Obstruction and uniformity in drip irrigation systems by applying treated wastewater

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ABSTRACT

The use of wastewater in agriculture is an alternative to control surface water pollution, and helps to promote the rational use of water. Therefore, the objective of this study was to evaluate the obstruction and uniformity of application of treated wastewater in drip irrigation systems. The study was conducted in a greenhouse at the Universidade Federal de Campina Grande. The treatments were composed by the factorial combination of two factors: three types of water (supply water-ABAST, effluent of a constructed wetland system -WETLAND and upflow of anaerobic reactor effluent followed by constructed wetland system -UASB + WETLAND), and two drip irrigation systems (surface and subsurface), set in a completely randomized design, with four replications. The results indicated that the pH, suspended solids, total iron and coliforms of the WETLAND and UASB + WETLAND treatments represented a severe risk of clogging of drippers; the flow of the emitters increased as the service pressure was increased; values of CUC and CUD in surface and subsurface drip were classified as excellent in ABAST and WETLAND treatments. The degree of clogging reduced as pressure under surface and subsurface drip was increased.

Key words: performance; emitters; water quality; reuse.

RESUMO

Obstrução e uniformidade em sistemas de irrigação por gotejamento aplicando-se água residuária tratada

A utilização de águas residuárias na agricultura é uma alternativa para controle da poluição das águas superficiais, contribuindo para a promoção do uso racional da água. Assim, objetivou-se com o presente estudo avaliar a obstrução e uniformidade de de sistemas de irrigação por gotejamento aplicando-se água residuária tratada. A pesquisa foi conduzida em casa de vegetação na Universidade Federal de Campina Grande. Os tratamentos foram compostos pela combinação de dois fatores: três tipos de água (água de abastecimento-ABAST, efluente de sistema alagado construído-WETLAND e efluente de reator anaeróbio de fluxo ascendente seguido de sistema alagado construído-UASB+WETLAND), e dois sistemas de irrigação por gotejamento (superficial e subsuperficial), organizados em delineamento inteiramente casualizado, com quatro repetições, os fatores arranjados em esquema fatorial 3x2. Os resultados obtidos indicaram que as características pH, sólidos suspensos, ferro total e nível populacional de coliformes nos tratamentos WETLAND e UASB+WETLAND, representaram risco severo de entupimento de gotejadores; a vazão dos emissores aumentou com a elevação da pressão de serviço; os valores de CUC e CUD no gotejo superficial e subsuperficial foram classificados como excelentes nos tratamentos ABAST e WETLAND. O grau de entupimento reduziu com o aumento da pressão estudada no gotejo superficial e subsuperficial.

Palavras-chave: desempenho; emissores; qualidade da água; reuso.

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INTRODUCTION

The increasing demand for water due to population growth and the need for food production combined with the environmental degradation of water bodies and climatic variations has created a scenario of water scarcity in several regions. This scenario has required changes in the habits of the population, especially in the irrigated agriculture activity, which has sought to reduce water consumption and optimize irrigation systems (Silva *et al*., 2012).

In Brazil, the use of effluents in agriculture is still incipient and the changes that may occur in the soil and irrigation system are little known, requiring further studies (Silva *et al*., 2012). It is known that, despite the actual benefits achieved by using salt water and household wastewater in agriculture, the practice of reuse also causes undesirable effects, mainly due to the presence of some constituents, such as sodium and heavy metals.

The localized irrigation method is used for the application of wastewater due to the high effluent application efficiency and to the low risk of contamination of agricultural product and the field operators as well (Batista *et al*., 2009; Batista *et al*., 2010).

According to Silva *et al*. (2012), in the systems of localized irrigation, the emitters present high susceptibility to clogging. The sensitivity to the clogging problem varies according to the characteristics of the dripper and to the quality of the water, related to the physical, chemical and biological aspects.

The obstruction of the emitters is directly related to the quality of the irrigation water and to the internal architecture of the dripper pipe. Hence, suspended solids, chemical composition and microbiological activity rule the type of water treatment required to prevent obstruction (Souza *et al*., 2006).

Liu & Huang (2009) report that clogging of the drippers impairs the functioning of the irrigation system in general, affecting its operating characteristics and requiring frequent maintenance. Commonly, the obstruction decreases the uniformity of effluent application in localized irrigation systems.

In this context, several techniques are recommended to minimize clogging of drippers. Among such practices, sedimentation, filtration, increase of service pressure and cleaning of the lateral lines with water are included (Puig-Bargues *et al*., 2010; Dazhuang *et al*., 2009; Duran-Ros *et al*., 2009). Considering that the use of wastewater treated by effluent of a constructed wetland system (WETLAND) system and UASB (upflow of anaerobic reactor effluent) + WETLAND in agriculture is incipient in Brazil, it is important to create new technologies to prevent clogging of drippers, with affordable costs to the producer and low risk to the health of humans, plants and the environment.

The objective of this study was to evaluate the obstruction and uniformity of application of drip irrigation when applying treated wastewater.

MATERIAL AND METHODS

The study was carried out from January/2012 to January/2013 in a greenhouse of Universidade Federal de Campina Grande (UFCG), Campina Grande, State of Paraíba, 7º12’88" S, 35º54’40" W and average altitude of 532 m.

For the experiment, metal structures with 8 meters in length and 1 m of width and 0.11 m of height were used, with three experimental modules and three reservoirs. The pressurizing system used in the study consisted of three 0.5-hp centrifugal pump motor. The operating was performed manually, following the start time at 7:00 a.m. and finishing time at 11:00 in the morning of each application cycle.

To avoid suspended particles larger than the diameter of the emitters entering into the system, three 1" disc filters with a flow capacity of 5 $m^3 h^{-1}$ were used. Three Bourdon-type pressure gauges were used to control the service pressure supplied to the system.

The drip hose used in the experiment was self-compensating (Rain Bird™, model XFS 0612500 dripline) with drippers spaced by 0.30 m and recommended pressure for operation according to the manufacturer, ranging from 60 to 420 kPa.

The treatments were composed of a combination of two factors: the first factor consisted of three types of water (public supply water-ABAST (control); effluent of a constructed wetland system -WETLAND and upflow anaerobic reactor effluent followed by constructed wetland system -UASB + WETLAND). The second factor was composed of two types of localized irrigation systems (surface and subsurface dripping).

The constructed wetland systems presented a high potential for removal of suspended solids and nutrients, and it could function as secondary decanters. However, the UASB anaerobic reactors have satisfactory chemical oxygen demand (COD) and biochemical oxygen demand (BOD) removal efficiency. Thus, the use of anaerobic systems as the only treatment usually does not meet the requirements for nutrient removal. Therefore, it is possible to obtain greater efficiency in the removal of pollutants from effluents, when working with conjugated treatments.

The experimental design was a completely randomized, with four replications, so the evaluated factors were arranged in a 3x2 factorial scheme. The experimental unit consisted of a PVC container with dimensions in millimeters: 100 x 600 (diameter x height), containing one emitter in each container. For the subsurface system, the emitters were buried at 10 cm of depth from the soil surface.

The sampling method used eight sites for flow collection per lateral line: the first emitter, the emitters placed at positions 1/7, 2/7, 3/7, 4/7, 5/7, 6/7, and the last emitter, with a collection time of five minutes measured in a digital chronometer.

The physical, chemical and biological characteristics of the supply water, the effluent of a constructed wetland system and upflow anaerobic reactor effluent followed by constructed wetland were evaluated in the initial phase of the experiment, in accordance with the recommendations of Standard Methods (APHA, 2005).

The values of pH, Biochemical Oxygen Demand (BOD_5), suspended solids (SS) and dissolved solids (DS) were measured in the Laboratory of Irrigation and Salinity (LIS) of the Departmento de Engenharia Agrícola of UFCG while the concentrations of total iron (Fe), total manganese (Mn), total calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined in the Laboratory of Basic Sanitation Program (PROSAB) - UEPB / UFCG. The populations of bacteria (TC) were quantified in the Laboratory of Environmental Sciences of the Universidade Estadual da Paraíba (UEPB), and the results were expressed in colony forming units per milliliter (CFU mL^{-1}).

By using the flow data collected from emitters used with 500 h of operation, the ratio of flow and pressure was determined to 50, 100, 150 and 200 kPa; Christiansen's uniformity coefficient (CUC), coefficient of distribution uniformity (CUD) and clogging degree (CD), are pointed in equations (1), (2), (3) and (4).

$$q = K * P^x \quad (1)$$

Where: q = drainage of the dripper (L h^{-1}); k = specific coefficient of each emitter, which also depends on the units of q and p; p = pressure available at the dripper entrance (kPa); x = exponent of the emitter, characterizing drainage at the dripper.

$$CUC = 1 - \left(1 - \frac{\sum_i^n |Q_i - Q|}{n * Q}\right) \quad (2)$$

Where: CUC = Christiansen's coefficient of uniformity (%); Qi = flow collected in each dripper (L h^{-1}); Q = mean of the flows collected in all drippers (L h^{-1}); n = number of analyzed drippers.

$$CUD = \left(\frac{Q25\%}{Q_{med}}\right) * 100 \quad (3)$$

Where: CUD = coefficient of distribution uniformity (%); Q25% = mean of the 25% of the total drippers with the lowest flows (L h^{-1}); Qmed = mean of the flows collected in the subarea drippers (L h^{-1}).

$$CD = 100 * \left(1 - \frac{q_{used}}{q_{new}}\right) \quad (4)$$

Where: DC = degree of clogging (%); qused = average flow of the used emitters (L h^{-1}); qnew = average flow of the new emitters (L h^{-1}).

The classification according to Christiansen's coefficient of uniformity, distribution uniformity coefficient and degree of clogging were in accordance with Keller & Karmeli (1974); ASAE (1996) and, Morata *et al*. (2014).

Data obtained were evaluated by means of analysis of variance by the F test at 0.01 and 0.05 levels of probability and for significance, polynomial regression analysis was carried out using statistical software SISVAR (Ferreira, 2008).

RESULTS AND DISCUSSION

The physical, chemical and microbiological characteristics of the supply water (ABAST), effluent of a constructed wetland system (WET) and upflow anaerobic reactor effluent followed by constructed wetland system (UASB + WET) used in the tests with drip irrigation systems, in addition to the risks of clogging emitters are shown in Table 1.

The characteristics of pH, SS, Fe and TC of the two treated effluents represent a severe risk of clogging of drippers; while for DS, Mn and Mg^{2+}, this risk was moderate and for Ca^{2+}, it was low, according to the classification proposed by Nakayama & Bucks, (1991) and Capra & Scicolone, (1998).

When the achieved results were compared (Table 1), greater risks of drip obstruction provided by wastewater treated by WET and UASB + WET were found. This fact is likely to be related to the greater amount of organic matter present in these waters.

This result is similar to those obtained by Liu & Huang (2009) in their work on clogging of drip emitters using freshwater and treated sewage effluent, since they state that the risk of emitter obstruction increased when applying treated wastewater.

The pH of the wastewater was classified as a severe risk for obstruction of the drippers. It is possible that this fact is related to incrustation issue in pipes caused by pH higher than 7.5. Batista *et al.* (2010) and Liu & Huang (2009) also stated that the pH of irrigation water represents a severe risk of drip obstruction.

Ribeiro & Paterniani (2013) observed in their studies that the obtained pH values presented an average risk of obstruction of the emitters. This result differs from the present study, possibly because water was filtered to retain more particles when compared to the present study.

In relation to the supply water, no risk of obstruction for the emitters was found since all analyzed characteristics were classified as low or no risk of obstruction. These results corroborate with others obtained by Liu & Huang (2009) and Batista *et al*. (2013).

From the flow and its respective pressure, the equation that relates the flow to the pressure of the emitter and the characteristic curve of the surface drip used for the different treated waters was determined (Figure 1).

By means of regression analysis, the ratio flow and pressure were obtained. It is observed that the characteristic curve for each WET, UASB + WET and ABAST treatment presents a potential equation with values very close to zero (0.097, 0.086 and 0.097), showing that the flow rate of the dripper varied very little with pressure variation regardless the treatment applied. These results agree with those observed by Almeida *et al*. (2006) who obtained values of exponent x very close to zero.

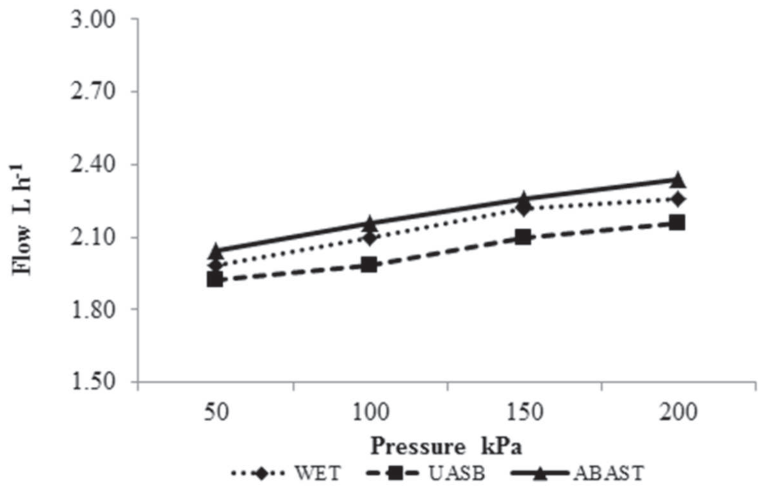
It was also verified that the flow of this emitter could be perfectly characterized by the potential functions that presented high coefficient of determination. Souza *et al*. (2006) also verified that all the flows found in their study are above the nominal flow rate and with small variations, indicating that probably no damage occurred in the compensation system.

The equation that relates the flow to the pressure of the emitter and the characteristic curve of the pipe of the subsurface drip used for the different treated waters is shown in Figure 2. The potential equations for each WET, UASB + WET and ABAST treatment showed values of discharge exponent (x) very close to zero (0.088, 0.093 and 0.093), respectively.

Table 1: Physical, chemical and microbiological characteristics of supply water (ABAST), effluent of the constructed wetland system (WET) and effluent of anaeroci reactor with upflow followed by constructed wetland system (UASB + WET) used in the experimental trials and the risks of clogging of emitters

Characteristics	ABAST	Risks of Clogging of Emitters		WET	Risks of Clogging of Emitters		UASB + WET	Risks of Clogging of Emitters	
		a	b		a	b		a	b
pH	6.83	B		8.09	S		8.09	S	
SS(mg L^{-1})	0	N		300	S		330	S	
DS(mg L^{-1})	49	B		1370	M		1310	M	
Fe(mg L^{-1})	0	N		5.3	S		5.1	S	
Mn(mg L^{-1})	0	N		0.56	M		0.75	M	
Ca^{2+}(mg L^{-1})	1.73		B	3.59		B	2.86		B
Mg^{2+} (mg L^{-})	3.14		M	4.07		M	4.34		M
BOD_5 (mg L^{-1})	10			318			345		
TC (CFU mL^{-1})	1.5* 10^3	B		7.2*10^5	S		6.5*10^5	S	

Note: N - None; B - low; M - Moderate; and S - Severe; (A) (Bucks *et al*., 1979); (B) (Capra & Scicolone, 1998); pH - hydrogenation potential; SS - suspended solids; DS - dissolved solids; Fe - total iron; Mn - total manganese; Ca^{2+} - calcium; Mg^{2+} - magnesium; BOD_5 - biochemical oxygen demand; TC - total coliforms; and CFU - colony forming unit.



Treatment	Equations
WET	$q = 1.348*P^{0.097}$ $R^2 = 0.98$
UASB	$q = 1.356*P^{0.086}$ $R^2 = 0.93$
ABAST	$q = 1.386*P^{0.097}$ $R^2 = 0.99$

Figure 1: Flow curve versus pressure curve with potential equation for emitters used for surface dripping with the types of treated water and evaluated pressures.

For Keller & Karmelli (1974), the "x" exponent characterizes the flow regime and the ratio of flow versus pressure of the emitter, so that: $0 < x < 0.5$, the flow regime varies from turbulent to completely turbulent, and the flow is less influenced by the pressure variation.

However, it can be observed from Figures 1 and 2 that, although it was possible to verify differences in the emitter's hydraulic behavior in the different evaluated treatments, the time of exposure of the emitter to the treated wastewater did not modify its self-compensating characteristic. This agrees with the results obtained by Silva *et al*. (2012) when studying the performance of self-compensating drippers with different household effluents. Pletsch *et al*. (2009) also obtained similar results when observing a change in the hydraulic behavior of drippers, only after 1000 h of application of wastewater from treated household sewage.

The values of CUC, CUD and CD of surface drippers used as a function of the type of water at the different pressures are shown in Figure 3. It can be seen that the CUC increased as the service pressure supplied to the system was increased. The highest results were verified for water treated by WET followed by ABAST, with values higher than 90%, considered excellent. For water treated by UASB + WET, only the CUC at 200 kPa pressure was higher than 90%, the others were classified as good.

The coefficients found in this study are classified as excellent. Thebaldi *et al*. (2013), when studying different water types and their effect on drip uniformity in tomato crop, also observed similar results, evidencing that the water quality used in the experimented did not influence the uniformity of the emitters.

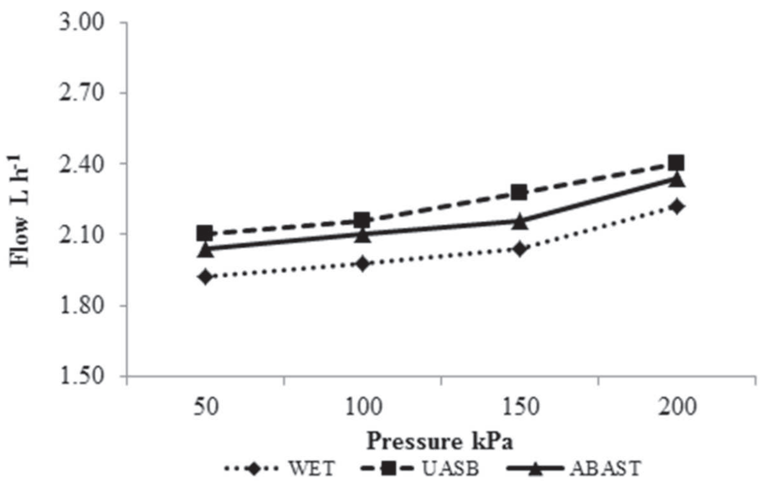
The coefficient of distribution uniformity for water treated by WET was higher at the pressure of 100 kPa. At ABAST, the highest value was observed at 150 kPa, classified as excellent, except at the pressure of 50 kPa for WET treated water that is below 90%. The UASB + WET treatment presented values below 90% regardless the applied service pressure, being classified as good. In the same way, Batista *et al*. (2006, 2010) who studied the influence of the application of treated sanitary sewage on the performance of a field-assembled drip irrigation system, found CUC and CUD values above 90%, classifying it as excellent.

A reduction was found in clogging degree of the emitters as the pressure in the different waters used in the experiment was increased, a fact that can be associated to the increase of the speed of the water caused by the increase of pressure and consequently drag of the deposited sediments over the emitters.

The highest values of degree of clogging were observed for the water treated by UASB + WET, evidencing that it was the treatment that most contributed to the clogging of emitters installed in a superficial way. The clogging of the drippers, besides decreasing the uniformity of application of water, provides a decrease in their flow.

Batista *et al*. (2006), comparing the operating times of 0 and 120 h, found a reduction of 4.56% in the average flow rate of the irrigation system, evaluations of water application uniformity and that drip clogging was more pronounced at the end of the lateral lines.

Cunha *et al*. (2006), when studying the uniformity of distribution in drip irrigation systems using wastewater from coffee tree fruits pulp, observed that in raw wastewater, there was a greater potential for clogging of



Treatment	Equations
WET	$q = 1.424*P^{0.088}$ $R^2 = 0.98$
UASB	$q = 1.438*P^{0.093}$ $R^2 = 0.89$
ABAST	$q = 1.312*P^{0.093}$ $R^2 = 0.80$

Figure 2: Flow curve versus pressure with potential equation for emitters used for subsurface dripping with treated water types and evaluated pressures.

drippers in relation to filtered wastewater. However for both cases, the uniformity levels of water application at the end of the experiment were classified as unacceptable from the point of view of irrigation management.

Christiansen's coefficient of uniformity (CUC), coefficient of uniformity distribution (CUD) and clogging degree (CD) of subsurface drippers used as a function of the type of water at different pressures are shown in Figure 4. It is observed that for subsurface drip, in all the pressures studied and in the three types of water, CUC was greater than 90%, being classified as excellent. However, the highest values observed were for water treated by WET and ABAST. Martins *et al*. (2010) in a study with ferruginous water, also classified the CUC as excellent, in almost all evaluations.

For CUD, as the pressure increased, the values increased. The best results were obtained in the drippers using ABAST and WET water.

Clogging degree for the subsurface drip in the emitters used had similar behavior to those of surface, reducing the clogging as the service pressure increased. However, the lowest values were verified for UASB + WET, evidencing that for subsurface drip, the treatment was better than for surface drip. Such operational variation of the emitters is possibly correlated with the architecture of each dripper, such as the length, shape, and dimensions of the emitter.

Ribeiro *et al*. (2010), when studying the clogging of conventional dripping pipes with the application of potassium chloride via two qualities of water, observed that the drippers had clogging values above 20% and reaching a 77% reduction in the flow rate, being considered a high susceptibility to clogging. These results differ from those obtained in the present study, due to the management and intrinsic characteristics of each dripper.

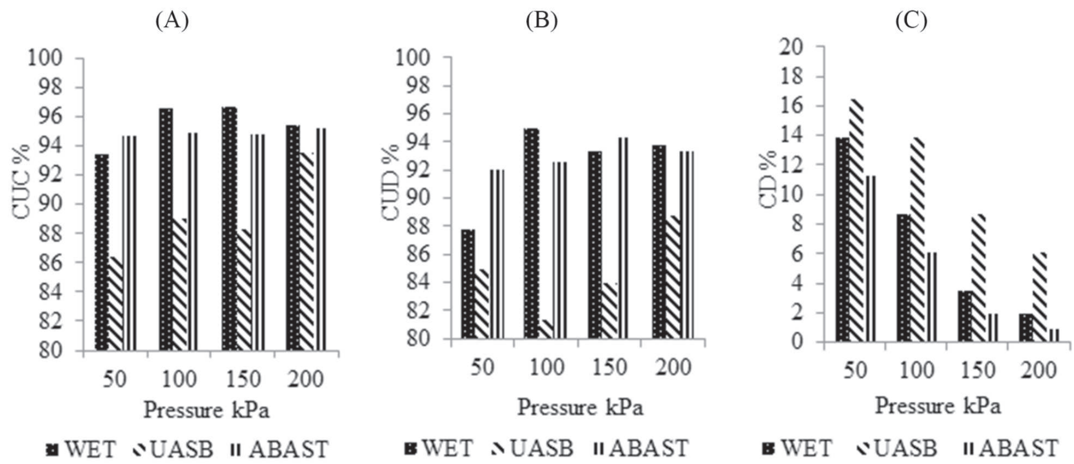


Figure 3: Christiansen's **c**oefficient of uniformity (A), coefficient of distribution (B) and clogging degree (C) of emitters used for surface dripping with the types of treated waters and evaluated pressures.

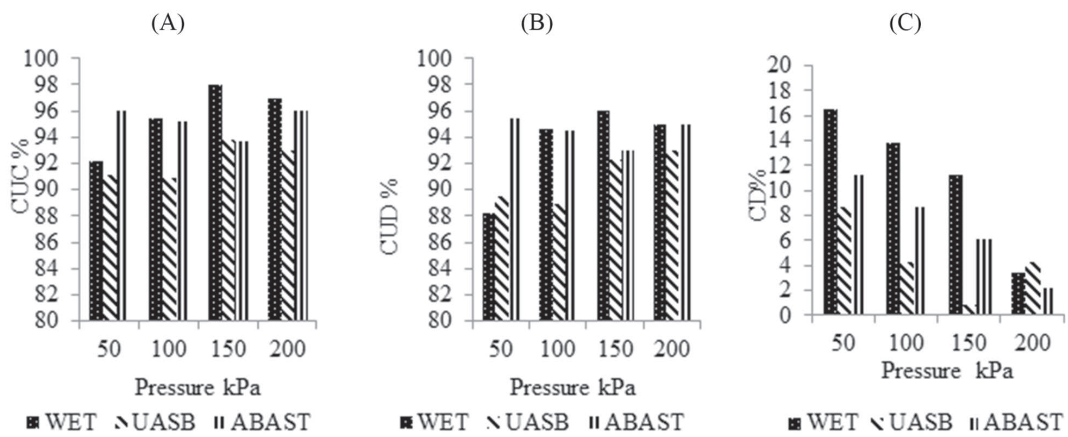


Figure 4: Christiansen's coefficient of uniformity (A), coefficient of distribution (B) and degree of clogging (C) of emitters used for subsurface dripping with the types of treated waters and evaluated pressures.

CONCLUSIONS

The pH, suspended solids, total iron and total coliforms of the effluents treated by WET and UASB + WET represented a severe risk of clogging of drippers.

The flow rate of the emitters increased with the service pressure in the different applied treatments and the potential equations were adjusted to the applied model.

The values of CUC and CUD in the surface and subsurface drip were classified as excellent in the treatments with effluent of a constructed wetland system and supply water.

Clogging degree was reduced as pressure under surface and subsurface drip was increased. In the superficial drip with supply water, the lowest levels of obstruction were evidenced and in the subsurface was with effluent of anaerobic reactor of ascending flow.

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