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DRIP UNITS OPERATING WITH DILUTE LANDFILL LEACHATE[1]

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ABSTRACT - Drip irrigation systems stand out for the use of wastewater, by minimizing water losses and risks to the environment and public health, however, the clogging of emitters is a potential problem in this technology. The objective of this study was to evaluate the flow coefficient of variation (FCV) and the coefficient of statistical uniformity (CSU) of drip irrigation units operating with water-diluted landfill leachate. The experiment was conducted in a completely randomized split-plot design, with emitter types in the plots (G1 - non-pressure compensating, and G2, G3 and G4 - pressure compensating) and evaluation times in the subplots (0, 20, 40, 60 80, 100, 120, 140 and 160 hours), with four replications. The FCV, CSU and physicochemical and biological characteristic values of the dilute landfill leachate were determined every 20 hours to complete 160 hours of operation of the drip units. The biofouling caused major value changes in the FCV and the CSU of the drip unit with the G1 emitter (non-pressure compensating) compared to the units with the G2, G3 and G4 emitters (pressure compensating). The G3 emitter was the most adequate for applying the dilute landfill leachate.

Keywords: Wastewater. Biofouling. Irrigação.

UNIDADES GOTEJADORAS OPERANDO COM PERCOLADO DE ATERRO DILUÍDO

RESUMO - Os sistemas de irrigação por gotejamento se destacam para a aplicação de águas residuárias, devido à minimização das perdas de água, dos riscos ambientais e de saúde pública, porém a obstrução dos emissores representa um problema potencial dessa tecnologia. Objetivou-se com este trabalho avaliar o coeficiente de variação de vazão (FCV) e o coeficiente de uniformidade estatístico (Us) de unidades gotejadoras abastecidas com percolado de aterro sanitário diluído em água de abastecimento. O experimento foi conduzido sob delineamento inteiramente casualizado no esquema de parcelas subdivididas, tendo nas parcelas os tipos de gotejadores (G1 não autocompensante; e G2, G3 e G4 autocompensantes) e nas subparcelas os tempos de avaliação (0, 20, 40, 60, 80, 100, 120, 140 e 160 horas), com quatro repetições. Os valores de FCV, CSU e das características físico-químicas e biológicas do percolado de aterro sanitário diluído foram determinadas a cada 20 horas, até completar 160 horas de operação das unidades gotejadoras. A bioincrustação proporcionou maiores alterações nos valores de FCV e CSU da unidade gotejadora com gotejador G1 (não autocompensante) em relação às unidades dotadas dos gotejadores G2, G3 e G4 (autocompensantes). O gotejador G3 foi o mais adequado na aplicação do percolado de aterro sanitário diluído.

Palavras-chave: Água residuária. Bioincrustação. Irrigation.

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INTRODUCTION

Landfill leachate is a liquid waste with high organic content and strong coloring, produced by chemical and microbial decomposition of the solid waste deposited on landfills. Their chemical composition has high variability, depending on the deposited waste nature, distribution form, management practices and landfill age, and are greatly influenced by climatic factors, such as rainfall intensity and air temperature (MORAIS et al., 2006).

Municipal solid waste, when processed and prepared in a planned and controlled manner, can be used for various purposes such as raw materials for construction and recycled products manufacturing, in various agricultural activities such as organic matter compound for fertilizers and controlled irrigation of plants, aiming the biomass production for energy purposes (SILVA et al., 2011).

Drip irrigation systems stand out for the use of wastewater within the environmental context (DAZHUANG et al., 2009; EROGLU et al., 2012). Although this technology limits human exposure to wastewater and presents high application efficiency, the susceptibility to clogging of the emitters by biofouling emerges as a potential problem (BATISTA et al., 2010; PUIG-BARGUES et al., 2010; SILVA et al., 2013).

This biofouling refers to a gradual process of microbial growth within the drip sidelines, particularly in the emitter labyrinths (DAZHUANG et al., 2009; OLIVEIRA et al., 2014). The physicochemical elements and the biomass of the wastewater grow in volume and blocks the effluent flow through the emitter labyrinths (SAHIN et al., 2005; BATISTA et al, 2013.). Thus, the flow in the emitters and the wastewater application uniformity decrease over operation time, resulting in low efficiency and lifetime of the drip irrigation system (BATISTA et al., 2011a, b; SILVA et al., 2012).

The biomass matrix formed inside the sidelines and the emitter labyrinths has been studied in recent years in drip irrigation systems operating with wastewater (PUIG-BARGUES et al., 2005; SAHIN et al., 2005; CUNHA et al., 2006; DAZHUANG et al., 2009; LIU; HUANG, 2009; LI et al., 2012; BATISTA et al., 2013; OLIVEIRA et al., 2014). These studies suggest that preventive measures against clogging of emitters were relatively ineffective due to the complexities involved in the biofouling process. The clogging of emitters is related with the wastewater quality, flow regimes, labyrinth shape and dimensions and irrigation practices (DEHGHANISANIJ et al., 2005; CARARO et al., 2006; DURAN-ROS et al., 2009; COELHO et al., 2013). The interference of these factors related to drip obstruction is widely debated in the scientific community (CAPRA; SCICOLONE, 2007). Multidisciplinary approaches have suggested that emitters with a turbulent flow regime offer greater protection against obstruction (ZHANG et al., 2010; LI et al., 2013).

In this context, the objective of this study was to evaluate the flow coefficient of variation (FCV) and the coefficient of statistical uniformity (CSU) of drip irrigation units operating with water-diluted landfill leachate.

MATERIAL AND METHODS

The experiment was conducted between August 21 and October 10, 2013, at the Water Reuse Experimental Unit (UERA) of the Federal Rural University of the Semi-Arid (UFERSA), in Mossoro, State of Rio Grande do Norte, Brazil (5º12’27’’S, 37º19’21’’W).

A plastic container of 1.0 m^3 was used to transport the leachate from the Mossoro landfill to the UERA/UFERSA. The water used in the experiment were from the public system, supplied by the Water and Sewerage Company of Rio Grande do Norte (CAERN).

The landfill leachate had high concentration of salts, therefore, it was diluted in the public water to the limit of 3.0 dS m^{-1}, as established by the Decree 154/2002 from the State of Ceara (CEARA, 2002), for electric conductivity of waste water used for irrigation purposes. The landfill leachate (1.25 m^3) was diluted in public water (3.75 m^3), for supply the drip units, in the waterproof reservoir of the UERA, which had capacity of 5 m^3.

The experimental tests were carried out in a bench, built of concrete, 2.0 m wide and 8.0 m long, with waterproof floor and declivity of 1%, equipped with a channel tube with declivity of 2% for recirculating the effluent (Figure 1).

A concrete reservoir with storage capacity of 5.0 m^3 was built next to the experimental bench, in which four drip units were installed, consisting of a suction line, a pump set of 1.0 hp, a hydrometer of 1.5 m^3 h^{-1}, a screen filter with mesh of 130 uM, a PVC derivation line with diameter of 32 mm and 16 polyethylene side lines with diameter of 16 mm equipped with four types of emitters, as shown in Figure 1.

The derivation line had 16 connectors, inserted with sealing rubber. Four sidelines of 8 m long were installed for each emitter type. The four evaluated emitter types were selected because they are widely used in the northeastern semi-arid for drip irrigation projects (Table 1).

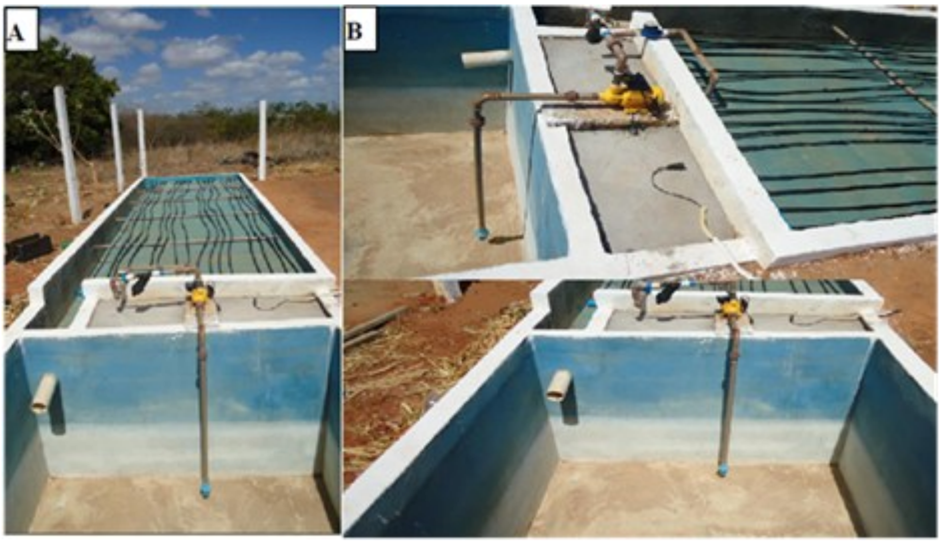

Figure 1. Experimental bench in which the drip units were installed: concrete reservoir and platform (A) and components of the application system, suction line, pump set, screen filter, hydrometer and derivation and side lines (B).

Table 1. Emitters (G) used in the experiments, manufacturer (M), pressure compensating device (PCD), nominal flow rate (Q), flow coefficient (k), flow exponent that characterizes the flow regime (x), filtering area (A), labyrinth length (L), manufacturing coefficient of variation (CV_m), recommended pressure range (P) spacing between emitters (SE).

G	M	PCD*	Q * ($L h^{-1}$)	k*	x*	A (mm^2)	L (mm)	CV_m* (%)	P* (kPa)	SE* (m)
G1	Plastro Hydrodrip Super	No	1,65	0,53	0,48	4,0**	37**	± 5	60 - 150	0,30
G2	Netafim PCJ-CNJ	Yes	2,00	2,00	0,00	2,0*	35*	± 7	50 - 400	0,80
G3	Netafim PCJ-CNJ	Yes	4,00	4,00	0,00	2,0*	35*	± 7	50 - 400	0,80
G4	Netafim PCJ-CNJ	Yes	8,00	8,00	0,00	2,0*	35*	± 7	50 - 400	0,80

*information from catalogs of manufacturers; ** measured with a digital caliper rule with accuracy of 0.01 mm. PCJ: uniform flow rate at various work pressures, ensuring exact distribution of water and nutrients, and has large passage sections of water and constant action of the self-cleaning mechanism, which increases its resistance to clogging; CNJ: anti-draining system.

The drip units worked an average of four hours a day until complete 160 h, following the recommendations of Batista et al. (2013) and Silva et al. (2013) who found significant obstruction levels with this operating time evaluating drip units supplied with wastewater.

The irrigation time in the field with wastewater is established based on the reference chemical element and not just taking into account the culture evapotranspiration demand. Therefore, the operating times found in experimental benches are greater than the field irrigation times with wastewater, however, the physical, chemical and biological clogging agents are similar in both cases.

The flow of the drip irrigation units was verified every 20 h to a total of 160 h. Nine emitters were selected from all sidelines of the irrigation units for measuring the flow of the emitters, collecting the effluent volume applied over a period of three minutes. Meanwhile, the flow coefficient of variation (FCV) and coefficient of statistical uniformity (CSU) of the effluent application were found using the equations 1 and 2, respectively.

$$FCV = \frac{S}{q} 100 \quad (1)$$

FCV = flow coefficient of variation (%);

S = standard deviation of the sample flow ($L h^{-1}$); and

q = average flow of the emitters ($L h^{-1}$).

$$CSU = (100 - FCV) \quad (2)$$

CSU = coefficient of statistical uniformity of the effluent application (%).

The physicochemical and microbial characteristics of the water-diluted landfill leachate, were determined every 20 h of operation of the drip units, following the recommendations of the *Standard Methods for the Examination of Water and Wastewater* (RICE et al., 2012).

Therefore, pH values were measured with a pH meter; electrical conductivity were measured conductivity, total iron and total manganese concentrations were measured by atomic absorption spectrophotometry and calcium and magnesium concentrations were measured by the titrimetric method. The suspended solid concentrations and total solids were evaluated by the gravimetric method, and the concentration of dissolved solids were evaluated by the difference between the total solids and the suspended solids contents.

Table 2 presents the mean values and standard deviations of the physicochemical and microbial characteristics of the water-diluted landfill leachate. The high concentration of salts in the landfill leachate, caused an increase in the mean value of the electrical conductivity of the diluted landfill leachate, however, this value meets the recommendation of the Ordinance 154/2002 of the State of Ceara (CEARA, 2002).

Table 2. Mean and standard deviation value of the physicochemical and microbial characteristics of the water-diluted landfill leachate.

Characteristics	Mean / standard deviation	Obstruction risk
pH	7,45 ± 0,36	Mid [a]
Electric conductivity (dS m^{-1})	2,80 ± 0,71	-
Suspended solids (mg L^{-1})	216 ± 183	High [a]
Dissolved solids (mg L^{-1})	2695 ± 2193	High [a]
Iron total (mg L^{-1})	0,85 ± 0,19	Mid [a]
Manganese total (mg L^{-1})	0,03 ± 0,01	Low [a]
Calcium ($mmol_c$ L^{-1})	1,16 ± 0,30	Low [b]
Magnesium ($mmol_c$ L^{-1})	1,94 ± 0,48	Low [b]
Bacteria population (100 MPN 100 mL^{-1})	20 ± 30	Low [a]

(a)According to Nakayama et al. (2006); (b) According to Capra and Scicolone (1998); MPN = Most Probable Number.

The experiment was conducted in a completely randomized split-plot design, with emitter types in the plots (G1 non-pressure compensating, and G2, G3 and G4 pressure compensating) and evaluation times in the subplots (0, 20, 40, 60 80, 100, 120, 140 and 160 hours), with four replications, according to the methodology proposed by Batista et al. (2013).

The operating pressure of the irrigation units was maintained at 140 kPa, in order to minimize the clogging of the emitters, following the recommendations of Silva et al. (2013) for drip irrigation units operating with wastewater. The operating pressure was measured daily using a 0-400 kPa glycerin manometer.

By the end of the experimental tests, some sideline emitters were removed for biofilm analysis, which was performed using optical microscopy.

Data were subjected to analysis of variance (ANOVA), using the F test at 5% probability. Means were compared using the Tukey test at 5% probability. The statistical analysis was performed using the computer program Sisvar 5.1 Build 72 (FERREIRA, 2011).

RESULTS AND DISCUSSION

The greatest changes in CSU values occurred in the drip unit G1, indicating a greater susceptibility to clogging compared to the other emitters, due to greater length of the labyrinth, lower flow and lack of self-cleaning device (Figure 2). This result confirms those found by Batista et al. (2013) in drip units operating with swine wastewater, in which the emitter with greater labyrinth length was the more susceptible to obstruction by physical, chemical and biological agents.

The CSU values, at the beginning of the experiment (0 hour), were 95.37% (G1), 94.07% (G2), 95.33% (G3) and 97.36% (G4), classified as excellent (95%<CSU<100%) and excellent-good (90%<CSU<95%), respectively (ASAE STANDARDS, 2003).

The CSU values, at the end of the experiment (160 hour) were 73.11% (G1), classified as poor (65%<CSU<70%), 94.04% (G2), classified as excellent-good (90%<CSU<95%); 96.62% (G3) classified as excellent and 96.19% (G4), classified as excellent (ASAE STANDARDS, 2003).

The comparison between the initial and final evaluation times showed a reduction of the CSU values of 23% (G1) and 1% (G4). These results differ from those found by Batista et al. (2011a), in which the reductions of CSU values were 24 and 59% in drip units which operated for 500 hours with three domestic wastewater qualities (untreated, secondary and tertiary).

The greater changes in the values of flow coefficient of variation (FCV) also occurred in the drip unit G1 (Figure 3), however, this increase in this clogging indicator was related to the operating time of the drip unit.

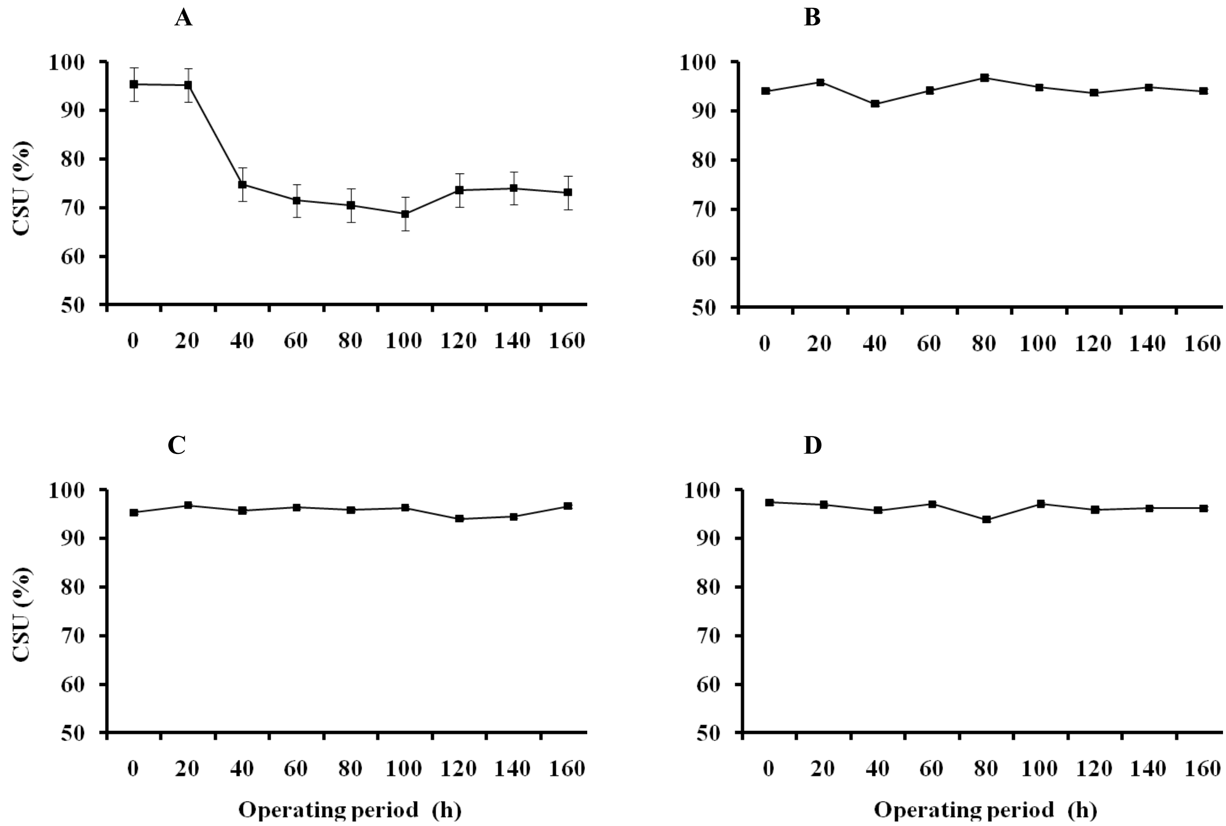

Figure 2. Mean values of CSU throughout the operating period of the drip units G1 (A), G2 (B), G3 (C) and G4 (D).

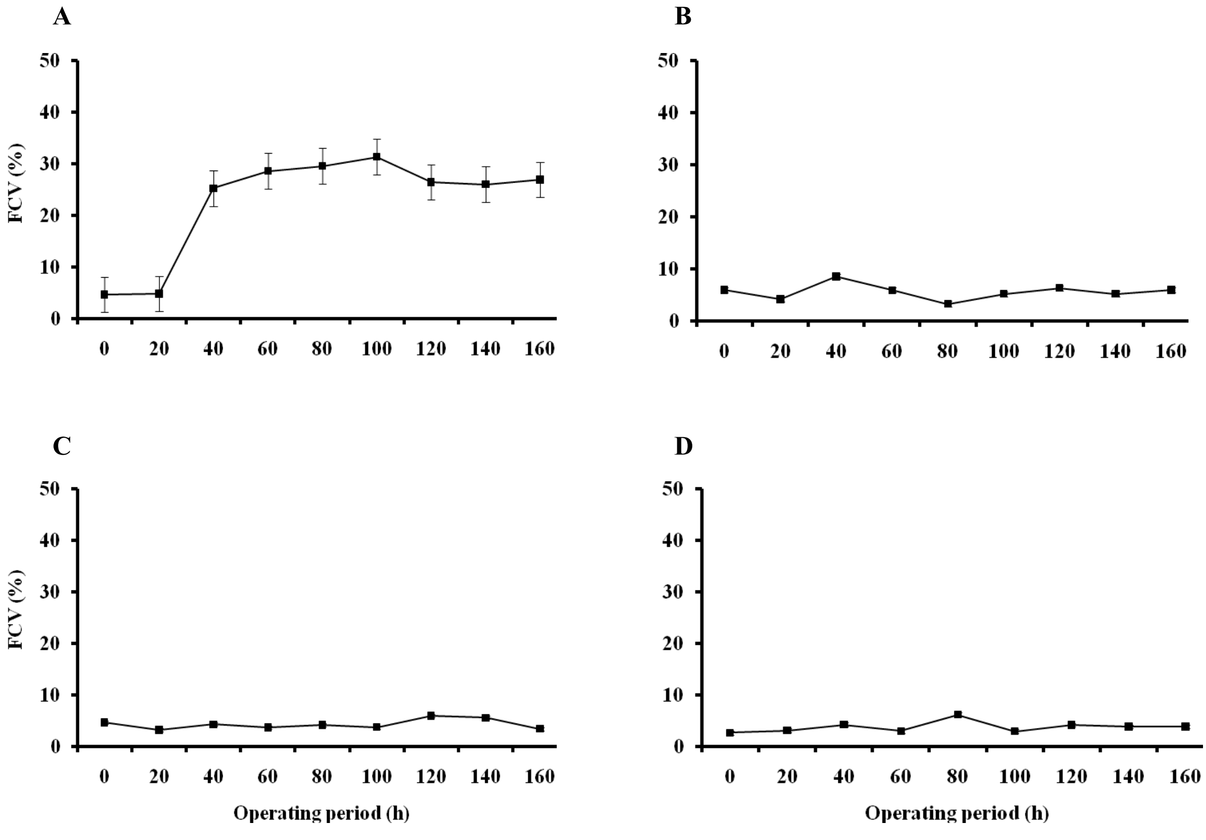

Figure 3. Mean values of FCV throughout the operating period of the drip units G1 (A), G2 (B), G3 (C) and G4 (D).

The FCV values at the initial evaluation time (0 hours) were 4.63% (G1), 5.93 (G2), 4.67 (G3) and 2.64% (G4), classified as good (FCV<10%) according to the ASAE Standards (2003). The FCV values at the final evaluation time (160 hours) were 26.89% in the drip unit G1, classified as unacceptable (FCV>20%) and the other drip units was classified as good (ASAE STANDARDS, 2003). Silva et al. (2013) found FCV values of drip units ranging from 4 to 5% after 160 hours of operation with wastewater from cashew processing and operating pressure of 140 kPa. The comparison between initial and final evaluation times showed an increase in FCV values of the drip units of 5.8-fold (G1) and 1.4-fold (G4).

A summary of the analysis of variance (ANOVA) of the CSU and the FCV variables of the drip units over the evaluation period is presented in Table 3. The G x T interaction was significant at 5% probability by the F test for the FCV and CSU variables. The ANOVA result found enabled to proceed with the mean test to verify the G x T interaction.

Table 3. Summary of the analysis of variance of the FCV and CSU variables in split-plot.

Variation source	Degrees of freedom	Mean square	
		CSU	FCV
Emitter type (G)	3	2954,7769*	2954,7769*
Residue (a)	9	741,0803	741,0803
Evaluation time (T)	8	126,1415*	126,1416*
G x T	24	105,3342*	105,3342*
Residue (b)	99	59,5033	59,5033
CV (%) plot		29,93	300,50
CV (%) subplot		8,48	85,15

*F significant at 5% probability. CV = coefficient of variation.

The CSU mean values of the drip units for the emitter factor within each evaluation time are presented in Table 4. No statistical difference between the CSU mean values was found for the evaluation times in the drip units G2, G3 and G4, indicating greater resistance of these emitter types compared to the G1. The CSU values for the 0 and 20 hours in the drip unit G1 differed statistically from the other operating times, due to the greater sensitivity to clogging of this emitter.

The CSU mean values for the drip units compared at each evaluation time, showed a statistical difference for the drip unit G1 compared to the others from the 40 hours. These results differ from those found by Batista et al. (2011a) with drip units operating with untreated, secondary and tertiary domestic wastewater, in which after 500 hours of operation, the CSU mean values were 54, 24 and 59%, respectively. According to Silva et al. (2012), at the final cycle of a *Ricinus communis* L. irrigated with secondary domestic wastewater, the CSU values ranged from 84.00 to 97.20%, differing from the results found in this study, which were 73.11% (G1) 94.04% (G2) 96.62% (G3) and 96.18% (G4), after 160 hours of operation with diluted landfill leachate.

The FCV mean values of the drip units for the emitter factor within each evaluation time are presented in Table 5. No statistical difference in FCV mean values was found comparing the drip units G2, G3 and G4 in any evaluation time. However, the drip unit G1 presented statistical difference in FCV mean between the 0 and 20 hours and the other operating times. The FCV values of the drip unit G1 presented a statistically difference to the other drip units from the evaluation time of 40 hours.

These results differ from those found by Liu and Huang (2009), in which drip units with flow rate of 2.83 and 1.88 L h^{-1}, showed an increase in FCV values of 62 and 135%, respectively, after 1680 hours of operation with treated domestic wastewater. Silva et al. (2012) found, at the end of the experimental tests, FCV values ranging from 11.88 to 22.83% in drip units of 3.75 L h^{-1} supplied with secondary domestic wastewater, different from the FCV values of 26.89, 5.96, 3.38 and 3.81% found in the present work after 160 hours of operation with dilute landfill leachate. However, these results confirm those found by Silva et al. (2013) in drip units operating 160 hours with wastewater from the cashew processing. The present study showed that the non-pressure compensating emitter (G1 with flow rate of 1.65 L h^{-1}) was more sensitive to obstruction by biofouling compared to pressure compensating emitters (G2 and G3 with flow rate of 2 and 4 L h^{-1}, respectively) because of the good efficiency of the self-cleaning mechanism of these emitters.

Table 4. CSU mean values (%) of drip units for the emitter factor within each evaluation time.

Evaluation time (hours)	Emitter type			
	G1	G2	G3	G4
0	95,38aA	94,07aA	95,33aA	97,36aA
20	95,21aA	95,82aA	96,81aA	96,91aA
40	74,75bB	91,47aA	95,72aA	95,78aA
60	71,44bB	94,14aA	96,32aA	97,04aA
80	70,48bB	96,74aA	95,85aA	93,86aA
100	68,70bB	94,80aA	96,28aA	97,08aA
120	73,56bB	93,67aA	94,06aA	96,86aA
140	74,01bB	94,80aA	94,43aA	96,18aA
160	73,11bB	94,04aA	96,62aA	96,18aA

*Means followed by at least one equal letter in columns and lines do not differ at 5% probability by the Tukey test.

Table 5. FCV mean values (%) of the drip units for the emitter factor within each evaluation time.

Evaluation time (hours)	Emitter type			
	G1	G2	G3	G4
0	4,63bA	5,93aA	4,67aA	2,64aA
20	4,80bA	4,18aA	3,19aA	3,08aA
40	25,25aA	8,54aB	4,28aB	4,22aB
60	28,56aA	5,86aB	3,68aB	2,96aB
80	29,52aA	3,27aB	4,15aB	6,14aB
100	31,30aA	5,20aB	3,71aB	2,92aB
120	26,44aA	6,33aB	5,94aB	4,14aB
140	26,00aA	5,20aB	5,57aB	3,82aB
160	26,89aA	5,96aB	3,38aB	3,81aB

*Means followed by at least one equal letter in columns and lines do not differ at 5% probability by the Tukey test.

The drip units with and without the presence of biofouling is presented in the Figure 4. The formation of slimes with dark brown color filling the small gaps and pressure compensating chambers of the emitters confirms the results found in drip units operating with wastewater from cashew processing (SILVA et al., 2013), domestic wastewater (BATISTA et al., 2011a,b; DAZHUANG et al., 2009; OLIVEIRA et al., 2014) and swine wastewater (BATISTA et al., 2013).

A B

C D

Figure 4. Emitters G1 (A), G2 (B), G3 (C) and G4 (D) with and without biofouling.

The biofouling consisted of suspended solids and biological agents (bacteria, worms and protozoa), as verified by the optical microscopy assessments (Figure 5). This result differs from those found by Duran-Ros et al. (2009) with an irrigation unit applying treated domestic wastewater, in which the biofouling consisted of biofilm, calcium, aluminum silicate, manganese, sand and algae. Batista et al. (2013) reported a complex biofilm formation, resulting from interaction between the physical (suspended solids), chemical (precipitated sulfur) and biological (bacteria, phytoplankton, fungi and protozoa) agents in the emitter operating with swine wastewater. Batista et al. (2010) also reported a biofilm formation resulting from the interaction between bacterial and algal slimes in a drip irrigation unit operating with tertiary domestic wastewater. Bacteria from the genus *Clostridium*, *Bacillus*, *Pseudomonas* and *Enterobacter* formed a microbial mucus, in which particles were adhered, especially from organic origin, represented by living or decomposing algal cells. The predominant algae were from the Cyanophyta (genus *Chlorococcus*), Euglenophyta (genus *Euglena* and *Phacus*) and Chlorophyta (genus *Selenastrum*, Scenedesmus and Sphaerocystis) groups.

A **B**

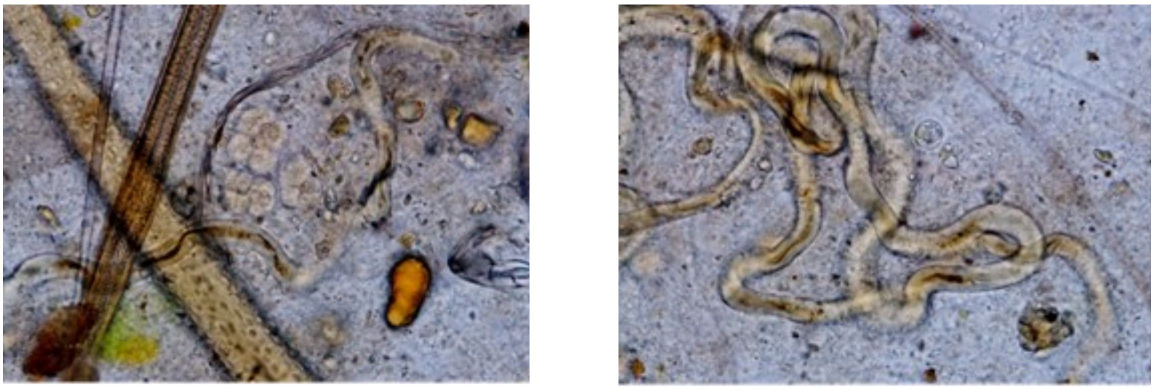

Figure 5. Biofilm formed inside the emitter with presence of worms and protozoa.

CONCLUSIONS

The biofouling caused major changes in the FCV and CSU values of the irrigation unit with emitter G1 (non-pressure compensating) compared to the units with emitters G2, G3 and G4 (pressure compensating).

The greater resistance to clogging with pressure compensating emitters (G2, G3 and G4) was attributed to the excellent efficiency of their self -cleaning device.

The emitter G3 was the most appropriate for applying the water-diluted landfill leachate.

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