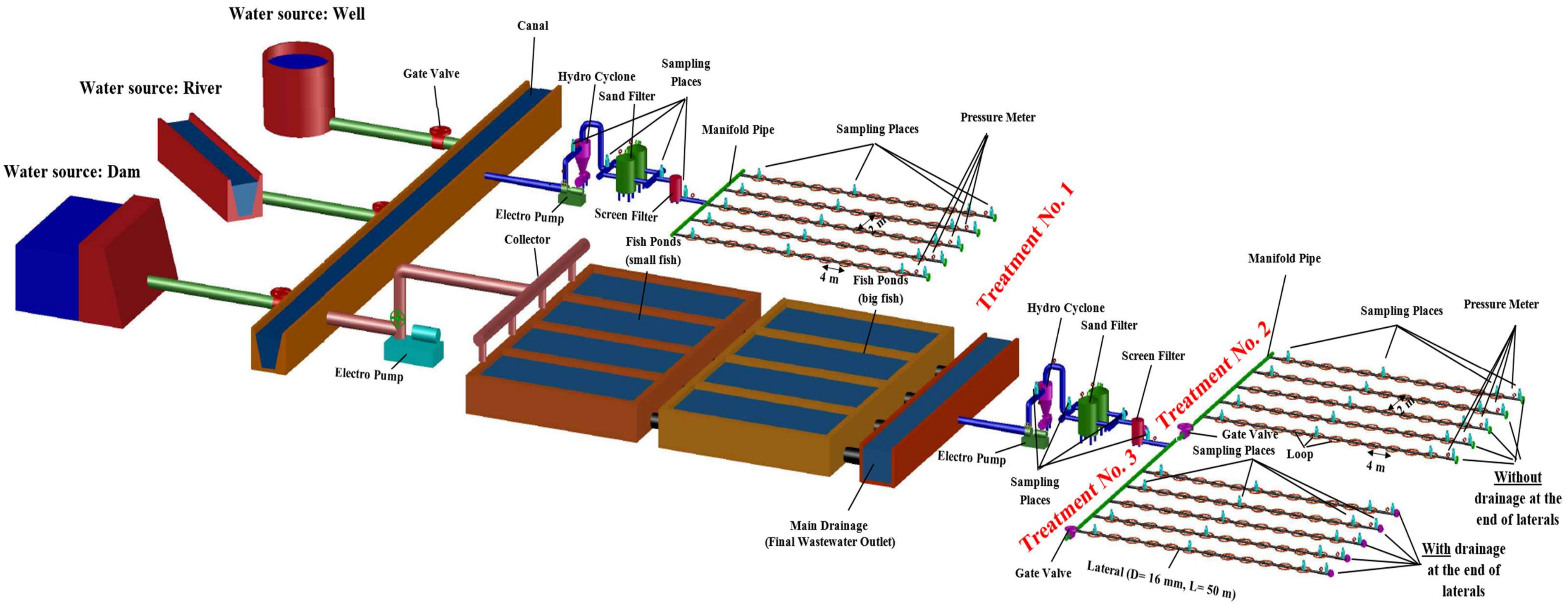

Figure 1. Experimental setup of the drip irrigation systems used with inlet fish farm fresh water and using rainbow trout's effluent

Table 1. Specifications of the emitters used in this study

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

Table 2. Specifications of the different filters used in this study

Filter type and model	External dimension (mm)		Maximum flow rate (m^3/h)	Inlet and outlet diameter (mm)	Pressure loss (kPa)	Filtration cross section (cm^2)	Grain Size/ Filtration level (mm)	Manufacture
	Diameter	Height						
Hydro cyclone (8 in)	210	830	18	50	3.92	-	-	Karaj Sazeh Equipment Co.
Sand filter (16 in)	400	1000	7.2	50	3.92	1300	First Layer: 3-5 Second Layer: 5-8	Karaj Sazeh Equipment Co.
Screen filter (6 in)	165	750	18	50	3.24	1570-2220	0.149-0.125	Abanegaan Company

2.2. Experimental procedure

At each irrigation event, the system was operated for 8 h. The inlet flow rate was 6 m^3/h for each filtration system with a pressure between 250 and 300 kPa. The extra flow rate was discharged from the end of the manifold, being minimum applied pressure for emitters at the end of laterals higher than 100 kPa. Using the pressure gauges installed at different parts of the filtration system in each treatment, the pressure drop of each filter was recorded. When the pressure drop reached the maximum allowable (which was considered to be 78 and 68 kPa for sand and screen filters, respectively, according to Bucks et al. 1979), filter washing was carried out. It should be noted that according to pressure measurements at different points of the filtration system, no overpressure was observed for the sand filter, but in the screen filter, washing was performed after most of irrigation events.

At the end of each irrigation event, the gate valve on the manifold was closed and the end of the laterals in treatment No. 3 were opened and the filtration system and laterals were drained. This maintenance operation was easily carried out due to the land slope (about 1 %). Then, the system was turned off for two days and irrigation was carried out on the third day. Overall, 16 irrigation events lasting a total of 128 h were carried out during two months. The characteristics of irrigation events are shown in Table 3. During these 16 irrigation events using different water sources in each system, freshwater and farm fish effluent samples in 3 repetitions were taken before and after the hydro cyclone, after the sand and screen filters, at emitter outlet in the first, sixth and twelfth loops, as well as from the ends of the laterals. A total of 240 samples from effluent treatments and 144 samples from control treatments were taken. In both effluent and control treatments, the materials filtered by sand and screen filters were analyzed using a Master Sizer Ver. S (Malvern Instruments Ltd, Malvern, UK) laser analyzer to determine the particle size distribution. It should be noted that "uniformity" (defined as the absolute deviation from the median particle diameter) and "span" $\left(Span = \left(D_{90} - D_{10}\right)/D_{50}\right)$ for particles filtered by sand and screen filters were determined. In addition, in each sample, suspended solid concentration (TSS), pH, electrical conductivity (EC), dissolved solids, iron, manganese, calcium, potassium, sodium, carbonate and bicarbonate concentrations, hydrogen sulfide, nitrate, ammonia, phosphate, sodium adsorption ratio (SAR), total hardness, and the number of bacterial coliforms were determined following standard methods (Adams 2017; Rice et al. 2005).

2.3. Data analysis

Data analysis was performed using SPSS software (IBM Corp., Armonk, NY, USA) as a part of a composite analysis based on the variables during the study period. At each time, a factorial experiment (4 × 4) with the factors of emitter position on the lateral, type of water and discharge of emitters, as well as their interactions, was performed based on completely randomized block design. Before the statistical analysis, using SPSS software, Kolmogorov-Smirnov test was fitted to the normality test. If the data were not normal, a normalization process of the data was performed.

Table 3. Characteristics of the different irrigation events

Irrigation event No.	Inflow water source	Washing fish ponds	Fish feeding	Screen filter washing for water treatment
1	Gheshlagh Dam	Yes	2 times	No
2		No	2 times	No
3		Yes	1 time	Yes (Effluent)
4		Yes	2 times	Yes (Effluent)
5		Yes	2 times	No
6		Yes	2 times	No
7		Yes	2 times	Yes (Effluent and Control)
8		Yes	2 times	Yes (Effluent)
9	Sirvan River	No	1 time	No
10		Yes	1 time	Yes (Effluent (morning and evening) and control)
11	Combined River and Well	Yes	-	Yes (Effluent and control (morning))
12		No	-	Yes (Effluent and control (morning))
13	Sirvan River	No	2 times	Yes (Effluent (morning))
14	Well	No	-	Yes (Effluent (morning))
15		No	2 times	Yes (Effluent)

16	No	2 times	No

3. Results and Discussion

3.1. Characteristics of water sources

Based on sampling at different points across the filtration system for the three irrigation treatments, differences in parameters of pH, EC, SAR, Na, K, Ca, Mg, NO_3, NH_3, PO_4, and HCO_3 were negligible (Table 4). According to Table 5, these parameters are within the permissible range of emitter clogging potential. The trend of changes in suspended solids, the number of bacteria and iron will be discussed in depth in the following sections.

Table 4. Average values of qualitative parameters for control and effluent treatments.

Property	**Parameter**	**Source**							
		Gheshlagh Dam		**Sirvan River**		**Mixed well and river water**		**Well**	
		Effluent	**Control**	**Effluent**	**Control**	**Effluent**	**Control**	**Effluent**	**Control**
Chemical	pH	8.0	8.0	8.1	8.1	7.9	7.9	7.9	7.8
	Soluble materials (mg/L)	208.9	204.2	293.4	293.8	202.5	201.6	189.7	181.8
	Potassium (mg/L)	1.9	1.7	1.9	2.0	2.0	1.7	1.9	1.6
	Calcium (mg/L)	49.7	49.7	49.2	54.7	41.4	46.8	46.8	42.8
	Magnesium (mg/L)	17.0	12.7	17.4	22.8	8.9	5.3	1.6	1.6
	Total hardness (mg/L)	194.2	176.1	194.5	230.3	140.1	138.4	123.4	116.8
	Bicarbonate (mg/L)	138.3	142.6	218.2	225.3	194.2	168.8	183.9	156.6
	Nitrate (mg/L)	45.0	9.3	53.9	15.5	---	---		---
	Phosphate (mg/L)	0.3	0.1	0.8	0.3	---	---		---
	Salinity (dS/m)	0.3	0.3	0.5	0.5	0.3	0.3	0.3	0.3
	Sodium absorption ratio $(meq/L)^{0.5}$	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2

Table 5. Comparison of the classification of qualitative criteria for irrigation water for emitter clogging potential

Property	**Parameter**	**Clogging hazard rating**								
		Minor			**Moderate**			**Severe**		
		a	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**
Physical	Suspended solids (mg/L)	n.c.	<50	n.c.	n.c.	50-100	n.c.	n.c.	>100	n.c.
Chemical	pH	<6.5	<7	<7	6.5-8.4	7.75	7-8	>8.4	>7.5	>8
	Electrical conductivity (dS/m)	<0.7	n.c.	<0.75	0.7-3	n.c.	0.75-3	>3	n.c.	>3
	Soluble materials (mg/L)	<450	<500	<700	450-2000	500-2000	700-2000	>2000	>2000	>2000
	Magnesium (mg/L)	n.c.	n.c.	<25	n.c.	n.c.	25-90	n.c.	n.c.	>90
	Iron (mg/L)	n.c.	<0.1	<0.2	n.c.	0.1-1.5	0.2-1.5	n.c.	>1.5	>1.5
	Total hardness (mg/L)	n.c.	<150	80-120	n.c.	150-300	120-200	n.c.	>300	>200
	Bicarbonate (mg/L)	<90	n.c.	n.c.	90-520	n.c.	n.c.	>520	n.c.	n.c.
	Nitrate (mg/L)	<5	n.c.	n.c.	5-30	n.c.	n.c.	>30	n.c.	n.c.
	Sodium absorption ratio $(meq/L)^{0.5}$	<3	n.c.	<3	3-9	n.c.	3-9	>9	n.c.	>9
Biological	Number of coliform bacteria (Mn/mL)	n.c.	$<10^4$	n.c.	n.c.	10^4-$5*10^4$	n.c.	n.c.	$>5*10^4$	n.c.

Notes: emitter clogging hazard classified according to (a) Ayers and Westcot (1994); (b) Pitts et al. (1990); and (c) Couture (2004).
n.c.: not classified.

3.2. Filtered Particles

It should be noted that due to the negligible amount of filtered particles at hydro-cyclone for both control and effluent treatment and at sand filter for the control treatment, the particle analysis was not conducted in these cases. The cumulative distribution function (CDF) and probability density function (PDF) for the filtered particles by screen filter is shown in Fig. 2 for both control and effluent treatments. According to this figure, the minimum diameter of the filtered particles by screen filter in both control and effluent treatments was 0.065 µm, while the maximum size of the filtered particles in the control and effluent treatments were 330 and 489 µm, respectively. In addition, the particle diameters that have 50% of the mass smaller (D_{50}) for control and effluent treatments were 18.41 and 53 µm, respectively. According to the classification of the United State Department of Agriculture (Adamchuk et al. 2015), the filtered particles from the screen filter of the control treatment contained 6.5% clay, 78.5% silt, and 15% fine-to-medium sand, and all particles are mineral. On the other hand, Fig. 2a shows that the filtered particles followed a normal distribution in the control treatment. However, in the fish farm effluent, the filtered particles were coarse and the particle size distribution was less skewed (Fig. 2b). The particles found in the fish farm effluent, unlike those in freshwater, were organic and consisted mainly of algae, sludge from fish farm and food residues given to fish. The lack of inorganic particles in the trout farm effluent was due to that those particles present in freshwater have enough time to settle in the fish farm ponds. Fish feces and secreted materials from their bodies that can be directly and indirectly by sticking other particles together appear in the outlet of the screen filter when filtering the fish farm effluent.

The cumulative distribution function (CDF) and probability density function (PDF) curves for the filtered particles by sand filters in the effluent treatment are shown in Fig. 3. The diameter of the smallest and largest filtered particles in sand filters were, respectively, 0.066 µm and 489 µm, being these values similar to those obtained with the screen filter in the effluent treatment. The average diameter of the gravel particles used in the first layer of sand filter was 4 mm (Table 2). According to Keller and Bliesner (1990), the sand filter should filter the particles having a diameter of one-twelfth of the average diameter of the sand media particles (i.e. 333 µm). However, only 1% of the filtered particles (Fig. 3) had a diameter greater than the aforementioned value. In fact, the particles in the fish farm's wastewater were much smaller than the above-mentioned diameter. On the other hand, according to Fig. 2b, about 99% of the filtered particles by screen filter had a diameter smaller than 333 μm. In addition, according to the results presented in Figs. 2 and 3, the uniformity (defined as the absolute deviation from the median particle diameter) of the particles filtered by screen filter in both control and effluent treatments were 1.20 and 1.19, respectively, while it was 1.59 for the particles at sand filter outlet. Particle uniformity below 1.5 means a good uniformity on particle distribution. On the other hand, the particle size distribution's span after the screen filters for both control and effluent treatments were 3.59 and 3.90, respectively, and for sand filter with effluent was 5.56. D_{90}, D_{50} and D_{10} describe the diameters where 90, 50, and 10% of the particle distribution had a smaller particle size, respectively. The smaller the particle size distribution's span the best is the particle distribution uniformity. The results indicated that the grain size used in the sand filter is not suitable considering the particle sizes in the effluent and its treatment efficiency is lower than those of the screen filter. It should be noted that the roughness and coarseness of the sand filter particles are factors affecting the filtering of particles in the wastewater by sand filter (Verma et al. 2017).

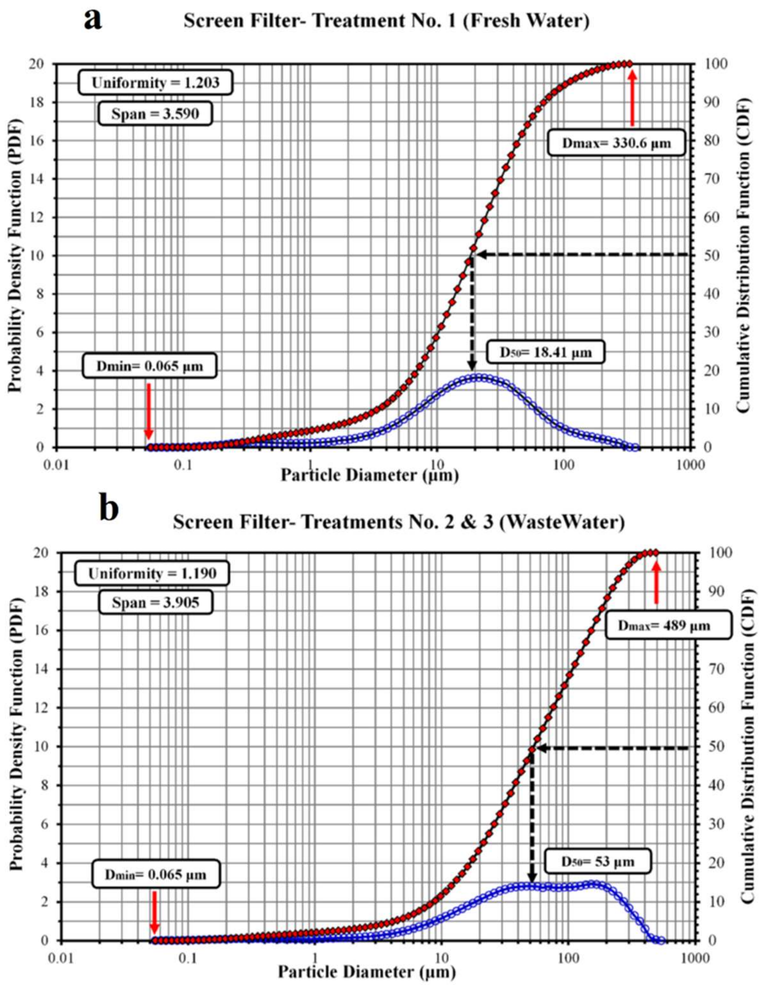

Figure 2. CDF and PDF diagrams of the particles filtered by screen filter using a) freshwater and b) fish farm effluent.

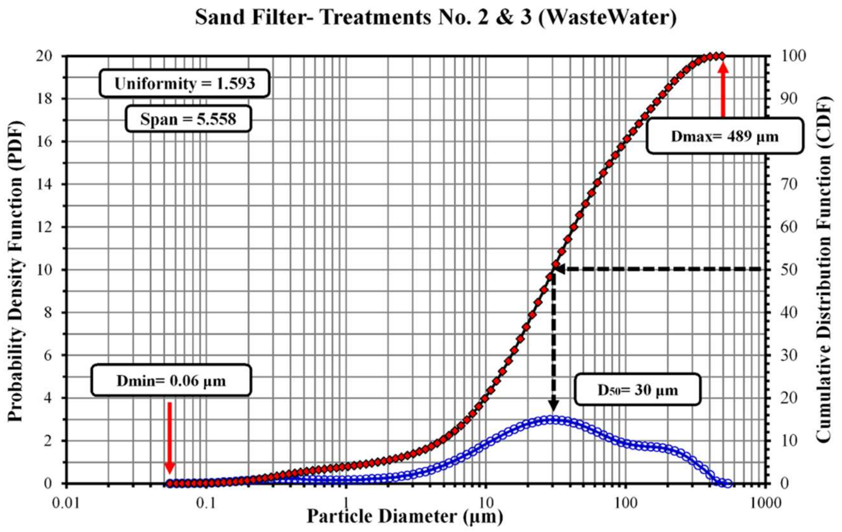

Figure 3. CDF and PDF diagrams of the filtered materials by sand filter using fish farm effluent.

3.3. Changes in suspended solids

3.3.1. Water Source: dam

Figure 4 shows the trend of changes in the suspended solids in fresh water and fish farm effluent in the first four irrigation events when this parameter was analyzed. The suspended solid concentrations for irrigation events No. 1 and 4 at filtration system inlet using the effluent were much higher than those of the irrigation events No. 2 and 3 (Fig. 4b). The reason was that fish farm effluents collected particles during the farm washing and during the two fish feeding events carried out at these irrigations events, as reported in Table 3. When trouts were fed, the suspended solid concentrations in the effluent reached the maximum values due to intense fish movements inside the fish farm. On the other hand, washing the farm pools caused a separation of particles from the bottom and, consequently, the suspended solid concentration increased. Average suspended solid concentrations across the filtration system decreased (Fig. 5) for both the control and effluent treatments, with the exception of sand filter using effluent. Suspended solids were significantly reduced ($p<0.05$) after being filtered in the hydro-cyclone, sand and screen filters for both freshwater and trout farm effluent. (Fig. 5). However, no significant differences were observed between any of the filter outlets. Screen filter achieved the highest suspended solids removal (23.33% and 43.17% with freshwater and effluent, respectively). Smaller suspended solid removals observed by hydro-cyclone (8.90% and 20.47% with freshwater and effluent, respectively) and sand filter (9.77% and 4.89% with freshwater and effluent, respectively) reflect the low role of these two filters in removing suspended solids and the good performance of the screen filter placed before the aforementioned two filters.

Mailapalli et al. (2007) analyzed the performance of a 0.20 m hydro-cyclone for drip irrigation that was tested with concentrations of suspended solids between 300 and 1200 mg/L. Working with an initial flow rate of 20 m^3/h, suspended solids removals were between 10 and 30% for 300 mg/L concentrations. In the present experiment, average suspended solid concentrations were below 300 mg/L, except when water river was used, and flow rates (1.44 – 2.88 m^3/h) were also smaller than those used by Mailapalli et al. (2007). Probably, the low suspended solids load and hydro-cyclone flow rate may explain the smaller suspended solid removals obtained.

Low suspended solids removal achieved by sand filter can be explained by the coarse media size used and the lack of filter backwashing. Higher solids removals have been observed with smaller media sizes (Duran-Ros et al. 2009; Elbana et al. 2012). Tripathi et al. (2014) found increases in solid content when wastewater was filtered using a gravel filter with 1-2 mm media size. The lack of sand filter backwashing allows solids to pass through this filter. In this sense, Elbana et al. (2012) recommended frequent back washings since they allow better filter performance and maintenance. However, in the present experiment, the great media size caused low pressure loss and no filter backwashing was carried out.

The results of the variance analysis on the changes in the suspended solid concentrations within each studied drip irrigation systems are presented in Table 6. There was a significant difference ($p<0.01$) between the suspended solid concentrations in the laterals (each treatment had 5 laterals) and in the different positions on the laterals (loops No. 1, 6, 12 and the end of the pipe). In addition, the interaction between the type of emitters and position along the lateral, and the interaction between the system, the type of emitters and position along the lateral were also significant at the 5% level (Table 6 and Fig. 6). The highest suspended solid concentrations were observed at the end of the laterals of the effluent treatments (treatments No. 2 and 3) with Netafim emitters (Fig. 6). In other cases, there was no significant difference between the suspended solid concentrations at different positions within the laterals for a given emitter. The reason was the different geometric structure of the Micro flapper and Netafim emitters. The flow path of the Micro Flapper emitters is narrow and relatively polygonal, being this emitter more sensitive to the changes in the pressure and sedimentation compared with the Netafim emitters (Patil et al. 2013; Wu et al. 2013; Shamshery and Winter 2018). Despite there was no significant difference between the amounts of suspended solid discharged by Micro Flapper and Netafim emitters, average values were greater for Micro Flapper emitters, which may mean that an accumulation of solids took place at the end of the lateral of Netafim emitters over the time. At this location, the difference between suspended solids was significant ($p < 0.05$) depending on the emitter.

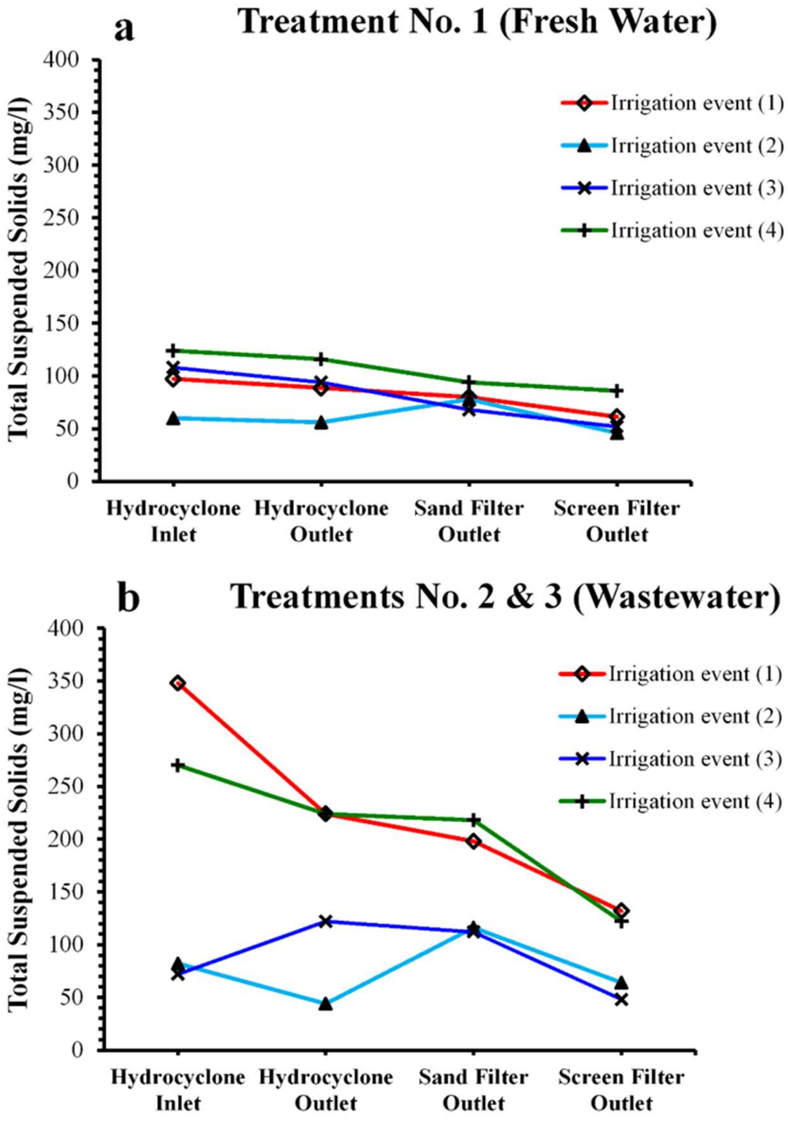

Figure 4. Changes in suspended solid concentrations across the filtration system when using a) freshwater and b) farm fish effluent.

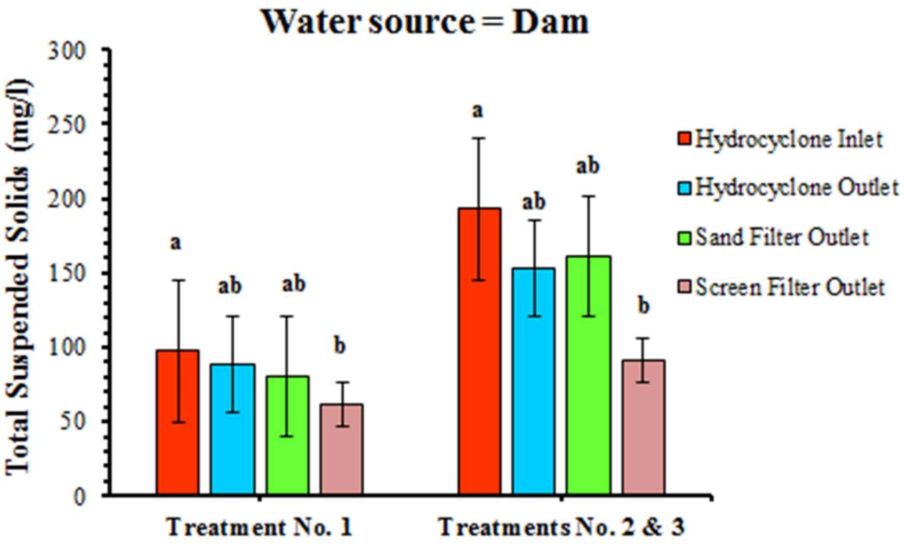

Figure 5. Average suspended solid concentrations and standard error bars across the filtration system of the control and effluent treatments.

Table 6. Variance analysis of changes in suspended solid concentrations in each drip irrigation system.

Source of change	**Degree of freedom**	**Mean Square**[*]	**Significance level (%)**
Block	3	$1.34 \cdot 10^5$	< 1
Treatment	2	$5.81 \cdot 10^3$	n.s.
Emitter	1	$1.39 \cdot 10^4$	n.s.
Position (on the lateral)	3	$2.24 \cdot 10^4$	< 1
Emitter * position	3	$1.63 \cdot 10^4$	< 5
Treatment * emitter	2	$0.24 \cdot 10^3$	n.s.
Treatment * position	6	$6.47 \cdot 10^3$	n.s.
Treatment * emitter* position	6	$1.11 \cdot 10^4$	< 5
Error	69	$4.89 \cdot 10^3$	n.s.
Total	95		n.s.

n.s.: Not Significant

* Mean Square value: sum of squares value divided by the degrees of freedom.

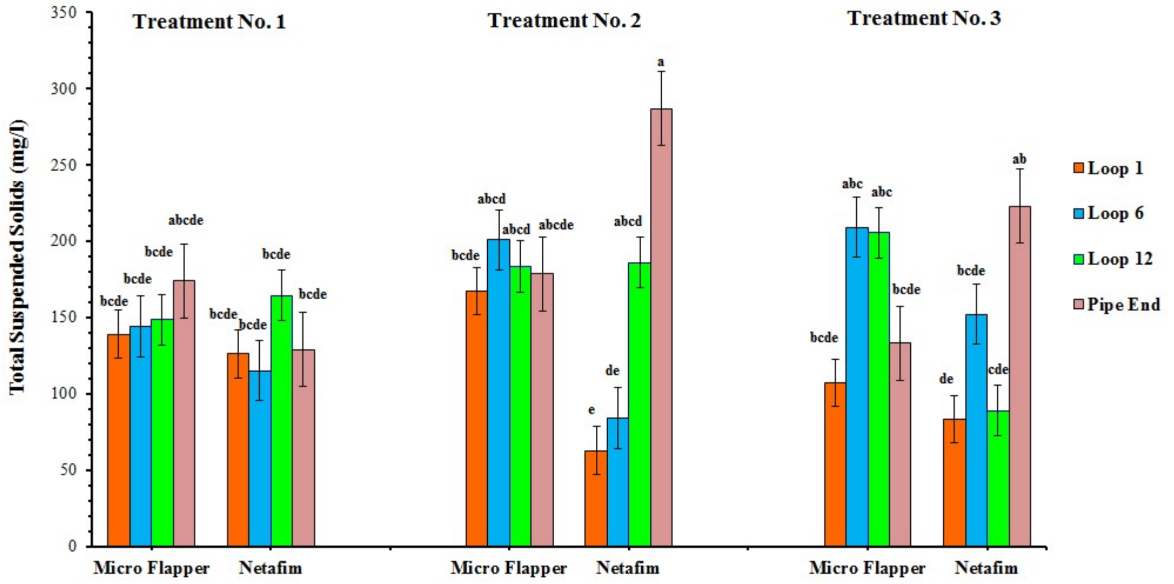

Figure 6. Effect of the treatment, emitter, and position along the lateral on the average total suspended solid (± standard error) concentrations.

3.3.2. Water Source: river and well

The previous results were obtained using water from Gheshlagh dam, which was used in irrigation events 1-8. The following irrigation events (Table 3) were carried out using the other inflow water supplies (Sirvan River, well and mixed River and well). The suspended solid concentrations for both control and effluent treatments decreased after filtration and then increased significantly ($p < 0.05$) at the end of the laterals of treatments No. 1 (control) and No. 2 (effluent without lateral drainage) (Fig. 7). The reason was the accumulation of sediments and suspended particles at the lateral endings. When lateral drainage was carried out in treatment 3, the concentration of suspended solids was significantly reduced compared to treatment 2. The concentration of suspended solids in irrigations events No. 12 and 13 (Fig. 7a) was high before the filtration system of the control treatment due to the use of Sirvan River water, which had higher TSS load (Table 3). For irrigations events No. 14, 15 and 16, well water was used and inlet TSS were reduced. Also, in irrigations events No. 13, 15, and 16 fish feeding were carried out twice, but TSS in irrigations events No. 12 and 13 (Fig. 7b) were slightly higher than in irrigation events No. 14, 15 and 16, which can be explained by the type of water supply and the feeding to the fish. As it was previously commented, fish ponds achieved reductions on TSS before filtration from 35 to 52%. For example, for irrigation event No. 12, TSS before entering the filtration system was 467.3 mg/L for freshwater, more than twice that in the effluent treatment (222.7 mg/L).

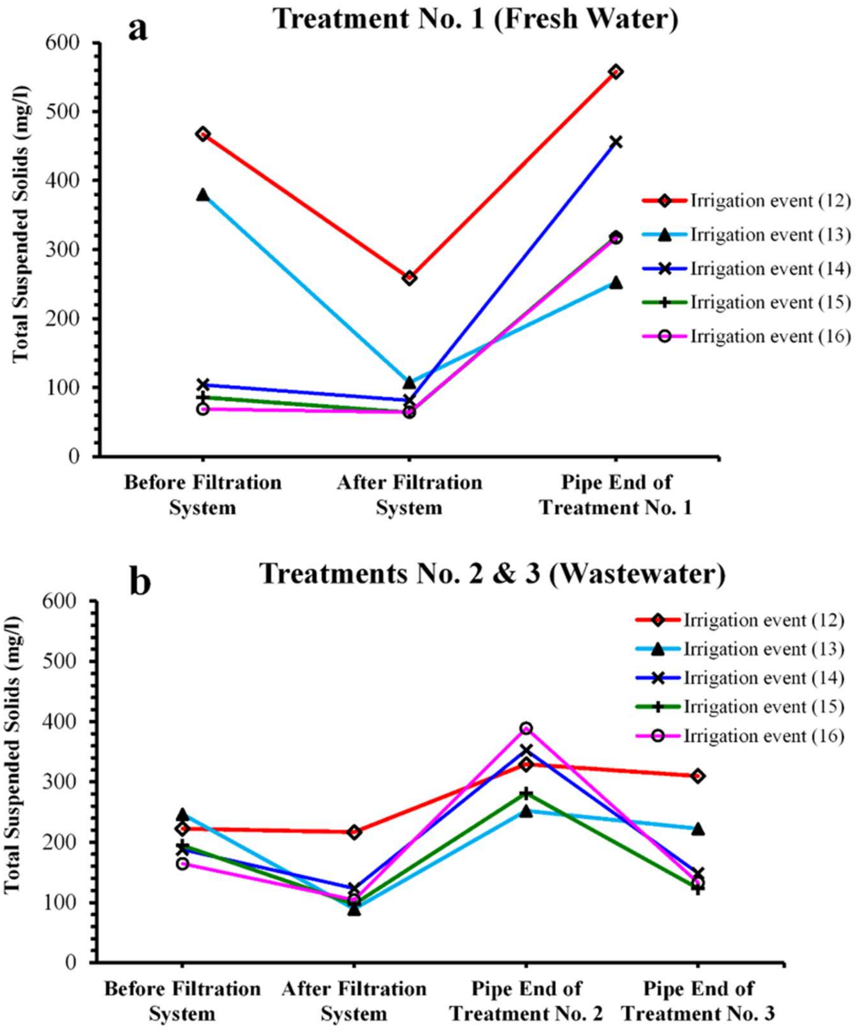

Figure 7. Changes in the suspended solid concentrations regarding water supply (river water and well) a) using fresh water (treatment 1) and b) farm fish effluent (treatments No. 2 and 3).

There were no significant differences in TSS at filter inlet and outlet when well water was used in the control treatment (Fig. 8a). However, at the end of the laterals, sediment accumulation increased and there was a significant difference ($p<0.05$) on TSS regarding filtration system outlet, with increases about 4 times more. TSS were also significantly reduced ($p<0.05$) after filtration when effluent was used but sediment accumulation at the end of the laterals for treatment 2 led to a significant increase on TSS at this location. Lateral drainage allowed to have TSS no significantly different than those of inlet and filtered effluent (Fig. 8a).

When river water was used, in the control treatment, the filtration system significantly reduced the highest values of TSS conveyed by these water source. However, despite the reduction effect of the filtration system, there was no significant difference between the TSS of the inflow water and the outflow water to/from the filtration system (Fig. 8b). In addition, a no significant increase on TSS was observed at the end of laterals that was not reversed by lateral drainage. Although flushing reduces sediment deposition on laterals (Puig-Bargués et al. 2010), the complexity of the flow regimes that occur within laterals and the effect of flushing velocity and time (Puig-Bargués and Lamm 2013) could explain the small reduction on TSS observed with the more loaded effluents.

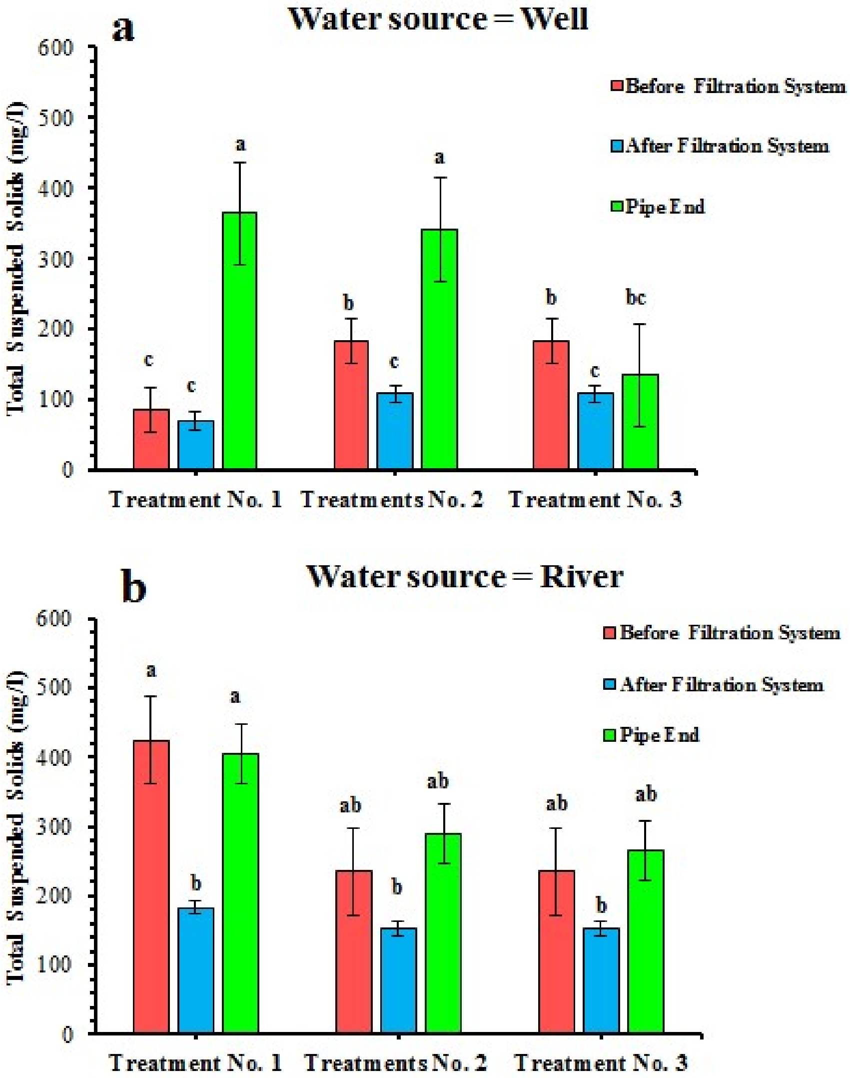

Figure 8. Changes in the average suspended solid concentrations and standard error bars in control and effluent treatments for water supply a) Well and (b) River water.

According to Fig. 8a, the suspended solids concentration in the effluent treatments (before filtration system) was significantly higher than the corresponding value in the control treatment for the well water source. Despite the low concentration of suspended solids in the well water, after entering the fish ponds and due to the fish activity, suspended solids increased considerably. Conversely, the suspended solids concentration in the control treatment was greater than the effluent treatments when river water was used (Fig. 8b). The reason was the role of pond fish as settling basins, leading to the deposition of suspended solids and the reduction of its concentration before entering the filtration system.

3.4. Changes in the number of coliform bacteria

3.4.1. Water source: dam

For both the control and effluent treatments, the number of coliform bacteria (Fig. 9) increased across the filtration system. However, maximum average values were below the minor biological clogging hazard threshold (10^4 bacterial population per ml) suggested by Bucks et al. (1979). In the control treatment with dam water (Fig. 9), the highest number of coliform bacteria was found after the sand filter, which was significantly higher ($p<0.05$) from other filter outlets, due to the accumulation of organic particles and microorganisms among the sand layers in the sand filter. The screen filter reduced coliform bacteria using freshwater; while when filtering effluent, increased them. As mentioned previously, when discussing particle results, those effluent particles entering to the filtration system in treatments No. 2 and 3 were mainly organic, containing more biological materials than the control treatment, while the particles from dam water (control treatment) were mainly inorganic. Screen filters are usually more efficient removing inorganic particles, as particle analysis shown (Section 3.2) but not bacterial population. However, for the effluent treatment, despite the significant coliform bacteria increase between the input and output of the filtration system, there were no significant differences at any filter outlet.

The results of the variance analysis for coliform bacteria in each drip irrigation system (effluent and control treatments and different emitters) are presented in Table 7. Differences between the number of bacteria in each irrigation treatment were significant ($p<0.01$). On the other hand, the interaction between the irrigation treatment and the position along the lateral as well as the interaction between the type of emitter and location were significant ($p<0.05$). Coliform bacteria number of dam water was significantly smaller ($p<0.05$) than that of effluent (Fig. 10a). However, the number of bacteria at the end of the lateral in the effluent treatment (with and without lateral drainage) was not significantly different, indicating that the lateral drainage did not affect the number of bacteria. Lateral drainage in the present experiment was carried out after each irrigation event. As no velocity was given to water during lateral drainage, biofilm detachment observed with a 0.45 m/s flushing velocity (Li et al. 2015) could not be produced. This could be the reason for the lack of effect of the drainage carried out in this experiment on reducing coliform recounts.

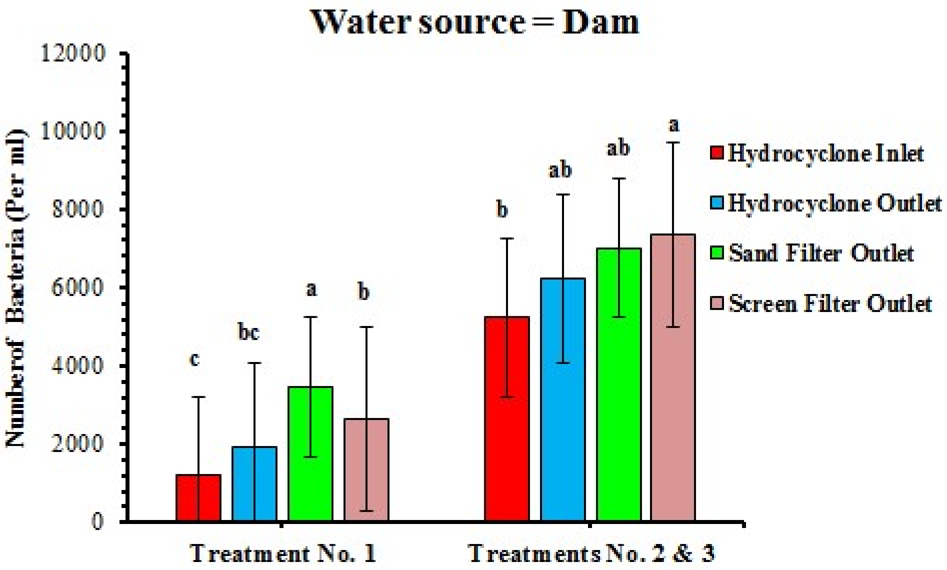

Figure 9. Trend of changes in the average number of bacteria in the filtration of control and effluent treatments.

Table 7. Variance analysis of the changes in the number of bacteria within each drip irrigation systems

Source of Change	Degree of freedom	Mean Square	Significance level (%)
Treatment	2	$5.41 \cdot 10^{8}$	< 1
Emitter	1	$2.48 \cdot 10^{3}$	n.s.
Position (on the lateral)	3	$1.03 \cdot 10^{7}1$	n.s.
Emitter * position	3	$1.92 \cdot 10^{7}$	< 5
Treatment * Emitter	2	$1.68 \cdot 10^{6}$	n.s.
Treatment * position	6	$1.28 \cdot 10^{7}$	< 5
Treatment * emitter* position	6	$4.91 \cdot 10^{6}$	n.s.
Error	168	$5.64 \cdot 10^{6}$	n.s.
Total	191		

n.s.: Not Significant

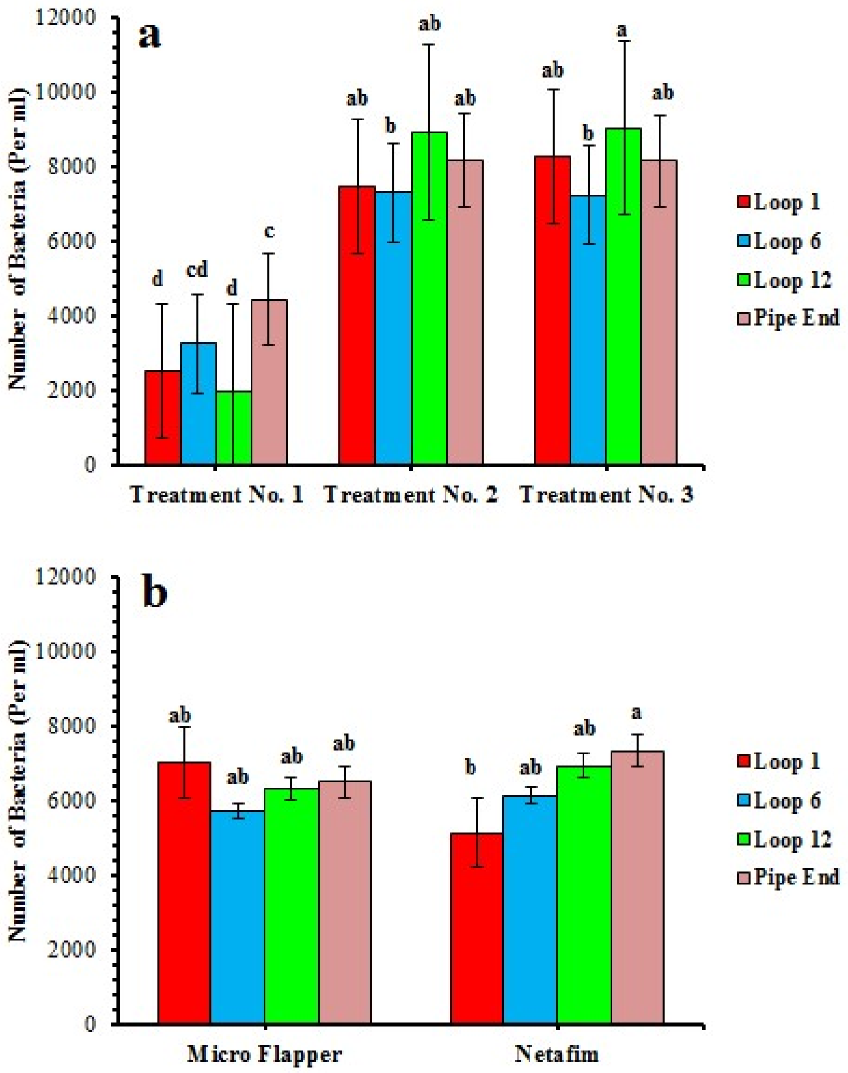

Figure 10. Number of coliform bacteria in the control and effluent irrigation treatments considering the effect of a) the treatment and the position along the lateral, and b) the type of the emitter and the position along the lateral pipe.

Coliform bacteria increased along the lateral for the Netafim emitters (Fig. 10b) in such a way that the maximum recount was found at the end of the lateral, being significantly higher ($p<0.05$) than at the first loop. The reason was the accumulation of sediments and fine sludge particles at the end of the lateral. However, for Micro flapper emitters, more coliform bacteria were measured in the first loop, although there were not significant differences along lateral length. By examining the clogged emitters, it was found that in the first regions of the laterals, Micro flopper emitters with flow rate of 8 L/h were clogged, which could be due to the increase in the number of bacteria in the first loop.

3.4.2. Water source: river and well

Results for coliform bacteria using river water and well as water supply are shown in Figs. 11 and 12. For both water sources, the number of coliform bacteria in the control treatments was smaller than that of effluent treatments. Although coliform bacteria increased at filtration system outlet, there were not significant differences ($p<0.05$) for either dam (Fig. 12a) or river (Fig. 10b) waters. Working with trout farm effluents, there were neither significant differences on coliform bacteria, although less average values at filtration system outlet were found with the effluent paired with river water (Fig. 11b). Coliform bacteria average values tended to be greater at lateral end, but without significant differences with the filter outlet. Lateral drainage had not any significant effect on coliform recounts for both effluents.

3.5. Changes in iron

The presence of iron and hydrogen sulfide in the waters containing organic carbon may cause the formation of filaments of sludge (Nakayama and Bucks 1991). On the other hand, the bacteria inside the system may feed on iron deposits during their growth process, leaving their own strands and sludge that can cause clogging (Goyal 2014). Algae and bacteria in the primitive state are so small that they are easily able to pass through the emitters and do not cause clogging; however, they can stick to suspended solids such as clay and silt particles to cause emitter clogging (Shortridge and Benham 2018). For this reason, it is important to study the changes in iron intake in fish farms. According to Fig. 13, for both control and effluent treatments, the iron concentration increased at hydro-cyclone outlet, reached the maximum at sand filter outlet, being then reduced at screen filter outlet. However, there were no significant differences ($p<0.05$) on iron concentrations at any tested point for both control and effluent treatments. In case of occurrence of any chemical reaction in the components of the filtration system that dissolved iron, it was necessary to change the concentration of some chemical elements, pH or salinity. Based on the water characteristics, these changes are negligible and there can be no chemical reaction to iron. There were no changes in the iron concentration in different points of irrigation system. On the other hand, the changes in the iron for both control and effluent treatments (Fig. 13) was in the range of μg/l. It should be noted that in all treatments, the iron concentration was lower than the smaller threshold (≤ 0.1 m/l according to Ayers and Westcot (1994) and ≤ 0.2 m/l according to Bucks et al. (1979)) for having a minor chemical clogging hazard.

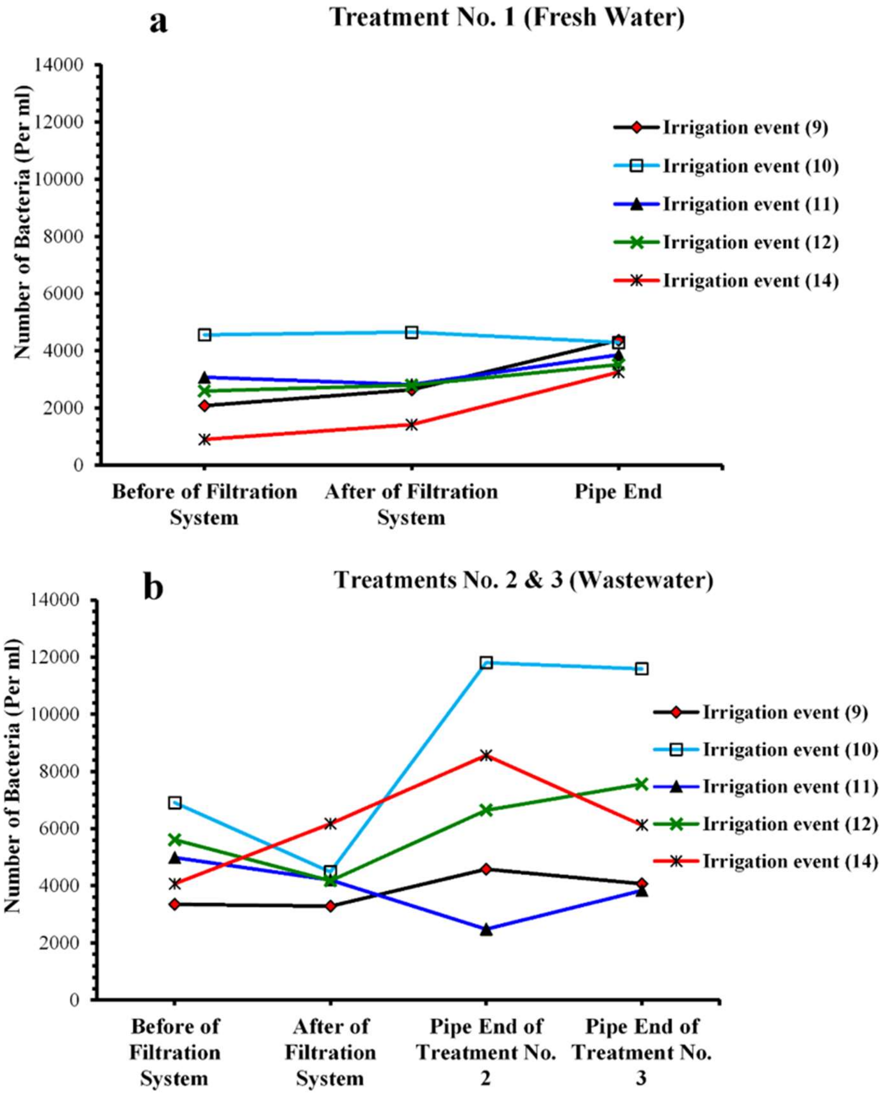

Figure 11. Changes in the number of bacteria by changing the main water supply a) treatment 1 b) treatments 2 and 3

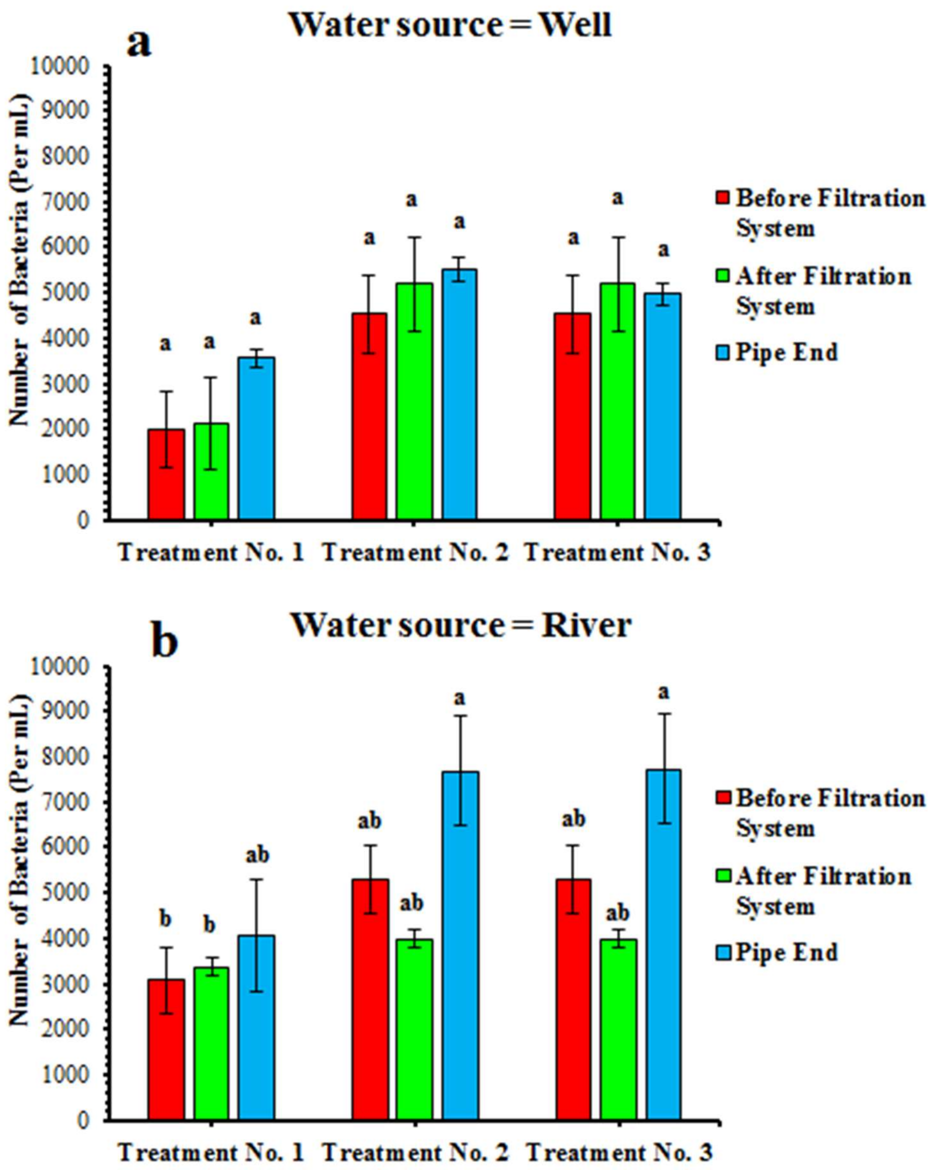

Figure 12. Changes in the average number of bacteria in the control and effluent treatments with water supply of a) Well b) River

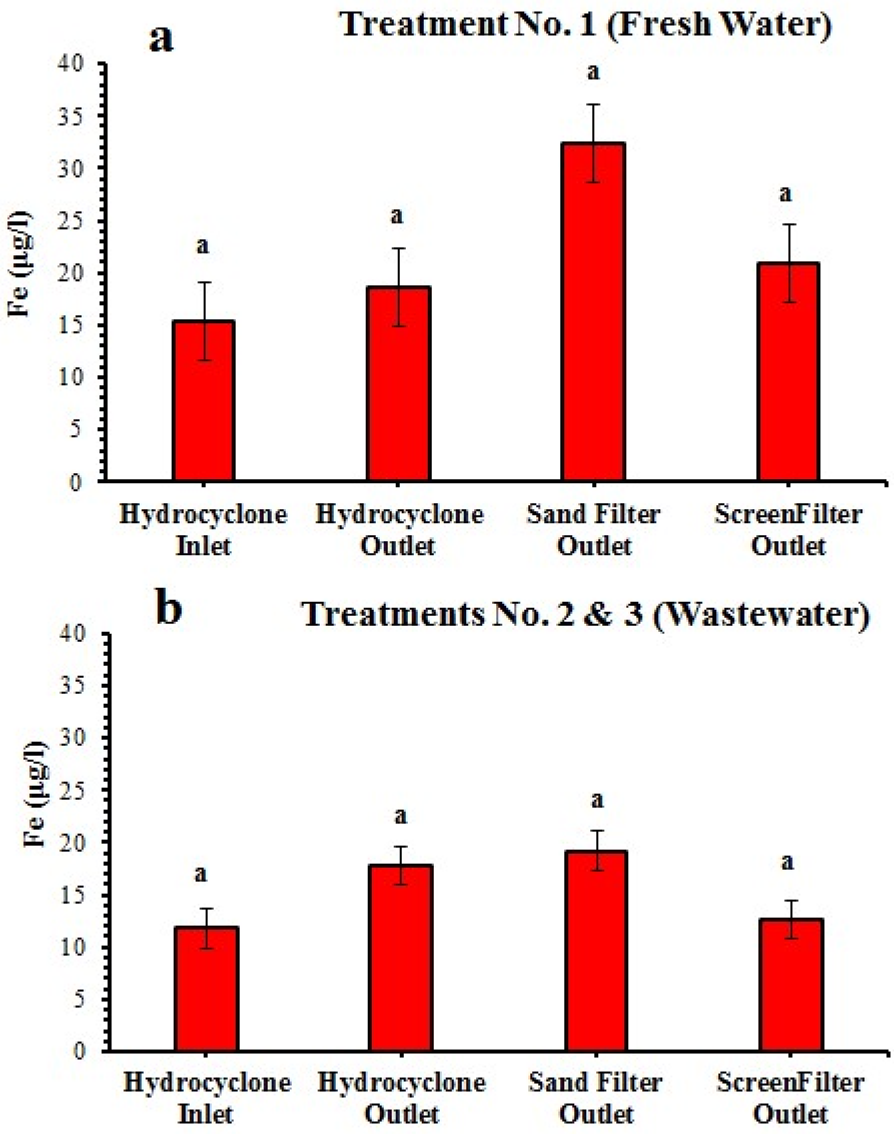

Figure 13. Changes in the average iron concentration in the filtration system a) Control treatment b) Effluent treatments

4. Conclusions

A filtration system consisting in a sequence of hydro-cyclone, sand and screen filters significantly reduced ($p<0.05$) the concentration of suspended solids for both control (23.33%) and rainbow trout fish farm effluent (43.17%) treatments, but increased the number of bacteria. The lateral drainage did not change the number of bacteria but reduced the suspended solid concentrations. The difference between the suspended solid concentrations at different positions on the laterals was significant, being the highest suspended solid concentration found at the end of the lateral with Netafim emitters that used fish farm effluent. Iron concentration for both irrigation systems was constant, however, and filters slightly changed its values at a no significant level. The effect of water supply (dam, well, and river) on the performance of the components of the filtration system was also studied. The results showed that the type of water supply and the initial quality of the water entering the filtration system had a significant effect on its performance.

The experiment carried out showed the feasibility of using effluents from a trout fish farm in a drip irrigation system. A combined filtration system with hydro-cyclone, sand and screen filter as well as a maintenance practice consisting on lateral drainage after each irrigation event, allowed having moderate physical and microbiological emitter clogging hazards. Further research is warranted for assessing the real effect on emitter clogging.

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Compliance with Ethical Standards

The authors declare that there is no conflict of interest.

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