Water Resources and Irrigation Management
Universidade Federal do Recôncavo da Bahia, Cruz das Almas, BA
Instituto Nacional do Semiárido, Campina Grande, PB
v.1, n.1, p.1-6, Sept-Dec, 2012

ISSN 2316-6886
WRIM
www.wrim.com.br

Hydraulic performance of drip irrigation subunits using wastewater from coffee fruit processing

Rafael Oliveira Batista[1], Antonio Teixeira de Matos[2], Fernando França da Cunha[3],
Paola Alfonsa Lo Mônaco[2] & Delfran Batista dos Santos[4]

Protocol 11.2012 - Received: September 22, 2012 - Accepted: October 30, 2012

Abstract: The hydraulic performance of the subunits of a drip irrigation system with coffee fruit wastewater was evaluated. The experiment was performed at the Hydraulic, Irrigation and Drainage Experimental Area of the Agricultural Engineering Department, at the Federal University of Viçosa, Viçosa, MG, Brazil. The structure was composed of non-compensable dripper tapes 0.3 m apart. Two irrigation subunits were evaluated: one operating with non-filtered coffee fruit wastewater (NCFW) and another with filtered coffee wastewater (FCFW). Results show that wastewater obtained from coffee fruit presented a greater risk of clogging the drippers, even after they were partial or totally treated by organic filters. The buildup of a biofilm caused by bacteria growth, which interacted with the solids in the wastewater, was the main factor in the clogging of the drippers used for the application of coffee fruit wastewater. The coffee fruit wastewater reduced the flow rate and the water uniformity distribution of the drip irrigation units.

Key words: biofilm, clogging, drippers, flow rate, uniformity distribution

Desempenho hidráulico de subunidades de irrigação por gotejamento operando com água residuária do cafeeiro

Resumo: O presente trabalho objetivou analisar o desempenho hidráulico de subunidades de irrigação por gotejamento operando com água residuária do cafeeiro. O experimento foi realizado na Área Experimental de Hidráulica, Irrigação e Drenagem do Departamento de Engenharia Agrícola da Universidade Federal de Viçosa, em Viçosa-MG, Brasil. A estrutura avaliada foi composta por fitas gotejadoras não autocompensantes com emissores espaçados a cada 0,30 m. Nos ensaios experimentais foram avaliadas duas subunidades de irrigação: uma operando com água residuária do cafeeiro não filtrada (NCFW) e a outra com água residuária do cafeeiro filtrada em filtro orgânico (FCFW). Os resultados indicaram que a água residuária do cafeeiro apresenta grande risco de entupimento de gotejadores, mesmo após tratamento de filtragem parcial ou total, em filtros orgânicos; a formação de biofilme resultante da interação entre os sólidos suspensos e as mucilagens microbianas foi o principal fator de entupimento dos gotejadores que operaram com água residuária do cafeeiro; e água residuária do cafeeiro reduz tanto a vazão quanto a uniformidade de aplicação de unidades de irrigação por gotejamento.

Palavras-chave: biofilme, entupimento, gotejadores, vazão, uniformidade de aplicação

[1] Universidade Federal Rural do Semi-Árido, Mossoró, RN, Brasil. E-mail: rafaelbatista@ufersa.edu.br
[2] Universidade Federal de Viçosa, Viçosa, MG, Brasil. E-mail: atmatos@ufv.br, paolalomonaco2004@yahoo.com.br
[3] Universidade Federal do Mato Grosso do Sul, Chapadão do Sul, MS, Brasil. E-mail: fernando.cunha@ufms.br
[4] Instituto Federal de Educação, Ciência e Tecnologia Baiano, Senhor do Bonfim, BA, Brasil. E-mail: delfran.batista@gmail.com

Introduction

The washing and pulping of coffee fruits, necessary to reduce drying costs and to improve its drinking quality, produce large amounts of solid and liquid residues with several organic and inorganic materials. If the latter are discarded of in the environment without any treatment, they may cause several problems, such as the death of animals and plants, and the contamination of water sources and soil.

The concentrations of nitrogen and mainly potassium in the coffee fruit processing wastewater are quite high, between 120 - 250 mg L^{-1} and 315 - 460 mg L^{-1}, respectively (Matos, 2003). According to the same author, increase in content may occur due to water reuse in the nut-removing process. The use of residual water as fertilizer indicates its potential for the soil-plant systems as a strategy for the treatment or disposal of residual waters.

The use of wastewater in agriculture minimizes a potential contamination source for underground and surface water, especially in arid regions where the shortage of water implies the use of every available water source.

Drip irrigation has been used to dispose of the wastewater because of its high application efficiency and the low contamination risk for food and people. Since emitters are highly susceptible to clogging, their sensibility depends on their characteristics (Trooien et al., 2000) and on the water quality characterized by its physical, biological and chemical properties (Nakayama et al., 2006).

There are several chemical, biological and physical factors in the wastewater that may potentially cause clogging in the drippers. Suspended solids, which clog the small parts of the drippers, are composed of organic and inorganic material. In general, particles larger than 1/10 of the dripper's diameter represent a potential clogging risk (Keller & Bliesner, 1990). Taylor et al. (1995) analyzed problems related to inorganic particles in sanitary sewage from treatment ponds. These authors registered that only 6% of all emitters were clogged by inorganic particles. Adin & Sacks (1991) stated that in most cases clogging severity depended more on the size of particle than on the amount of the particles in the irrigation water. In fact, algae and other microorganisms may be a problem in dripper irrigation systems, principally when their growth is stimulated by excess of nutrients, such as nitrogen or phosphorus, frequently found in wastewater. A detailed analysis of emitters has shown that bacteria of the genera Pseudomonas, Enterobacter, Clostridium, Flavobacterium, Brevibacterium, Micrococcus and Bacillus may cause obstruction problems (Nakayama et al., 2006). The formation of a biofilm, caused by the interaction of mucilage and suspended solids, has been the main cause of clogging in dripper used for wastewater application (Capra & Scicolone, 2004). Ravina et al. (1997) observed the development of a biofilm on the equipment wall only when flow velocity was less than 0.5 m s^{-1}.

Dripper obstruction reduces flow rate and consequently water uniformity application in drip irrigation system. Hills et al. (2000) verified a decrease in the mean flow rate of up to 75% after 3000 hours of operation in an irrigation system that applied pre-treated sanitary sewerage. Rav-Acha et al. (1995) and Batista et al. (2010) verified reductions of 68 and 20% in the mean flow rate of drip irrigation systems that applied treated sanitary sewerage after 60 and 560 hours of operation, respectively. Sagi et al. (1995) described a similar case in which protozoa colonies occupying 57% of the emitter area, decreased the mean flow rate by 38% in a drip irrigation system. Dehghanisanij et al. (2003) showed that the application of treated sanitary sewerage reduced up to 9% the statistic coefficient of water application uniformity after 187 hours of operation of drip irrigation systems. Capra & Scicolone (2004) reported water uniformity distribution coefficients varying from 0 to 77% after 60 hours of operation in drip irrigation systems used to apply treated sanitary sewerage.

The clogging of emitters brings heavy liabilities to the general operation of the irrigation system, affects its operational characteristics and makes more frequent repairs necessary. Faria et al. (2002) verified that when 50% of the drippers are clogged, 80% of the system's pipes exert a pressure above the PVC pipe nominal pressure.

Certain techniques are recommended to minimize the clogging of drippers for wastewater disposal. The most frequently used techniques include filtration, opening of the pipeline at one of its extremities and use of chemical treatment.

This study evaluates the hydraulic behavior of the subunits of a drip irrigation system using wastewater derived from a coffee fruits processing plant.

Materials and Methods

The experiment was conducted at the Hydraulic, Irrigation and Drainage Experimental Area of the Department of Agricultural Engineering of the

Federal University of Viçosa, Viçosa - MG Brazil, at 20°45'14" S and 42°52'53" W and mean altitude 650 m. According to Koppen classification, the climate is Cwa, with mesothermal humidity featuring hot summers and dry winters. Mean maximum and minimum temperatures are respectively 26.1 and 14.0°C.

Two platforms were prepared for testing each made of three fertigation subunits, each containing four lateral lines, as shown in Figure 1. A non-pressure compensating drip tape with the following technical specifications was used: flow rate of 1.0 L h^{-1}, at a pressure of 56 kPa, spaced 0.3 m, and pressure ranging between 29 to 101 kPa.

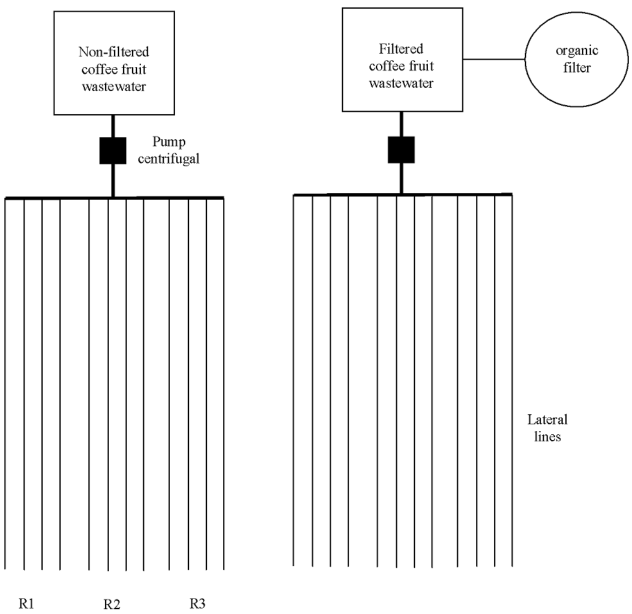

Figure 1. Fertilization-irrigation subunits scheme showing equipments used

Treatments consisted in comparing the hydraulic performance of two irrigation subunits, one operating with non-filtered coffee fruit wastewater (NCFW) and another with filtered coffee fruit wastewater (FCFW).

Part of the prime wastewater from the coffee fruit underwent a primary treatment through an organic filter constituted by a 1.20 m column, with the parchment of coffee nuts, granulometry 3-4 mm, as the filtrating element, as recommended by Lo Monaco et al. (2002), prior to its conduction to the drip irrigation system.

The tests with two wastewaters could be accomplished, the pressure at the start of the lateral lines was kept at 101 kPa. This permitted an initial mean flow rate of 1.25 and 1.35 L h^{-1}, at the fertigation subunits that respectively applied the treated and non-treated wastewater.

The experiment was performed from 3rd July 2004 to 13th August 2004. The fertigation subunits operated on an average of 4 hours a day, seven days a week.

During the experimental period, analyses were performed to determine the physical and chemical characteristics of the wastewater at the Water Quality Laboratory of the Agricultural Engineering Department of UFV. Concentrations of total and suspended solids were obtained by gravimetric method and the dissolved solids were obtained by the difference between total solids and suspended solid concentrations.

During the test period with the filtered wastewater, five evaluations of the flow rate were undertaken, at every 36 hours, by selecting 16 drippers equally spaced, in each lateral line. The same could not be done with the non-filtered wastewater because the system worked for only 36 hours, when it clogged totally. Data were interpreted through uniformity distribution (UD), as shown in Equation 1.

$$CUD = 100\frac{q_{25\%}}{\bar{q}} \qquad (1)$$

The flow rate of each dripper was obtained dividing the wastewater volume collected from the emitter by the three minutes collecting time. After 144 hours during which the subunits applied the filtered wastewater, the samples from the emitters were taken for biofilm analysis at the Food Microbiology Laboratory of the Microbiology Department of UFV. Aliquots of silt in the drippers were removed, later placed in culture medium (petrifilm plaque) and moved to an incubator under controlled temperature at 37°C, for 48 hours. After this period, the plaque was removed from the incubator to count the bacteria colonies with a magnifying glass.

Results and Discussion

Table 1 presents the mean values of physical and chemical characteristics of the non-filtered coffee fruit wastewater (NCFW) and of the filtered one (FCFW), besides the classification of these types of water, as suggested by Nakayama et al. (2006) on the risk of dripper clogging.

During the test period, the mean values of suspended solids, dissolved solids and pH were 100 and 23 mg L^{-1}; 3.916 and 3.685 mg L^{-1}; and 4.38 and 4.36 respectively for non-filtered and filtered water. Results for the suspended solids in the filtered wastewater showed that organic filters were effective in reducing the risk of clogging . The concentrations of dissolved solids

Table 1. Physical and chemical characteristics of the non-filtered coffee fruit wastewater (NCFW) and filtered coffee wastewater (FCFW)

Characteristics	Units	NCFW		FCFW	
		Values	Obstruction potential*	Values	Obstruction potential*
Suspended solids	mg L^{-1}	100	Moderate	23	Low
Dissolved solids	mg L^{-1}	3,916	Severe	3,685	Severe
pH	-	4.38	Low	4.46	Low

* Classification proposed by Nakayma & Bucks (1986) related to the potential risk of obstruction of the drippers

were higher than the limit of 2,000 mg L^{-1}, established by Nakayama et al. (2006), classifying the wastewater as potentially dripper obstructer. The high concentrations of dissolved solids in the filtered wastewater indicate that a physical and chemical treatment is required to minimize the risks of clogging in low pressure systems used for the application of coffee fruit processing wastewater. This may be achieved by adding coagulant agents, such as aluminum sulfate, ferric sulfate and moringa seeds extract (Cabanellas, 2004), prior to filtration The pH values show that acid wastewater has a low potential for dripper obstruction. Nevertheless, techniques to decrease the water's pH value must be used before its application to the soil.

Table 2 shows the results of the microbiological analysis on the mucilage (biofilm) formed inside the pipes and principally near to the emitters' outlet. Aerobic mesophylls and enterobacteria were identified in the material inside the hydraulic system that applied NCFW, whereas only a group of enterobacteria was identified in the system used to apply FCFW. The suspended and dissolved solids in the disposal water (Figure 1) remained adhered to the bacteria mucilage. The volume of the biofilm increased in proportion to the time of the operation.

Table 2. Analytical results of the biofilm formed inside the lateral lines in the fertigation subunits applying non-filtered coffee fruit wastewater (NCFW) and filtered coffee fruit wastewater (FCFW)

Microorganisms	Unit	NCFW	FCFW
Standard count of mesophyll aerobic bacteria	UFC mL^{-1}	3.4×10^{7}	ND
Enterobacteria count	UFC mL^{-1}	$< 10^{2}$	4.5×10^{4}

* UFC = Colony Forming Units
** ND = not detected

Figure 2 shows biofilm accumulation inside and outside the drippers, partially (A, B) and totally (C, D) clogged due to the application of coffee fruit wastewater. The pictures show a development of the biofilm, resulting in the drippers' partial or total clogging. The picture also reveals that the structure which caused the head loss (red lines) facilitated the development of the biofilm. This fact was particularly due to the deposition of organic solids in the disposal water.

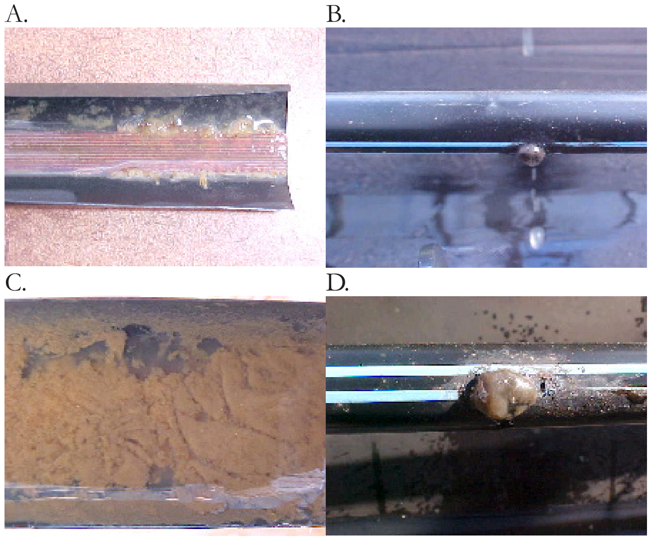

Figure 2. Detailed accumulation of the biofilm inside and outside the drippers. Partially (A, B) and totally (C, D) clogged, due to the application of coffee fruit wastewater

Table 3 shows flow rates obtained during the performance of the irrigation system with NCFW and FCFW. Mean flow rates of the fertigation subunits decreased with the time for filtered and non-filtered wastewater.

Table 3. Flow rates obtained during the operation time of the drip irrigation system with non-filtered wastewater (NCFW) and filtered wastewater (FCFW)

Repetitions (L h^{-1})	Operation time - hours				
	0	36	72	108	144
A. Unfiltered wastewater of processing ofcoffee fruit (NCFW)					
R_1	1.26	0.06	-	-	-
R_2	1.23	0.11	-	-	-
R_3	1.25	0.03	-	-	-
Mean	1.25	0.07	-	-	-
B. Filtered wastewater of processing of coffee fruit (FCFW)					
R_1	1.36	0.82	0.54	0.39	0.46
R_2	1.38	0.85	0.54	0.48	0.48
R_3	1.31	0.80	0.55	0.47	0.42
Mean	1.35	0.82	0.54	0.45	0.45

Although, the reduction in the system with NCFW occurred faster during 36 hours of operation, the flow rate was reduced to 94.50%. The organic filter permitted a greater time of operation with FCFW. The same table shows that the mean flow rates of the subunits used to apply FCFW decreased considerably after 108 hours of operation. The mean flow rates of fertigation subunits, at 108 and 144 hours, were identical, and indicated the stabilization of the system. During the evaluation of flow rates, some drippers were cleaned randomly especially because of the rapid movement of the lateral lines. The application of FCFW by drip irrigation system reduced to 67% the mean flow rate of the fertigation subunits. Decrease in dripper flow rate was greater than the 20% obtained by Batista et al. (2010) in drip irrigation systems operating with domestic tertiary sewage during 560 hours. Although it increased the performance of the system, the use of organic filters with NCFW was not enough to avoid the relatively fast obstruction of the drippers.

Table 4 shows the distribution uniformity calculated during the operation time of the hydraulic system that applied NCFW and FCFW.

Mean distribution uniformity from the units used to apply the NCFW were 92.4 and 0.0% for 0 and 36 hours of operation, respectively. According to above results, after 36 hours of operation, a reduction of 100% in the distribution uniformity occurred, which is unacceptable. A similar behavior was observed in the unit used to apply FCFW. After 144 hours, the operation also had a 100% reduction.

Table 4. Mean values of uniformity distribution during the working time for the irrigations subunits provided with non-filtered coffee fruits wastewater (NCFW) and with filtered coffee fruit wastewater (FCFW)

Repetitions	Operation time - hours				
	0	36	72	108	144
	UD (%)				
A. Unfiltered wastewater of processing ofcoffee fruit (NCFW)					
R_1	96.2	0.0	-	-	-
R_2	94.2	0.0	-	-	-
R_3	86.9	0.0	-	-	-
Mean	92.4	0.0	-	-	-
B. Filtered wastewater of processing ofcoffee fruit (FCFW)					
R_1	93.4	18.3	3.7	0.0	0.0
R_2	96.2	32.3	6.0	0.5	0.0
R_3	91.1	38.9	9.3	0.5	0.0
Mean	93.6	29.9	6.4	0.3	0.0

Although in the case of wastewater, a good uniformity distribution for fertigation of agricultural crops can not be obtained with the coffee fruit processing wastewater, it was verified that distribution uniformity rates by FCFW application for 36 hours (Table 4) were lower than 40% which is unacceptable even for wastewater.

Consequently, a physical and chemical treatment is essential to trigger a higher efficiency of filters for the removal of dissolved solids.

Conclusions

1. Wastewater from coffee fruit processing plant has a high risk of clogging drippers even after being submitted to treatment by organic filters.

2. Wastewater from coffee fruit processing plant (filtered and non-filtered) reduced considerably the mean flow rate and the water distribution uniformity of the subunits of the drip irrigation system.

3. The biofilm buildup, caused by the interaction between the bacteria that form mucilage and the suspended and dissolved solids, was the main factor in the partial and total clogging of the drippers.

4. Wastewater from coffee fruit processing plant must undergo a physical treatment (filtration) when applied by a drip irrigation system for long periods of time.

Literature Cited

Adin, A.; Sacks, M. Dripper-clogging factors in wastewater irrigation. Journal of the Irrigation and Drainage Engineering. v.117, p.813-826, 1991.

Batista, R. O.; Souza, J. A. R.; Ferreira, D. C. Influência da aplicação de esgoto doméstico tratado no desempenho de um sistema de irrigação. Revista Ceres, v.57, p.18-22, 2010.

Cabanellas, C. F. G. Tratamento da água sob recirculação, em escala laboratorial, na despolpa dos frutos do cafeeiro. Viçosa: UFV. 2004. 103p. Dissertation Master.

Capra, A.; Scicolone, B. Emitter and filter for wastewater reuse by drip irrigation. Agricultural Water Management, v.68, p.135-149, 2004.

Dehghanisanij, H.; Yamamoto, T.; Rasiah, V.; Inoue, M.; Keshavarz, A. Control of clogging in microirrigation using wastewater in Tohaku, Japan. ASAE Meeting, St. Joseph: ASAE. 2003 (Paper n. 032027).

Faria, L. F.; Coelho, R. D.; Flecha, P. A. N.; Robles, W. G. R.; Vásquez, M. A. N. Entupimento de gotejadores e seu efeito na pressão da rede hidráulica de um sistema de microirrigação. Revista Brasileira de Engenharia Agrícola e Ambiental, v.6, p.195-198, 2002.

Hills, D. J.; Tajrishy, M. A.; Tchobanoglous, G. The influence of filtration on ultraviolet disinfection of secondary effluent for microirrigation. Transactions of the ASAE, v.43, p.1499-1505, 2000.

Keller, J.; Bliesner, R. D. Sprinkle and trickle irrigation. New York: Avibook, 1990, 649p.

Matos, A. T. Tratamento e destinação final dos resíduos gerados no beneficiamento do fruto do cafeeiro. In: Zambolim, L. Produção integrada de café. Viçosa: UFV, 2003. p.647-708.

Nakayama, F. S.; Boman, B. J.; Pitts, D. Maintenance. In: Lamm, F. R.; Ayars, J. E.; Nakayama, F. S. (ed.). Microirrigation for crop production: Design, operation and management. Amsterdam: Elsevier, 2006, cap.11, p.389-430.

Lo Monaco, P. A.; Matos, A. T.; Martinez, M. A.; Jordão, C. P. Eficiência de materiais orgânicos filtrantes no tratamento de águas residuárias da lavagem e despolpa dos frutos do cafeeiro. Engenharia na Agricultura, v.10, p.40-47, 2002.

Rav-Acha, C.; Kummel, M.; Salamon, I.; Adin, A. The effect of chemical oxidants on effluent constituents for drip irrigation. Water Research, v.29, p.119-129, 1995.

Ravina, I.; Paz, E.; Sofer, Z.; Marcu, A.; Schischa, A.; Sagi, G.; Yechialy, Z.; Lev, Y. Control of clogging in drip irrigation with stored treated municipal sewage effluent. Agricultural Water Management, v.33, p.127-137, 1997.

Sagi, G.; Paz, E.; Ravina, I.; Schischa, A.; Marcu, A.; Yechiely, Z. Clogging of drip irrigation systems by colonial protozoa and sulfur bacteria. In: International Microirrigation Congress, 5., 1995, Orlando. Proceedings... St. Joseph: ASAE, 1995. p.250-254.

Taylor, H. D.; Bastos, R. K. X.; Pearson, H. W.; Mara, D. D. Drip irrigation with waste stabilisation pond effluents: Solving the problem of emitter fouling. Water Science Technology, v.31, p.417-424, 1995.

Trooien, T. P.; Lamm, F. R.; Stone, L. R.; Alam, M.; Rogers, D. H.; Clark, G. A.; Schlegel, A. J. Subsurface drip irrigation using livestock wastewater: Drip-line flow rates. Applied Engineering in Agriculture, v.16, p.505-508, 2000.