

Flow rate variation and biological agents that obstruct drippers of swine effluent

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Abstract

Emitter clogging is the major problem of drip irrigation systems operating with wastewater. The objective of this study was to evaluate the alteration of the flow rate variation coefficient (FVC) and to identify the biological agents that cause obstruction in drip units operating with swine effluent and public water supply. The experiment was set up in a split-plot scheme, with the times of application of swine effluent and public water supply in the main plots and dripper types in the secondary parcels, evaluating times of FVC in the tertiary parcels, using a completely randomized design (CRD) with three repetitions. The FVC of the drip subunits was calculated on every 40 hours as well as the microscopic analysis of the biological agents of clogging, until 160 h. At the end of the tests, biofilm samples were collected in each drip unit to identify the groups of predominant bacteria. The results indicated that the FVC was effective in detecting the clogging of the emitters, evidencing that the construction characteristics and the times of application of swine effluent and of the public water supply interfere in this process. Microscopic analyzes of the biofilm indicated that the main biological agents that caused obstruction were algae, bacteria, fungi and protozoa.

Keywords: algae, bacteria, clogging, water reuse

Introduction

The water scarcity and pollution problems increase worldwide, indicating that the use of wastewater for irrigation purposes minimizes the current imbalance between supply and demand for public water supply (Puig-Bargués et al., 2010; Song et al., 2017).

In this context, emitters clogging has become one of the main obstacles of drip irrigation in the application of effluents. Several studies with wastewater types have shown that drip obstruction affects both the useful life and the hydraulic performance of the application systems (Liu & Huang, 2009; Eroglu et al., 2012; Li et al., 2012; Batista et al., 2013; Silva et al., 2013;

Batista et al., 2014; Oliver et al., 2014; Batista et al., 2016; Marques et al., 2016; Zhou et al., 2016; Batista et al., 2018).

In the wastewater it is possible to find several types of biological agents that can lead to drip obstruction, such as bacteria and fungi (Şahin et al., 2005; Dazhuang et al., 2009), algae (Batista et al., 2009; Batista et al., 2015), protozoa and worms (Mesquita et al., 2016a, b).

The drippers obstruction lead to lower flow rate (Batista et al., 2014; Fernandes et al., 2014) and uneven application of the effluent (Yan et al., 2010; Batista et al., 2013; Batista et al., 2018) in drip irrigation systems.

In order to detect the clogging of the

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emitters, there are several indicators of hydraulic performance, however the coefficient of variation of the flow is an indicator that has been used in several studies with wastewater (Silva et al., 2013; Batista et al., 2016; Mesquita et al., 2016b).

According to the exposed, the objective of this study was to evaluate the variation of the coefficient of flow variation, as well as to identify the main biological agents that cause obstruction in dripping units operating with times of swine effluent and public water supply.

Materials and Methods

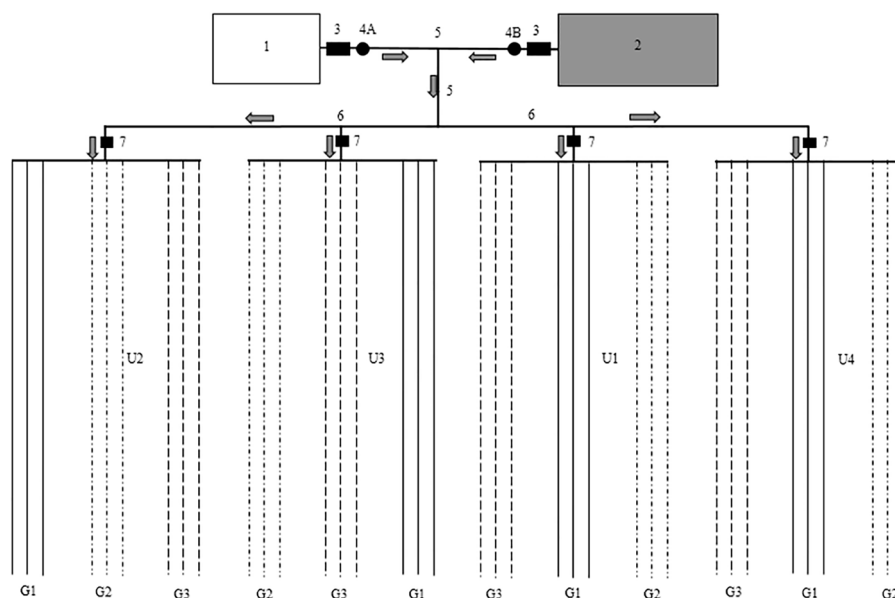
The experiment was performed at the Pilot-unity of treatment and localized application of swine residual water (UTARS) of the Federal University of Viçosa (UFV) in Minas Gerais State, Brazil (20°46'11.25" S and 42°51'44.96" O) from August 2nd to September 10th, 2006.

The experiment was settled in subdivided plots, being the main plots the times of swine effluent (ES) and public water supply (AAP) application (U1 - 1h of EF plus 3h of AAP; U2 - 2h of

EF plus 2h of AAP; U3 - 3h of EF plus 1h of AAP, U4 - 4h of ES), being the secondary plots the drippers types (G1 – not self-compensating dripper of 2.0 L h⁻¹; G2 – not self-compensating dripper of 1.7 L h⁻¹; and G3 – self-compensating dripper of 3.6 L h⁻¹) and in the tertiary plots the times of evaluations (0, 20, 40, 60, 80, 100, 120, 140 and 160h) of the coefficient of flow variation (FCV) in a completely randomized design (CRD) with three repetitions.

For this, an experimental bench was settled, consisting of a public water supply reservoir with 5.6 m³ (1), a swine effluent reservoir with 7.0 m³ (2), two pump sets of 3 CV each (3), one disc filter with apertures of 130 μm (4A), one sieve with a screen with openings of 47 μm (4B), a main line in 32 mm PVC (5), a branch line in 32 mm PVC (6), four pressure regulating valves of 105 kPa (7), dripper units operating with effluent application times of swine effluent -ES and public water supply - AAP (U1 - 1h of EF plus 3h of AAP, U2 - 2h of EF plus 2h of AAP, U3 - 3h of EF plus 1h of AAP, U4 - 4h of ES) and 12 drip subunits equipped with emitters G1, G2 and G3, as shown in Figure 1.

In each drip subunit were installed nine






Source: U - Dripper units operating with times of application of swine effluent and public water supply; G1 - not self-compensating dripper of 2.0 L h⁻¹; G2 - Not self-compensating dripper of 1.7 L h⁻¹; and G3 - self-compensating dripper of 3.6 L h⁻¹.

Figure 1. Scheme of dripper units and subunits, randomly drawn, operating with times of application of swine effluent and public water supply.

lateral lines in level, being three of each type of emitter with 18 m of length. The technical characteristics of the emitters tested with swine effluent application times and public water supply are shown in Table 1.

In these, 22 emitters were marked for flow measures, according to the collection of the applied volume during three minutes, according to the recommendations of NBR ISO 9261 (ABNT, 2006) for tests with drippers. Then, each emitter

Table 1. Technical specifications of the drippers used in the experiment with the respective images, adapted from Batista et al. (2013) and Batista et al. (2014).

Drippers	Nominal flow	Orifice area	Labyrinth length	Recommended pressure range	Drippers images
	rate (L h ⁻¹)	(mm ²)	(mm)	(kPa)	
G1 - Not self-compensating dripper	2.00	4.45	327	80-300	
G2 - Not self-compensating dripper	1.70	1.86	176	40-100	
G3 - Self-compensating dripper	3.60	2.54	44	80-350	

flow (q_i in L h⁻¹) were calculated using the following equation (1):

$$q_i = \frac{v}{1000} \frac{60}{t} \quad (1)$$

In which:

v - Volume of each effluent collected in each emitter, in mL; and

t - time of effluent collection for each emitter, in minutes

With the emitters flow it was determined the coefficient of flow variation (FVC in %) of the drippers subunits, using the equation 2 of NBR ISO 9261 (ABNT, 2006), for each 20 hours of operations until 160 hours, according to Silva et al., (2013), who detected levels of obstruction in drippers units that use waste water from cashew nuts at the same time of evaluation.

Table 2. Mean and standard deviation for the physical-chemical characteristics of swine effluent (ES) and public water supply (PSA) applied by dripper subunits.

Fluids	Temperature	DBO ₅ ²⁰	DQO	OG	Alc	Na ⁺	RAS
	°C	mg L ⁻¹	mmol _c L ⁻¹			(mmolc L ⁻¹) ^{0.5}	
ES	19.02±0.66	602±252	1228±635	27±25	1752±99	2.14±0.20	1.10±0.13
AAP	19.28±0.48	NR	NR	NR	NR	0.34±0.10	0.56±0.15

Note: DBO₅²⁰ - Oxygen biochemical demand † 5 days of incubation at 20 °C. DQO - Chemical demand of oxygen; OG - Oil and fat; Alc - Alkalinity at pH 4.3; Na⁺ - Sodium; RAS - Sodium absorption ratio; NR - Not realized.

During the experimental period, ES samples were collected on every 20 h of operation of the drip subunits, which were then preserved in an isothermal box at 4°C and sent to the laboratories of the Departments of Animal Biology and Plant Biology of the Federal University of Viçosa (UFV). In these samples the presence of fungi, protozoa, cyanobacteria, zooplankton and phytoplankton were identified, as well as their frequency of occurrence, through the microscopic examination of the collected

$$FVC = 100 \frac{SD_q}{q} \quad (2)$$

In which:

SD_q - Standard deviation of the emitters flow for each dripper unit, in L h⁻¹; and

q - Mean flow for the emitters in each dripper unit, in L h⁻¹.

The FVC values were classified according to ASAE EP 405 (Asabe, 2003), where the following values are suggested: less than 10%, good (G); between 10 and 20%, regular (R); and more than 20%, unacceptable (U).

In Table 2 is possible to observe the mean value and the standard deviation of the physical-chemical characteristics of the swine effluent (ES) and the public supply water (AAP) applied by the dripper subunits.

samples.

After 160 h of operation of the drip subunits, samples of the material that caused the emitters obstructions were collected and immediately conditioned in a sterilized container, being preserved in an isothermal box at 4°C, until the arrival at the laboratories of the Departments of Plant Biology, Animal Biology and Microbiology of the UFV and the Laboratory of Biological Processes of the Department of Hydraulics and Sanitation of USP, aiming to identify the agents

that cause microscopic clogging using objective of 100, ocular of 10 and zoom of 1.25.

Results and Discussion

According to the variance analysis, the interaction N x G x T was significant at 1% of

probability for the variable FCV, with CV of the tertiary plots of 32%. Similar results were observed by Silva et al. (2013) studying dripping unities using cashew nuts production wastewater, with CV of 29% (Table 3).

Table 3. Variance analysis for the FCV variable, in a scheme of subdivided plots.

Source of variation	Degree of freedom liberdade	Mean square
Times of effluent and water application	3	4266**
Residue (a)	8	81
Dripper type (G)	2	1357**
N x G	6	854**
Residue (b)	16	53
Time of operation (T)	8	5416**
N x T	24	762**
G x T	16	253**
N x G x T	48	143**
Residue (c)	192	18
CV (%) main plots		68
CV (%) secondary plots		58
CV (%) tertiary plots		32

** F significant at 1% of probability. CV - Coefficient of variation.

In Table 4, the mean values of FCV for the drip type factor were presented within each operating time level and each level of application time of swine effluent and public water supply. It was verified, in this table, that there was no effect of the effluent and water application times on the FCV, for each type of dripper, up to the operating time of 60 h; this result differs from that obtained by Mesquita et al. (2016b) that showed a significant reduction of FCV, from 40 h of application of percolate of diluted landfill, in the dripper unit with a non-compensating emitter of 1.65 L h⁻¹.

Using the classification of ASAE EP 405 (Asabe, 2003), it was shown that the value of FCV was classified as good (<10%) throughout the experimental period only in the drip subunits equipped with emitters G2 and G3 of U1 and in the dripping subunits G1 and G3 of U4, evidencing that the susceptibility to clogging is related to the constructive characteristics of the emitters and the quality of the applied fluid; however, at 160 h, the drip subunits G1, G2 and G3 presented FCV classified as unacceptable (> 20%) for U2 and U3, where the constructive characteristics of the emitters and the quality of the applied fluids

contributed to obstruction of the emitters. It was also noted in Table 4 that the emitter obstruction started at 80h in the G4 drip subunit of U4, where FCV was classified as regular (10% < FCV <20%).

These results are in accordance with those found by Mesquita et al. (2016b) in dripping units by applying percolated landfill diluted for 160 h, where the not self-compensating dripper of 1.65 L h⁻¹ resulted in FCV also classified as unacceptable, due drippers obstruction.

Comparing the means of the FCV variable followed by at least one same capital letter in the columns of Table 4, it was found that: at U1 level, from 120 h, the FCV of the subunit with G1 dripper differed from the FCV of the subunits with G2 and G3 drippers; at the U1 level, from 100 h, the FCV of the G1 drip subunit differed from the FCV of the subunits with G2 and G3 drippers; at U3 level, the FCV of the G1 drip subunit differed from the FCV of the subunits equipped with the G2 and G3 drippers, at the 80, 100 and 120 h operating times, while the FCV values of the G1, G2 and G3 drip subunits differed between them, in the operating times of 140 and 160 h; and at U4 level, from 100 h, the FCV of the subunits with G1 and G3 drippers differed from the FCV of

Table 4. Mean values for FCV (%) for the factor dripper type for each level of time of application of the effluent and water, with the respective ASAE EP 405 classification (Asabe, 2003).

Operation time (h)	Drippers	Times of application of swine effluent and water from public supply *			
		U1	U2	U3	U4
0	G1	2.37Aa (G)	2.24Aa (G)	2.04Aa (G)	2.03Aa (G)
	G2	1.78Aa (G)	1.55Aa (G)	1.59Aa (G)	1.45Aa (G)
	G3	2.85Aa (G)	3.45Aa (G)	3.47Aa (G)	4.48Aa (G)
20	G1	2.12Aa (G)	1.94Aa (G)	2.24Aa (G)	2.62Aa (G)
	G2	1.58Aa (G)	1.68Aa (G)	1.70Aa (G)	1.49Aa (G)
	G3	4.08Aa (G)	3.89Aa (G)	3.97Aa (G)	4.30Aa (G)
40	G1	2.18Aa (G)	2.47Aa (G)	3.54Aa (G)	7.93Aa (G)
	G2	2.08Aa (G)	2.55Aa (G)	2.47Aa (G)	5.38Aa (G)
	G3	3.47Aa (G)	4.54Aa (G)	6.27Aa (G)	3.41Aa (G)
60	G1	2.92Aa (G)	3.35Aa (G)	4.47Aa (G)	5.35Aa (G)
	G2	1.93Aa (G)	2.29Aa (G)	2.21Aa (G)	3.61Aa (G)
	G3	4.11Aa (G)	4.64Aa (G)	6.18Aa (G)	4.88Aa (G)
80	G1	3.64Ab (G)	8.82Ab (G)	22.55Aa (U)	4.36Ab (G)
	G2	2.17Aa (G)	5.86Aa (G)	5.75Ba (G)	12.29Aa (R)
	G3	5.77Aa (G)	6.82Aa (G)	9.44Ba (G)	3.75Aa (G)
100	G1	9.37Ab (G)	26.67Aa (U)	30.73Aa (U)	5.75Bb (G)
	G2	3.26Ab (G)	13.90Ba (R)	17.21Ba (R)	16.62Aa (R)
	G3	4.81Ab (G)	10.09Bab (R) (R)	15.11Ba (R)	5.00Bab (G)
120	G1	17.46Ab (R)	55.40Aa (U)	47.78Aa (U)	3.87Bc (G)
	G2	4.38Bc (G)	25.93Bb (U)	26.94Bb (U)	37.20Aa (U)
	G3	6.70Bb (G)	27.82Ba (U)	28.06Ba (U)	3.73Bb (G)
140	G1	20.47Ab (U)	69.32Aa (U)	62.75Aa (U)	5.14Bc (G)
	G2	5.64Bc (G)	32.80Bb (U)	43.13Ba (U)	29.26Ab (U)
	G3	5.58Bb (G)	38.32Ba (U)	32.40Ca (U)	3.79Bb (G)
160	G1	22.45Ab (U)	77.71Aa (U)	67.67Aa (U)	7.17Bc (G)
	G2	7.94Bc (G)	37.46Bb (U)	50.65Ba (U)	35.61Ab (U)
	G3	6.82Bb (G)	45.11Ba (U)	37.42Ca (U)	4.43Bb (G)

* Means followed for at least one uppercase letter in the columns for each operation time and lowercase letters in lines for each water amount are not different, at 5% of probability, according to Tukeys Test. Classification of ASAE EP 405 (Asabe, 2003): G – Good, R – Regular and U- Unacceptable.

the subunit provided with drip G2. These results differ from those presented by Silva et al. (2013), where the average FCV values of the dripper unit with non self-compensating emitter differs from the FCV of the other dripper units with self-compensating emitters, after 20h operation with cashew nut residual water under the service pressure of 70 kPa.

Comparing the means of the FCV variable followed by at least one same lowercase letter in the lines of Table 4, it was observed that: at the 80 h time, the FCV of the G1 subunit submitted to the U1 level differed from the FCV of the subunits submitted at levels U1, U2 and U4; in the operating time of 100 h, the FCV of the subunits equipped with the G1 drippers submitted to the U1 and U4 levels differed from the FCV of the subunits submitted to levels U2 and U3, the FCV of the subunits with drip G2, submitted to the U1 level, differed of FCV of the subunits submitted to levels U2, U3 and U4, and the FCV of the subunits with G3 dripper, submitted to level U1, differed

from the FCV of the subunit submitted to level U3; in the operating times of 120, 140 and 160 h, the FCV values of the subunits equipped with the G1 and G2 drippers, submitted to levels U1, U3 and U4, were different, while the FCV of subunits with G3 dripper, submitted to levels U1 and U4, differed from the FCV of subunits submitted to levels U2 and U3.

In Table 5, the biological groups present in swine wastewater are shown, according to the time of operation of the drip subunits, identified by optical microscopy.

The effluent of the phytoplankton was represented by the groups *Bacillariophyta*, *Chlorophyta*, *Euglenophyta*, *Cyanophyta*, *Cryptophyta* and *Dinophyta*. In the primary domestic wastewater, Batist et al. (2015) observed other groups of phytoplankton, such as *Chlorella*, *Scenedesmus*, *Chaetophora* and *Navicula*. The group *Bacillariophyta* was observed for all times of evaluation, being mainly represented by *Diatomaceous*. The groups *Chlorophyta* and

Table 5. Characterization of the biological groups presented in swine wastewater according to the operation periods of the drip units identified using the optical microscopy.

Groups	Observed frequencies for the operation periods (h)								
	0	20	40	60	80	100	120	140	160
Fitoplancton									
Bacillariophyta	++	++++	++++	++++	++++	+++	++++	+++	+++
Chlorophyta	++++	-	++	+++	+++	+++	+++	+++	++++
Euglenophyta	+++	+++	+++	++	+++	++++	-	++++	+++
Cyanophyta	-	-	+++	-	++	++	-	-	-
Cryptophyta	-	++	-	+++	-	-	-	-	-
Dinophyta	-	-	+++	-	-	-	-	-	-
Zooplancton									
Rotifera	-	-	-	-	-	-	-	-	-
Cladocera	-	-	-	-	-	-	-	-	-
Copepoda	-	-	-	-	-	-	-	-	-
Bacteria	++++	++++	++++	++++	++++	++++	++++	++++	++++
Fungi	+++	+++	+++	+++	+++	+++	+++	+++	+++
Protozoa	+++	+++	+++	+++	+++	+++	+++	+++	+++

Range: (++++) predominant, (+++) frequent, (++) less frequent and (-) not observed.

Euglenophyta were not observed, except for the periods of 20 and 120 h, respectively. The group *Cyanophyta* was observed in the periods of 40, 80 and 100 h, being mainly represented by Cyanobacterias. The group *Cryptophyta* was observed in the periods of 20 e 60 h, while the *Dinophyta* group was only observed for the period of 40h. The lack of dissolved oxygen in the effluent avoided the development of zooplankton groups such as *Rotifera*, *Cladocera* and *Copepoda*, commonly observed in secondary domestic effluents.

The biological groups bacteria, fungus and protozoa were also identified in the effluent throughout the testing period. In the study developed by Şahin et al. (2005), it was observed problems of drippers clogging due to the formation of mucilage by the activity of bacteria, fungi and protozoa.

Microscopic analysis of biofilms, performed to characterize the biomass present in each subunit (Figure 2), presented different phase contrast morphologies. In all biofilms, the predominant microorganisms

were curved bacilli (probably sulphate-reducing bacteria), bacilli in pairs, bacillus cocci, filaments, filamentous bacteria (similar to *Methanosaeta*) and diatoms. Moraes & Paula Júnior (2004), studying swine effluent, found the predominance of curved bacilli, straight bacilli and cocci bacilli in the biofilm formed inside reactors. Luiz (2007) identified bacilli, bacillus cocci, filaments and bacteria similar to *Methanosaeta* and *Methanosarcina* in the biofilm formed in reactors operating with coffee production wastewater.

Evaluating the culture media, it was observed population level of bacteria that could cause drippers clogging, as shown in Table 6. The population levels of bacteria in the U1, U2, U3 and U4 biofilms were 8.5×10^5 , 1.8×10^6 , 1.9×10^6 and 1.1×10^6 CFU ml⁻¹, respectively. According to reports by Nakayama et al. (2006), the genera *Enterobacter*, *Pseudomonas* and *Clostridium* bacteria can cause serious obstruction problems in drippers.

Table 6. Characterization of the bacteria of the biofilm formed in the subunits submitted to the levels U1, U2, U3 and U4.

Bacteria	Water proportion			
	U1	U2	U3	U4
Bacteria population (UFC mL ⁻¹)	$8,5 \times 10^5$	$1,8 \times 10^6$	$1,9 \times 10^6$	$1,1 \times 10^6$
<i>Enterobacter</i> (UFC mL ⁻¹)	$2,0 \times 10^3$	$7,5 \times 10^3$	$4,5 \times 10^3$	$2,0 \times 10^3$
<i>Pseudomonas</i> (UFC mL ⁻¹)	$3,5 \times 10^3$	$5,5 \times 10^3$	$1,0 \times 10^4$	$1,0 \times 10^4$
* <i>Clostridium</i> (UFC mL ⁻¹)	$1,0 \times 10^3$	$< 10^2$	$6,5 \times 10^3$	$< 10^2$

Note: UFC = colony forming units. *Sulphite reducers *Clostridium*

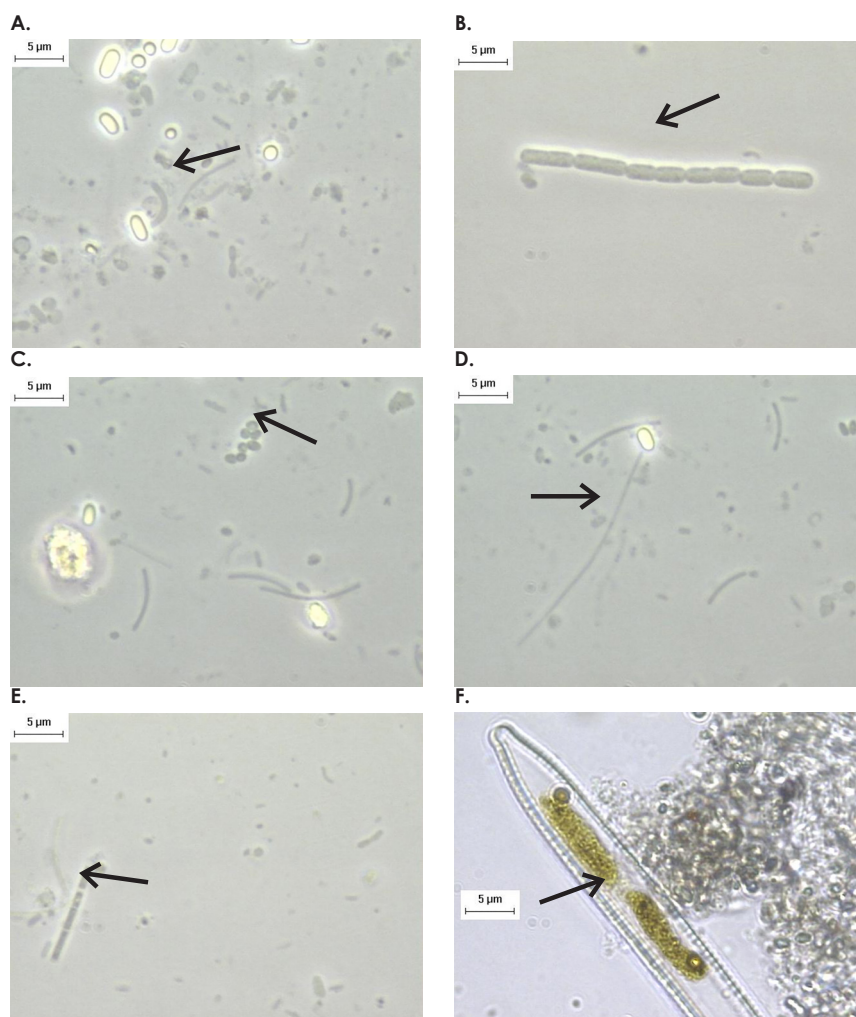


Figure 2. Morphologies observed by microscopy in the biofilm of subunit drippers submitted to levels 1E3A, 2E2A, 3E1A and 4E: bacillus curved (A), bacilli in pairs (B), cocci bacilli (C), filament (D), filamentous bacteria similar to *Methanosaeta* (E) and diatom (F) (objective of 100, ocular of 10 and zoom of 1.25).

Conclusions

The obstruction levels of the emitters were lower when the times of application of water of public supply were also lower.

The coefficient of variation of the flow was effective in detecting the clogging of the emitters, evidencing that the construction characteristics and the times of application of swine effluent and public water supply interfere in this process.

The main biological agents responsible for drip clogging were algae (*Bacillariophyta*, *Chlorophyta*, *Euglenophyta*, *Cyanophyta*, *Cryptophyta* and *Dinophyta*), bacteria (*Enterobacter*, *Pseudomonas* and *Clostridium*), fungi and protozoa.

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