Feeding Emitters for Microirrigation with a Digestate Liquid Fraction up to 25% Dilution Did Not Reduce Their Performance

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Abstract: Irrigation with wastewater can strongly contribute to the reduction of water abstraction in agriculture with an especial interest in arid and semiarid areas. However, its use can have drawbacks to both soil and micro-irrigation systems, especially when the total solids in the wastewater are high, such as in digestate liquid fractions (DLF) from plant material. The aim of this study was thus to evaluate the performances of a serpentine shaped micro-emitter injected with a hydrocyclone filtered DLF (HF-DLF) from corn + barley biomass and evaluate the traits of the liquid released within a 8-h irrigation cycle. HF-DLF was injected at 10%, 25%, and 50% dilution compared to tap water (at pH = 7.84) and the system performances were measured. No clogging was found, which likely depended on both the shape of the emitter and the high-pressure head (200 kPa). HF-DLF dilution at 10%, 25%, and 50% consisted in +1.9%, +3.5, and −4.9% amount of liquid released compared to the control. Fluid temperature during irrigation (from 9:00 to 17:00) did not explain the difference in the released amounts of liquid. In 10% HF-DLF % and 25% HF-DLF, a pH difference of + 0.321 ± 0.014 pH units compared to the control was found, and such difference was constant for both dilutions and at increasing the time. In contrast, 50% HF-DLF increased pH by around a half point and such difference increased with time. Similar differences among treatments were found for the total solids in the liquid. These results indicate that 50% HF-DLF was accumulating materials in the serpentine. These results suggest that a low diluted HF-DLF could directly be injected in irrigation systems with few drawbacks for the irrigation system and contribute to water conservation since such wastewater are available from the late spring to the early fall, when water requirements are high.

Keywords: clogging; drip irrigation; emitter; hydrocyclone; digestate liquid fraction; wastewater

1. Introduction

Water availability for crops in various areas of the world is reducing because of climate change and the use of fresh water for other human uses. Climate change is increasing the demand for water in agriculture through both a general increase of temperatures, and thus of the evapotranspiration demand, and the increase of their variability [1,2].

Irrigation with low-quality water, and especially wastewater, was thus proposed a long time ago as a suitable measure to mitigate the shortage of high quality water [3,4]. The use of wastewater

or filtrate of the liquid fractions of various wastes can increase the availability of water for agriculture. However, its use may result in a wealth of problems following the effects wastewater has on soil and irrigation systems. These include salinization or pH variation [5], a reduction of other soil fertility properties [6], and an increase of soil hydrophobicity [7], the clogging of the emitters [3], as well as the deposition of solid materials in the tanks or other parts of the irrigation system [8]. Besides, wastewaters may contain pollutants and pathogens which harm plants and animals, albeit the treatments they undergo are meant to prevent health risk following their use or disposal [9,10].

Drip systems allow the achievement of high irrigation efficiency in areas with high water demand and low water availability. In these systems, water pressure is usually below 200 kPa, and emitters have internal serpentine to compensate pressure loss along the line and potential fluctuations in the water pressure.

The success of the use of wastewater in the irrigation depends on a wealth of factors. These include the amount of solids in the wastewater or its filtrate, the ability of the suspended material to form biofilms, the pressure of the water in the system, the type of filters and emitters, and age of the systems [8,11–14]. In case of low pressure (60 kPa) and low rate emitters (0.9 and 1.4 L h^{-1} emitter^{-1}), high quality drip tapes showed a reduction of uniformity of distribution by 5.2% on average depending on the activated sludge used as secondary effluent [15]. Similar results were found by Puig-Bargués et al. [14], who also reported that pressure compensating emitters performed better than non-pressure compensating emitters. Chlorination or flushing of the pipes at the end of each irrigation cycle proved to reduce the impact on clogging [14,16]. However, such treatments imply an additional cost, and application of chlorine to the soil may have harmful effects both on the soil and on plants. In the latter work [16], application of compressed air cleaning at a pressure of 1.96 kPa did not mitigate the incidence of drippers clogging.

Digestate from crop biomass and manure is increasingly being used, and its liquid fraction was indicated as a potential source for a wastewater irrigation [17]. When used for irrigation purposes, information on the solid particles fractions, mostly salts, of these liquids in the irrigation systems are scarce. Such salts are likely to precipitate and, together with other suspended solids, can easily clog the emitters of a drip irrigation system by a fouling accumulation [18]. In turn, digestate filtrates used for irrigation can increase plant yield [6], even when compared to an irrigated + fertilized treatment [19]. However, little information is available about the efficiency of many emitters when subjected to wastewater, especially when using the liquid fraction of the biomass-based digestate, as the solid fraction can contain high amounts of organic material [20].

The aim of the present study was thus to test the efficiency of a commercial emitter when injected with the liquid fraction of the effluent from an agricultural biogas unit previously treated with a hydrocyclone filtration system.

2. Materials and Methods

2.1. Experimental Setup

The study was conducted in February 2020 at the CREA-IT institute (45°31′21.9″ N 9°33′54.9″ E, Treviglio, Bergamo, Italy). The liquid digestate used was gathered from an anaerobic digestion plant, stored in a tank and filtered using a hydrocyclone filter (Alfaturbo Hydrocyclone Sand separator 2″). The hydrocyclone filter was placed between a storage tank and the operating tank. Both tanks had a 1 m^3 maximum volume. After the filtration, the filtered liquid was shaken once per day before the beginning of the tests (see below) by gently shaking the tank using a forklift truck. The storage of the liquid digestate before using it at the irrigation setup lasted for 8 days.

The characteristic of the liquid digestate before the filtration are depicted in Table 1. The digestate liquid fraction was kindly provided by the Società Agricola Pallavicina S.R.L. (Via Fara—24047 Treviglio, IT), which also undergoes quality analyses, and did not display the presence of any pathogen nor pollutants according to the Italian laws.

Table 1. Composition of the digestate liquid fraction used for the test. Values are means ± s.d. (3 subsamples) provided by the management office of the digester. The analyses were made on the digestate liquid fraction hydrocyclone filtering.

Trait	Value	Unit	Method
Dry matter content at 105 °C	4.91 ± 0.03	%	IRSA CNR Q 64 Vol 2 1985
Ashes (dry matter content at 600 °C)	1.42 ± 0.02	%	
Chemical Oxigen demand (COD)	51.0 ± 1.8	$g\,O_2\,kg^{-1}$	APAT IRSA CNR 5130 Man 29 2003
Total N	3.55 ± 0.02	$g\,N\,kg^{-1}$	IRSA CNR Q 64 Vol 3 1985
NH_4^+-N	1.848 ± 0.025	$g\,N\,kg^{-1}$	
Phosphorus	0.843 ± 0.051	$g\,P\,kg^{-1}$	UNI EN 16174:2012 and 16170:2015
Potassium	4.96 ± 0.25	$g\,K\,kg^{-1}$	

A water pump of 0.75 kW power (Pedrollo company, model: JSWm 2CX, San Bonifacio, Verona, Italy) was used to pump the digestate liquid fraction in the irrigation system. The operating pressure was set to 0.2 MPa. Samples were taken from the non-filtered digestate liquid fraction (DLF), from the filter outlet and from the filtered DLF to determine dry matter content and pH.

The experimental design consisted of two factors: filtrate dilution (FD) × time of the sampling within the irrigation cycle (TIME). The FD factor had four treatments: One control using freshwater and three filtrate dilutions (10%, 25%, and 50% of filtrate in freshwater). Each irrigation cycle lasted 8 h and samples were taken once per hour.

One irrigation cycle per day was performed, the irrigation cycles began with the tap water and continued with each increasing concentration of the digestate to avoid contamination. Each water-HF-DLF mixture was prepared mixing the relevant amount of tap water and HF-DLF in an operating tank and reflushing it several times with the pump. The water pump used was set at 0.2 MPa operating pressure, and the irrigation tank was filled with 400 L of DLF. Before starting each test, three samples were collected from the irrigation tank to measure the dry matter and the pH of the solution, following the methodology described above. In addition, flushing with tap water was performed by 15 min at the end of each cycle to allow for the cleaning the system. A pre-flushing was also made before the beginning of the first experiment with tap water. Within each irrigation cycle, the pump recycled part of the water or diluted HF-DLF into the tank to keep it mixed and avoid particle deposition. The irrigation system was organized by three polyethylene 1-m long dripper tubes (Stocker company N°26085, Bozen, Italy), as replicates, with three emitters each. The dripper tubes used had 0.016 m of diameter (maximum design pressure 0.4 MPa) and were spaced 0.33 m each other. Water flow declared by the manufacturer was 2 L h^{-1}. Emitters were not changed from each cycle to the following one.

2.2. Measurements and Analyses

During the tests, the water or filtrate dropping from the tubes was collected in plastic flagons placed underneath each emitter (Figure 1). The flagons were weighted once per hour with a portable scale (RADWAG WLC6/C1/R, Radom, Poland, used with 0.1 g sensitivity) to calculate the water flow (g h^{-1}). At the time of weighting the turbidity and the temperature of the liquid were measured. The temperature of the water or DLF were measured in °C using the DS18B20 digital thermometer (Maxim IC, San Jose, CA, USA). The turbidity of water or DLF were measured by using the turbidity sensor SKU:SEN0189 (Arduino, Ivrea, Italia), which was used as an indirect measurement of filtrate and water quality. The turbidity sensor SKU:SEN0189 uses light to detect suspended particles in water by measuring the light transmittance and scattering rate, which depends on the concentration of the total suspended solids (TSS) in the solution/dispersion. In particular, the sensor provide an output expressed in mV, which should be calibrated to the corresponding Nephelometric Turbidity Units (NTU). The output slightly and linearly decreases at increasing temperatures. In addition, the relationship between output and NTU value is not linear (for a brief description see https://wiki.dfrobot.com/Turbidity_sensor_SKU__SEN0189). In particular, the higher the sensor output, the lower the liquid NTU value. The manufacturer provide an output for pure water of 4.1 ±

0.3*V* when temperature span from 10 °C to 50 °C. Integration of the temperature and turbidity systems was made according to [21]. In the present work, the output of sensor was provided along with a direct measurement of the total suspended solids.
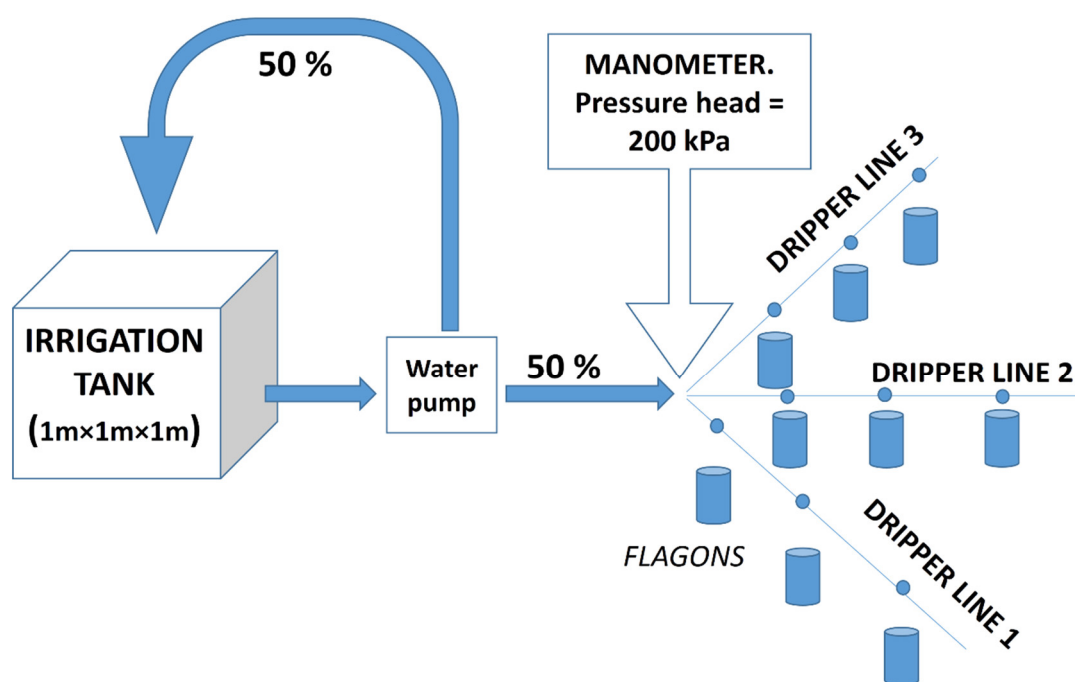

Figure 1. Design of the irrigation tests.

Dry matter and moisture content of the samples were assessed by oven drying at 105 °C until constant weight [22]. The pH of the samples was measured with no dilution by using a CRISON GLP21 pH-meter (Hach Lange Spain, S.L.U., Barcelona, Spain).

Then, the samples of each emitter per line were mixed and a random composite subsample of 500 mL of liquid was taken. In total, 24 sample per irrigation test were obtained (8 sampling moments × 3 irrigation lines). Each irrigation test consisted of the injection of a DLF dilution in an 8-h irrigation cycle. Thus 72 total samples of DLF released by each line were obtained. Dry matter of each subsample and its pH, following the methodology described above, were measured. For the control test (100% water), turbidity and pH were measured only before starting the test and no samples were collected during the test. This was done since these variables did not change by the time in the control from previous tests (data not shown). To monitor the air temperature and humidity of the indoor environment where the test was performed a sensor DHT22 (Guangzhou Aosong Electronics Co., Ltd., Guangzhou, China) was used. The Waterproof DS18B20 Digital Temperature Sensor was used to read the liquid temperature.

2.3. Computations and Statistical Analysis

The amounts of OH^- ions per ton of solution released by the emitters were computed by using the pH and used as a proxy of the potential of the irrigation with the DLF to increase the pH of a soil compared to the tap water used as a control. The analysis of variance was performed according to the statistical design by means of a general linear mixed model (Glimmix procedure in SAS/STAT 9.2 statistical package; SAS Institute Inc., Cary, NC, USA). The model used was similar to that shown in Saia et al. [23] (see the supplementary material in [23] for both a description of the procedure and the SAS package model applied) in which TIME was modelled as a repeated measurement [24]. Unbiased estimates of variance and covariance parameters were estimated by restricted maximum likelihood (REML). Repeated measurement analysis was modelled by applying a random statement with a first-

order autoregressive covariance structure. In particular, the subject of reference was the emitter for the data related to the amount of liquid released, its turbidity and temperature, and it was the line for date on the pH. Denominator degrees of freedom of each error were estimated by Kenward–Roger approximation and least square means (LSmeans, see below for a definition) of the treatment distributions were computed. Data were provided both as LSmeans in figures and arithmetic means in supplemental materials, along with each standard error estimation or computation, respectively. Differences among means were compared by applying t-grouping at the 5% probability level to the LSMEANS *p*-differences. Time-sliced significance was also computed.

When the effect of time was significant, variation per unit time was modelled. Variation by time per each variable and treatment significantly varying by time was fitted to a linear distribution function and significance of the regression models were computed using the Slide Write Plus for Windows version 7.01 (Advanced Graphics Software, Inc., Encinitas, CA, USA).

3. Results

3.1. Effects of the Hydrocyclone Filtration and Resting Time on the Traits of the Digestate Liquid Fraction

Filtration of the digestate liquid fraction (DLF) influenced the pH of the different resulting fractions (Figure 2) pointing out that the native fraction before filtering had a pH value higher than 8.2 and not statistically appreciable differences were found after the filtration (hereafter referred as hydrocyclone filtered DLF, or HF-DLF). When the HF-DLF was allowed to rest for eight days before the beginning of the experiment, the solution at 50% dilution showed a lower pH compared to both the freshly made native DLF and the freshly made HF-DLF soon after the filtration. However, such latter difference was not statistically appreciable according to the conservative post-hoc test used. The pH value of the native DLF was higher than the fraction discarded from the filter and the tap water.
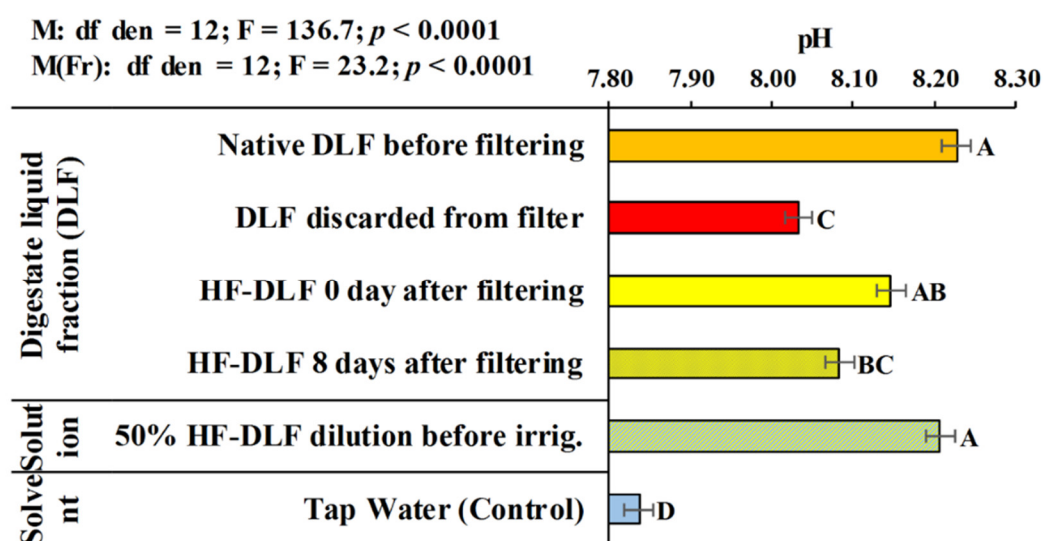

Figure 2. Values of pH of the digestate liquid fraction (DLF), before and after hydrocyclone filtering (HF), the 50% dilution of the HF-DLF, and the tap water used for the experiment. Bares are least square means (LSmeans) ± Lsmeans standard error estimates. Bars with a letter in common cannot be considered different according to a conservative Tukey-grouping applied to the *p*-differences of the LSmeans. Results of the statistical analysis are embedded.

The output of the turbidity sensor did not change by the filtration among the DLFs (Figure 3), which recorded value closed to 14.2 mV (please mind that, in theory, the lower the conductibility, the

higher the turbidity). The tap water showed a turbidity sensor output close to 800 mV, 56-fold than any of DLFs or HF-DLF, on average.
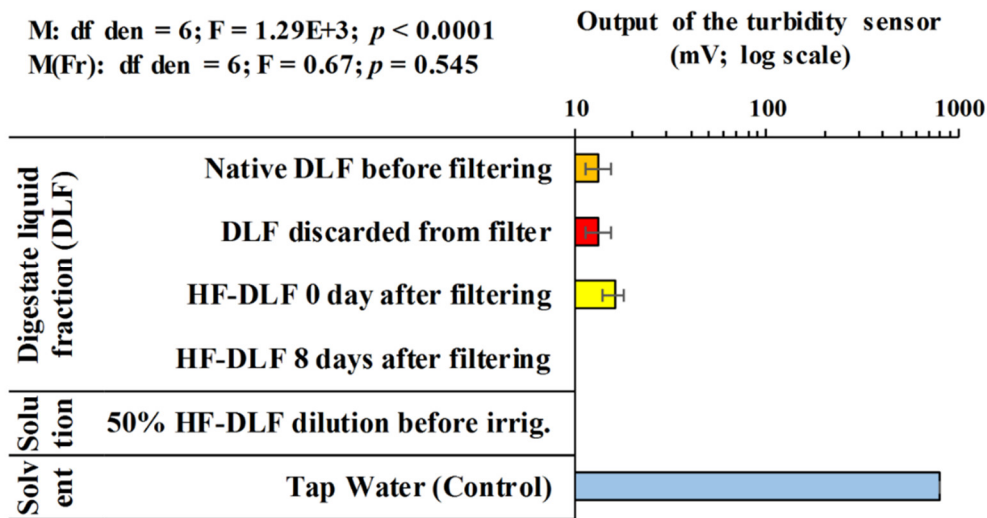

Figure 3. Output of the turbidity sensor in the digestate liquid fraction (DLF), before and after hydrocyclone filtering (HF), the 50% dilution of the HF-DLF, and the tap water used for the experiment. Bars are LSmeans ± Lsmeans standard error estimates. Bars with a letter in common cannot be considered different according to a conservative Tukey-grouping applied to the *p*-differences of the LSmeans. Results of the statistical analysis are embedded.

The dry matter concentration varied among the DLFs (Figure 4), with the fraction discarded from the filter showing a relative concentration compared to the native DLF 45% higher. The native DLF also showed a marginally, albeit significantly, lower dry matter concentration than the HF-DLF (−1.1% relative difference, corresponding to −0.02%).
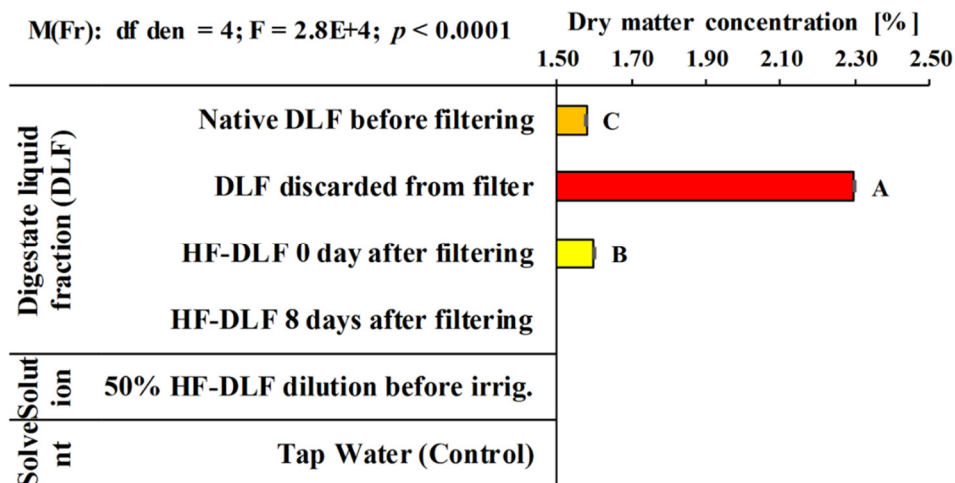

Figure 4. Dry matter concentration of the digestate liquid fraction (DLF), before and after hydrocyclone filtering (HF), the 50% dilution of the HF-DLF, and the tap water used for the experiment. Bars are LSmeans ± Lsmeans standard error estimates. Bars with a letter in common cannot be considered different according to a conservative Tukey-grouping applied to the *p*-differences of the LSmeans. Results of the statistical analysis are embedded.

3.2. Effects of the Digestate Liquid Fraction Dilution on the Emitter Performances and Solution Traits

Results of the statistical analyses of the irrigation test are shown in Table 2. Both the amount of water in the control and HF-DLF and its turbidity varied by the treatment at increasing time, with differences more marked among treatments in the early stages of the irrigation. The dilution of the DLF influenced the quantity of the solution released by the emitters during the test depending on the percentage of the dilution (Figure 5, Supplementary Material Table S1). In particular, water release increased almost constantly, whereas 10% and 25% dilution during the first 3 h. The 50% showed milder increases, and a total amount of water released slightly lower than the other treatments. The coefficient of variation of the system was in general lower than 5%, with some outlier only in the HF-DLF 25% dilution (Table 3).

Table 2. Results of the statistical analysis (degrees of freedom estimate of the error (DF den); F statistics; and *p* values) of the general linear mixed model applied to the amount of solution released each hour, its turbidity, dry matter concentration, pH difference compared to the control, and the amount of OH⁻ released with the solution per hour (expressed as mol ton⁻¹). Factors were the solution dilution (FD) and variation in time (1-h step of a 8-h irrigation cycle). Data were analyzed with a repeated treatment option and after which differences by each time-step were sliced. When the *p*-values were lower than 0.05, F and *p* were shown in bold. See the Supplementary Material for the post-hoc test.

Effect	Amount of Solution Released Each Hour			Turbidity			Dry Matter Concentration			[OH⁻] Concentration			pH Difference Compared to Control		
	Den DF	F	*p*	Den DF	F	*p*	Den DF	F	p	Den DF	F	*p*	Den DF	F	*p*
FD	101.8	3.2	0.0284	52.03	3.6×10^{04}	<0.0001	7.395	540.3	<0.0001	11.12	912.2	<0.0001	15.5	188.2	<0.0001
Time	83.06	47.3	<0.0001	139.6	9.1	<0.0001	30.7	1.2	0.3452	25.62	24.0	<0.0001	20.06	12.7	<0.0001
FD × Time	149.6	52.9	<0.0001	149.8	7.4	<0.0001	28.01	2.2	0.0389	29.78	12.9	<0.0001	21.15	7.4	<0.0001
Sliced By Time [h]															
1	97.0	3.9	0.011	64.9	9.7×10^{03}	<0.0001	23.6	121.5	<0.0001	18.5	34.4	<0.0001	13.0	41.4	<0.0001
2	109.4	4.7	0.004	91.6	9.7×10^{03}	<0.0001	11.4	97.8	<0.0001	24.5	72.8	<0.0001	20.0	64.2	<0.0001
3	111.0	3.2	0.025	95.0	1.0×10^{04}	<0.0001	24.1	165.7	<0.0001	25.5	74.4	<0.0001	20.5	65.4	<0.0001
4	111.4	3.1	0.031	95.4	9.8×10^{03}	<0.0001	12.7	128.3	<0.0001	25.5	111.4	<0.0001	20.5	85.9	<0.0001
5	111.5	4.1	0.008	95.4	9.1×10^{03}	<0.0001	22.3	129.1	<0.0001	25.5	149.7	<0.0001	20.5	101.7	<0.0001
6	111.6	3.0	0.034	95.4	9.8×10^{03}	<0.0001	13.2	142.3	<0.0001	25.5	205.9	<0.0001	20.5	140.0	<0.0001
7	111.7	4.4	0.006	95.4	9.5×10^{03}	<0.0001	20.3	159.0	<0.0001	25.5	183.6	<0.0001	20.5	110.3	<0.0001
8	111.8	2.5	0.065	95.4	9.5×10^{03}	<0.0001	15.5	112.9	<0.0001	25.5	226.2	<0.0001	20.5	119.0	<0.0001

Table 3. Coefficient of variation of each treatment (n = 9, consisting of 3 lines with 3 emitters each) and relative distribution percentiles at 0.025, 0.25, 0.5 (median), 0.75, and 0.975. Data of the three dilutions of the hydrocyclone filtered digestate liquid fraction (HF-DLF) were showed singly and bulked.

	Control (Tap Water)	10% Dil. HF-DLF	25% Dil. HF-DLF	50% Dil. HF-DLF	10% + 25% + 50% Dil. HF-DLF Bulked Data
Mean of coefficient of variation	1.65	3.41	3.69	3.66	3.59
Percentile 0.025	1.24	3.26	2.65	3.55	2.71
Percentile 0.250	1.45	3.35	2.79	3.59	2.89
Percentile 0.500 (median)	1.66	3.41	2.82	3.65	3.43
Percentile 0.750	1.86	3.46	2.86	3.68	3.61
Percentile 0.975	2.07	3.49	8.86	3.86	6.44

The dry matter content of the solutions (Figure 5) showed that the concentration strongly depended on the dilution rate, and to a lesser extent on time. In fact, higher values >0.6%) were recorded in the DLF 50%, compared to those in DLF 10% < 0.2%) and DLF 25% showed values ranging from 0.4% to 0.3%. The value of dry matter concentration (%) was quite stable all along the 8 h of irrigation test for all the treatments, except for DLF50 % that showed a slight increase with time (Supplementary Material Table S1; Supplementary Material Table S2).
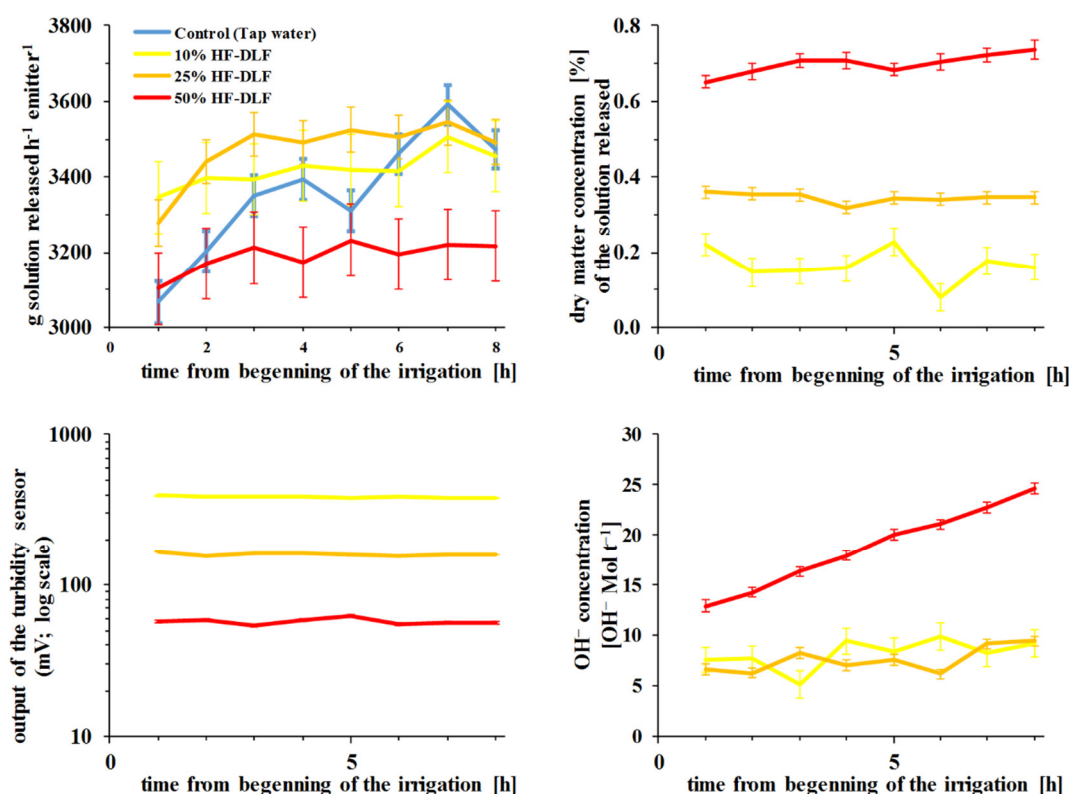

Figure 5. Amount of solution (tap water in the control and digestate liquid fractions (HF-DLF) diluted at the 10%, 25%, and 50%) released by the emitter each hour (upper left panel); dry matter concentration of the DLF released (upper right panel); turbidity of the HF-DLF released (lower left panel); and amount of OH⁻ ions released per ton of water released each hour. Data are LSmeans ± LSmeans standard error estimates. For post-hoc comparisons and raw data see Supplementary Material Table S3.

A similar trend, but more pronounced by the time, was found regarding turbidity (Figure 5; please mind that the higher is the turbidity value, the lower the liquid turbidity). For all the treatments the values recorded were stable over time and around 60 mV, 160 mV, and 380 mV for DLF 50 %, 25 % and 10 % respectively. The analysis of the concentration of ions OH^- (Figure 5), calculated using the pH values, showed that even if the trend of treatments DLF 10 % and 25 % was slightly variable during the irrigation test, the values were included between 5 and 10 OH^- mol t^{-1} solution, with scarce differences by the time. Instead, treatment DLF 50 % showed an increasing trend during the test with an initial value of 13 OH^- mol t^{-1} and a final value of 25 OH^- mol t^{-1}. Finally, we inspected a serpentine from the control and the DLF 50% (Figure 6) and found that no clogging occurred.
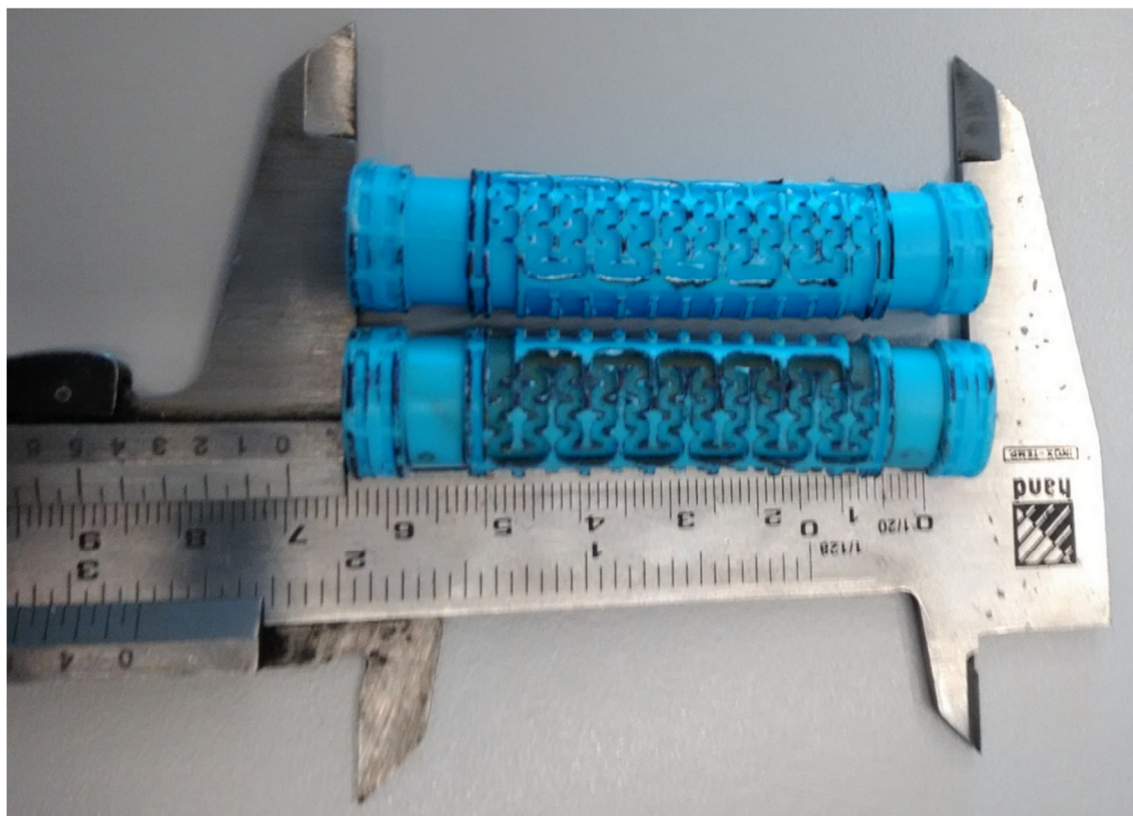

Figure 6. Serpentine inspection of the control (tap water; above) vs. 50 % diluted hydrocyclone filtered digestate liquid fraction (below) emitters.

4. Discussion

In the present work, we studied the role of an increasing ratio between a hydrocyclone-filtered digestate liquid fraction (referred to as HF-DLF) and tap water on the performance of an irrigation system and water quality. Treatments included 3 HF-DLF ratios (10%, 25%, and 50% of total solution used for the irrigation) in contrast to tap water as control and measurements were taken at an hourly basis on an 8-h irrigation cycle, that simulates most of the irrigation cycles occurring in a broad range of crops.

The native digestate liquid fraction used before the hydrocyclone filtering had a higher pH than the tap water used (pH = 8.23 vs. 7.84, respectively) and such pH slightly reduced after the hydrocyclone filtering. Information on the effect that the hydrocyclone filtering has on the pH of digestate liquid fraction and its total solids are scarce, nonetheless, centrifuge filtering was shown to have relatively high efficiency [25]. Thus, the pH reduction after the hydrocyclone treatment may have been due to the fractionation of the calcium carbonates or other high-weight solids in the digestate liquid fraction, including cations. The digester diet of the material in the present study was mainly composed of corn and barley biomasses (residual and dedicated) and to a lesser extent of cow

slurry. This kind of digestate has high contents in potassium, chloride, carbonates, and proteins [20]. It is thus likely that the high pH of the HF-DLF under study was due to a high content of basic, high molecular weight proteins, which can be removed by hydrocyclone filtering. Such a hypothesis is corroborated by the further reduction of pH of the DLF found eight days after filtering, before the irrigation experiment started, which may have been due to oxidation of the organic material in the HF-DLF that in such time-lapse was resting. Hydrocyclone filtering, however, did not result in a reduction of the turbidity and such results could be due to the high total solid concentration in the DLF following incomplete filtering, as pointed by Guilayn et al. [25]. Indeed, in our study, the HF-DLF showed a dry matter concentration of 16.0‰ (on a weight basis) and a pH = 8.15 soon after the filtration. These traits suggested a low quality fraction for drip irrigators according to the early classification by Nakayama and Bucks [3]. This likely was a main cause of the differences among the amount of HF-DLF released by the emitters at increasing time and varying the HF-DLF ratios within the irrigation system.

The manufacturer declared the used emitters as and releasing 2 L h^{-1} at 100 kPa. When subjected to the 200 kPa pressure of the present study, we found that the amount of water released in the control ranged from 3.07 L in the first hour and such an amount increased on average by the 1.9% h^{-1}. Such variation were higher than those found by Bodole et al. [26]. The variation of the amount of HF-DLF each emitter released per hour also increased with time in the three dilution treatments (0.5–0.9% h^{-1}), but to a lesser extent compared to the control. Such variations likely depended on the usury of the system. In particular, the dilution at 10% and 25% released 1.9% and 3.5%, respectively, more HF-DLF per cycle than the water released by the control, whereas the dilution at 50% released 4.9% less HF-DLF per cycle than the control. Besides, the differences between each HF-DLF dilution and control in the amount of water released per unit time declined with time. The temperature of the tap water or the HF-DLFs was similar among the treatments and increased linearly during each irrigation cycle, starting at 9.42 °C ± 0.27 °C at the 9:00 a.m. (moment of the beginning of each experiment) and increased at a rate of 0.94 °C h^{-1} ± 0.05 °C h^{-1} (data not shown). This implies that differences by time can only partly be explained by a heating of the emitters and thus the expansion of their pore size. We hypothesize that the emitters used in this experiment rapidly lost their ability to compensate for the irrigation rate at the pressure we used. In addition, the 10% and 25% diluted HF-DLF did not likely consist in a strong occlusion of the emitters. This is consistent with the constant rate of the dry matter content of 10% and 25% HF-DLF and increasing rate of the dry matter content of the 50% HF-DLF, which progressively increased at a rate of 27.98 × 10^{-3} ± 0.95 × 10^{-3} pH units h^{-1}. When using the 50% dilution, 6.63% less HF-DLF was released, on average, if compared to the water released in the control or the HF-DLF in the 10% and 25% dilutions. Despite such difference, the potential effect on the pH (expressed as [OH^{-}] amount of a putative medium receiving the HF-DLF at the 50% dilution) strongly increased over time, whereas it did not vary in the in the control or the HF-DLF in the 10% and 25% dilutions 1.68 ± 0.04 Mol OH^{-} (t HF-DLF)$^{-1}$ h^{-1}. Results from other experiments were variable and depended on the pressure, kind of emitter and kind of wastewater. In contrast to our study, Gamri et al. [27] found a strong reduction of the emitter performance with time and difference between the present and the one by Gamri et al. [27] experiment can be due to the higher pressure we used, which is two-fold compared to their study, and this occurred despite our HF-DLF had a solid concentration 2.3–9.8 fold higher than the synthetic wastewater composition used by Gamri et al. [27]. Nonetheless, these differences can be due to the high-frequency flushing in our experiment (one every 8 h). And indeed, Puig-Bargués et al. [14] showed that flushing every 540 h was sufficient to almost completely avoid the emitter clogging. Puig-Bargués et al. [14] also found, as in the present study, that dripline flow increased 8% and 25% over time when using a pressure compensating and a non-pressure compensating emitter, respectively, when used with a tertiary effluent from a wastewater treatment plant filtered with a 0.130 mm filtration level. Similarly, we found that coefficient of variation computed at an hourly basis was 1.653% (CI$_{95\%}$ 1.240%–2.065%) in the control and 3.587% (CI$_{95\%}$ 2.713%–6.444%) in the HF-DLF, with scarce differences among dilution, suggesting that accumulation of deposited material in the emitters affected the dripline flow performance. Such coefficient of variation was lower than those found in other similar studies [28,29] and can be

marginally acceptable as indicated by Bodole et al. [26], according to which a test duration of more than 60 min is enough to minimize the uncertainty due to the initial fluctuation of the data. The lower variation of the HF-DLF is likely due to an anti-clogging shape of the present emitters if compared to other emitters [30].

5. Conclusions

In conclusions, hydrocyclone filtration scarcely affected the traits of the digestate liquid fraction used for the irrigation. Irrigation with hydrocyclone-filtered digestate liquid fraction (HF-DLF) injected in the system at 10% and 25% dilution did not affect the performance of the system nor the traits of the liquid fraction released by the emitters, whereas using 50% dilution of the HF-DLF consisted in a lower amount of liquid released at increasing pH. In particular, HF-DLF dilution at 10%, 25%, and 50% consisted in +1.9%, +3.5, and −4.9% amount of liquid released compared to the control. In 10% HF-DLF % and 25% HF-DLF, a constant pH difference of + 0.321 ± 0.014 pH units compared to the control was found, in the 50% HF-DLF pH increased by around a half point and such difference increased with time.

This implies that that highly concentrated digestate liquid fractions, i.e., low dilutions, can pose problems for the functioning of the system and may have potentially harmful effects on soils with high pH. Nonetheless, the use of digestate liquid fractions for irrigation purposes may be a valuable option in those areas with a high amount of biogas plants and digestate production, such as various nations in Europe, America and Asia including USA, China, Germany, United Kingdom, Italy, and France [31,32]. Results from the present study have beneficial implication on the on water conservation since digestate production by feeding the digester with barley and corn provide wastewater from the late spring to the early fall, when water requirements are high. At the one time, the ability to use such wastewaters with minimal impact on the irrigation system, and thus with reduced negative impacts due to the system maintenance and disposal.

The digestate liquid fraction used in the present study was previously subjected to an additional hydrocyclone filtering, that likely discarded the high-molecular weight fraction. However, since few differences were found between filtered and non-filtered liquid digestate fraction, it is likely that a dilution at least up to 25%, according to the present study, can allow for a direct use of the digestate liquid fraction in microirrigation system with a minimal harming of the system performances. However, since the present is a short-term experiment, these results would require additional experiments with unfiltered liquid fractions.

Conflicts of Interest: The authors have no conflicts of interest to disclose. The authors declare that they have no financial interests or personal relationships with the brands cited, nor endorse any of the brands cited or their products. Furthermore, the funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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