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AVALIAÇÃO DE GOTEJADORES COM USO DE ÁGUA RESIDUÁRIA DE PISCICULTURA E SUINOCULTURA EM DIFERENTES DILUIÇÕES

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1 RESUMO

Este artigo é parte integrante da dissertação de mestrado da primeira autora. As águas residuárias apresentam em sua composição alta carga orgânica, elevada quantidade de sólidos suspensos e variação no pH, que podem proporcionar risco de obstrução dos emissores. O objetivo deste trabalho foi avaliar o desempenho hidráulico do sistema de irrigação por gotejamento superficial com uso de água residuária de piscicultura e suinocultura em diferentes diluições. O delineamento experimental foi em blocos ao acaso, analisado em esquema de parcelas subdivididas 2×4, com três repetições. Os tratamentos consistiram em duas fontes de água residuária (piscicultura e suinocultura) diluídas em quatro proporções de água de abastecimento, sendo: dose recomendada de água residuária + 0, 25, 50 e 75% de seu volume em água de abastecimento, totalizando 24 parcelas experimentais. Cada parcela foi constituída por quatro vasos, totalizando 96 unidades experimentais. Depois de tabulados os dados de vazão foram efetuados os cálculos de Uniformidade de Christiansen (CUC) e de Distribuição (CUD), vazão relativa (Qr), coeficiente de variação (CV) e grau de entupimento (GE). O uso do sistema de irrigação por gotejamento operando com água residuária de suinocultura e piscicultura, durante 470 horas de funcionamento, não compromete a uniformidade de distribuição de água.

Palavras-chave: *Zea mays* L., efluentes, irrigação localizada, uniformidade

ALVES D. K. M.; TEIXEIRA, M. B.; CUNHA, F. N.; CABRAL FILHO, F. R. EVALUATION OF DRIPPERS WITH USE OF WASTEWATER FROM SWIMMING AND SWINE FARMING IN DIFFERENT DILUTIONS

2 ABSTRACT

This article is an integral part of the first author's dissertation. The wastewater presents in their composition high organic load, high number of suspended solids and variations in pH, which may provide a risk of obstruction of emitters. This work aimed to evaluate the hydraulic performance of a surface drip irrigation system with the use of fish and pig farming wastewater at different dilutions. The experimental design was in randomized blocks, analyzed in a split plot scheme 2×4, with three replications. The treatments consisted of two sources of wastewater (fish and swine) diluted in four proportions of water supply, with a recommended dose of wastewater + 0, 25, 50 and 75% of its volume in water supply, totaling 24 experimental plots.

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Each plot consisted of four vessels, totaling 96 experimental units. After tabulating the flow data were performed the calculations of Uniformity of Christiansen (CUC) and Distribution (CUD), Relative Flow (RF), Coefficient of Variation (CV) and Degree of Clogging (DC). The use of the drip irrigation system operating with swine and fish-farming wastewater during 470 hours of operation does not compromise the uniformity of water distribution.

Keywords: *Zea mays* L., effluents, drip irrigation, uniformity

3 INTRODUCTION

The use of wastewater appears to be an alternative source of nitrogen fertilization, as it contains nitrogen and other nutrients, such as potassium, in its composition, which reduces the doses of mineral fertilizers required for the crop (ABREU, 2019).

In addition to enabling productivity improvements due to the supply of nutrients, the use of wastewater in the fertigation of agricultural crops constitutes an option for the appropriate disposal of this waste, contributing to the reduction in environmental pollution caused by the release of these effluents into water bodies (FRANCISCO, 2014). Activities in the agroindustrial sector, such as pig and fish farming, produce a significant amount of effluents with high nutrient and organic matter loads daily (SILVA, 2019; GOMES, 2016), which can compromise the water quality of water bodies receiving these effluents.

Wastewater has a high organic load, a high amount of suspended solids and pH variation in its composition (MACAN *et al.*, 2017). When used in irrigation systems, gelatinous deposits may form because of the interaction between organic particles, one of the relevant factors in the process of dripper clogging (BATISTA *et al.*, 2013a), impairing the general functioning of the irrigation system, which affects its operating characteristics and interferes with the uniformity of water distribution (CUNHA *et al.*, 2006; BATISTA *et al.*, 2013b).

With the development of new technologies, Silva *et al.* (2015) noted that there is a trend toward expanding areas irrigated by drip irrigation to replace other irrigation systems in some regions of Brazil. Despite its high efficiency, the main limitation of this system for use in fertigation with wastewater is the sensitivity of the emitters to obstruction by physical, biological and chemical contaminants present in these waters (DOSORETZ *et al.*, 2011; SILVA *et al.*, 2013).

The drip irrigation system is recommended for the application of wastewater because of the optimization of effluent application and the low risk of contamination of agricultural products and operators in the field (LOPES *et al.*, 2015), standing out among other methods for its efficiency and uniformity.

The performance of drip irrigation systems can be evaluated via water application uniformity coefficients, such as the Christiansen uniformity coefficient (CUC), distribution uniformity coefficient (CUD) and coefficient of variation (CV), in addition to knowledge of criteria such as the relative flow and degree of clogging of the irrigation system.

According to Mantovani, Bernardo and Palaretti *et al.* (2009), the assessment of irrigation uniformity is a fundamental step in defining the efficiency of water use by the irrigation system, losses during application and the need for system maintenance due to clogging, which alters the uniformity of water distribution.

Therefore, the objective of this work was to evaluate the hydraulic performance of a surface drip irrigation system using wastewater from fish farming and pig farming at different dilutions.

4 MATERIAL AND METHODS

The surface drip irrigation system was designed for fertigation in plastic pots placed in open air at the experimental station of the Instituto Federal Goiano – *Campus* Rio Verde – GO. The area is located at an altitude of 720 m and at the geographic coordinates of 17°48'28" S and 50°53'57" W. The climate of the region is classified according to Köppen and Geiger (1928) as Aw (tropical), with rain in the months of October to May and dry months in the months of June to September. The average annual temperature varies from 20 a35°C and precipitation varies from1.500 a 1.800 mmannual and the relief is gently undulating (6% slope).

The soil used to fill the pots was classified as dystroferric Red Latosol (LVdf), with a clayey texture (SANTOS *et al.*, 2018), and was collected from a layer of 0.00–0.20 m depth in an area of the native Cerrado belonging to IF Goiano – *Campus* Rio Verde (Table 1).

Table 1. Physicochemical characteristics of the dystroferric Red Latosol used to fill the pots in the 0.00–0.20 m depth layer.

Here	Mg	Ca+Mg	Al	H+Al	K	K	S	P	$CaCl_2$
------------------- cmol $_c$ dm $^{-3}$ -------------------						--------- mg dm $^{-3}$ ---------			pH
0.77	0.34	1.11	0.04	2.15	0.05	18:00	9.90	0.47	5.20
In the	Faith	Mn	Ass	Zn	B	CTC $_a$	SB	V%	m%
--------- Micronutrients (mg dm $^{-3}$) ---------						cmol $_c$ dm $^{-3}$		SB	m%
0.00	75.56	12.96	4.16	3.93	ns	3.31	1.16	35.00	3.30
Texture (%)			MO	Ca/Mg	Ca/K	Mg/K	Ca/CTC	Mg/CEC	K/CTC
Clay	Silt	Sand	gdm $^{-3}$	------------------ Relationship between bases -------------------					
50.20	4.90	44.90	15.20	2.30	15.40	6.80	23.26	10.27	1.51

Source: Author (2021)

Ca (Calcium), Mg (Magnesium), and Al (Aluminum): KCl 1 mol L $^{-1}$; K (Potassium); S (Sulfur): $Ca(H_2PO_4)_2$ 0.01 mol L $^{-1}$; P (Phosphorus): Mehlich 1; Na (Sodium); Fe (Iron); Mn (Manganese); Cu (Copper) and Zn (Zinc): Melich 1; B (Boron): hot water; Cation exchange capacity (CEC); sum of bases (SB); base saturation (V%); aluminum saturation (m%); MO (Organic matter): Colorimetric method.

The experimental design was randomized blocks, analyzed in a 2 × 4 split-plot design, with three replicates. The treatments consisted of two wastewater sources (fish farming and pig farming) diluted in four proportions of supply water: recommended doses of wastewater added at 0, 25, 50, and 75% of its volume in supply water, totaling 24 experimental plots. Each plot consisted of four pots, totaling 96 experimental units. The wastewater dose applied via fertigation was calculated on the basis of the recommended dose of 100 kg ha $^{-1}$ of nitrogen (MATOS; MATOS, 2017).

Swine wastewater (SWW) was obtained from a pig farm at IF Goiano – Rio Verde *Campus*, with 32 finishing pigs. After collection, the SWW was subjected to anaerobic treatment in a biodigester until the organic matter stabilized. Fish farming wastewater (FWW) was obtained from a fish farm tank for tilapia (*Oreochromis*) production. *niloticus*), with a volume of 1000 L and a density of 131 fish in the juvenile phase, weighing approximately 53 g $_{fish^{-1}}$.

Before each fertigation, the physical-chemical and bacteriological characterization of the two wastewater sources was carried out (Table 2) according to the methodologies described in the *Standard Methods for Examination of Water and Wastewater* (APHA, 2005).

Table 2. Physicochemical and bacteriological characteristics of wastewater from pig and fish farms used for fertigation.

Parameter	Wastewater	
	Pig farming	**Fish farming**
pH	8,10	7.67
Turbidity (NTU)	280.00	3.79
Temperature (°C)	22.97	22:15
Electrical conductivity (dS m^{-1})	0.01	0.43
Chemical Oxygen Demand (mg L^{-1})	966.94	587.5
Dissolved Oxygen (mg L^{-1})	3.43	4.60
Total solids (mg L^{-1})	5472.22	175.69
Fixed solids (mg L^{-1})	3822.92	73.29
Volatile solids (mg L^{-1})	1649.30	102.40
Total nitrogen (mg L^{-1})	478.92	91.17
Ammonia (mg L^{-1})	408.08	30.00
Nitrite (mg L^{-1})	<0.01	<0.01
Nitrate (mg L^{-1})	41.00	37.00
Kjeldahl nitrogen (mg L^{-1})	437.92	54.17
Organic nitrogen	29.12	24.17
Phosphorus (mg L^{-1})	9.19	5.00
Potassium (mg L^{-1})	147.49	21.00
Calcium (mg L^{-1})	26.65	11.90
Magnesium (mg L^{-1})	26.65	11.90

Source: Author (2021)

The surface drip irrigation system was equipped with self-compensating drippers with a nominal flow rate of 4.0 L h^{-1}, inserted in a 16 mm low-density polyethylene hose, with a spacing of 0.5 m and pressurized by a 1/4 hp motor–pump set. With the aid of a slide valve, the service pressure was maintained at 1.25 bar and monitored via a 0–200 psi digital pressure gauge.

The collection and subsequent evaluation of the irrigation system flow uniformity were performed at 0 and 470 hours of system operation. The methodology proposed by Keller and Karmeli (1975) was used, in which water volumes were collected from 48 drippers, 6 per line. The system was pressurized, and then the collection containers (capacity of 0.35 L) were positioned under the respective drippers with a 5-s time lag. The containers were sequentially removed after 3 min with a 5-s time lag. The water volumes emitted by the drippers were measured in 0.10 L test tubes. These data were subsequently tabulated, and the average flow rate of the drippers was obtained according to equation (1).

$$q = 60 \left(\frac{V}{1000\, t}\right) \quad (1)$$

where q represents the dripper flow rate (L h^{-1}); V represents the volume of water collected (L); and t represents the collection time (min).

After the flow data were tabulated, calculations were performed for

Christiansen uniformity (CUC) (CHRISTIANSEN, 1942) and distribution (CUD) (CRIDDLE *et al.*, 1956), relative flow (Qr), coefficient of variation (CV) and degree of clogging (GE), which are highlighted in equations 2 to 6.

$$CUC = 100 \cdot \left(1 - \frac{\sum_{i=1}^{n} |Xi - \overline{X}|}{n \cdot \overline{X}}\right) \quad (2)$$

$$CUD = 100 \cdot \left(\frac{X_{25\%}}{\overline{X}}\right) \quad (3)$$

$$Qr = \left(\frac{Q_{x,y}}{Q_i}\right) \cdot 100 \quad (4)$$

$$CVq = 100 \cdot \left(\frac{S}{\overline{\overline{X}}}\right) \quad (5)$$

$$GE = \left(1 - \frac{q_{usado}}{q_{novo}}\right) \cdot 100 \quad (6)$$

Where: CUC: Christiansen uniformity coefficient (%); Xi: flow rate of each dripper (L h^{-1}); $\overline{X}$: average flow rate of the drippers (L h^{-1}); n: number of drippers observed ; CUD: distribution uniformity coefficient (%); $X_{25\%}$: average of 25% of the total drippers , with the lowest flow rates (L h^{-1}); Qr : relative flow rate (%); $Q_{x,y}$: flow rate of an emitter x on an irrigation day y (L h^{-1}); Q_i : flow rate of this emitter on the first day of irrigation (L h^{-1}); CVq : coefficient of variation of the flow rate (%); S: standard deviation of the dripper flow rate (L h^{-1}); GE: degree of clogging (%); q_{used} : flow rate of the used dripper (L h^{-1}); q_{new} : flow rate of the new dripper (L h^{-1}).

The irrigation system's hydraulic performance data were subjected to analysis of variance via the F test at a 5% probability level, and in cases of significance, linear and quadratic polynomial regression analyses were performed for the dilution levels (D). For the wastewater source (F) factor, the means were compared with each other via the Tukey test at the 5% probability level via the SISVAR® statistical program (FERREIRA, 2011).

5 RESULTS AND DISCUSSION

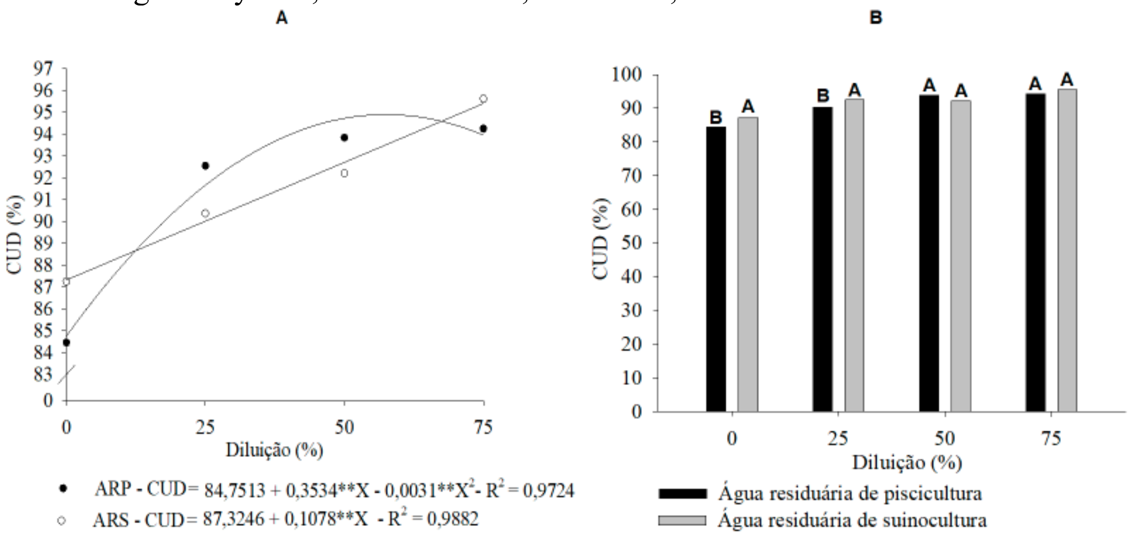
For the initial operating time, the average values for Christiansen's coefficients of uniformity (CUC) and distribution (CUD) were 94.01 and 92.30%, respectively. According to the performance classification proposed by Merriam and Keller (1978) and Bernardo, Soares and Mantovani (2009), the system is classified as excellent (>90%). The results are in accordance with the fertigation work with wastewater, without dilution, carried out by Cunha *et al.* (2006), who reported average CUC and CUD values of 94.77 and 92.42%, respectively, during the initial operating time.

For the relative flow (Qr), flow variation coefficient (CVq) and degree of clogging (GE), during the initial operation time, the averages obtained were 8.44, 94.40 and 6.86%, respectively. ASAE (2003) recommends that the coefficient of variation of drippers be a maximum of 10%, which indicates good quality of the emitters. Notably, the average GE remained below 8%, and according to Dalri *et al.* (2014), a GE of less than 40% suggests that there is no serious clogging of the emitters.

After 470 hours of operation in the drip irrigation system, the effects of the F × D interaction on the CUD, Qr and GE coefficients were observed. There was a significant effect of the isolated factors F and D on the CUC and CVq coefficients.

A difference in the behavior of the UDC is observed when evaluating the dilutions in each wastewater source. For the fish farming wastewater (FWW) source, the UDC fit a second-degree polynomial equation, with 57% dilution providing the highest UDC value, estimated at 94.82%. For SWW, the data were fitted with a first-degree polynomial equation, where each 25% increase in dilution resulted in a 2.7% increase in the UDC, with a 75% dilution providing the highest UDC value, estimated at 95.41% (Figure 1A).

Figure 1. Breakdown of the dilution × wastewater sources interaction (fish farming – ARP and pig farming – ARS) for the distribution uniformity coefficient (CUD) of the drip irrigation system; after 470 hours, Rio Verde, Goiás.



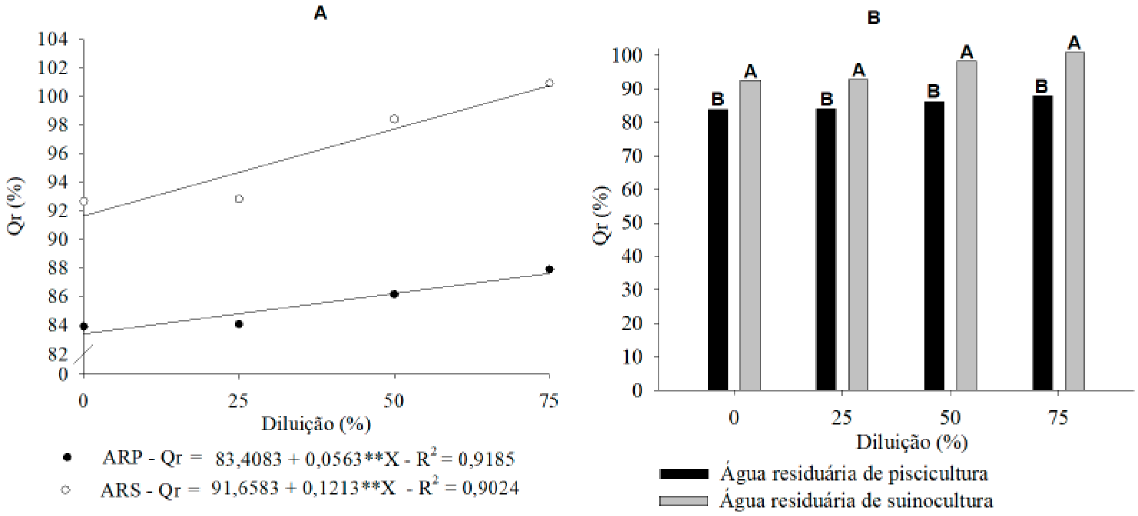
Source: Author (2021)

Regardless of the wastewater source used, the highest CUD values of the drip irrigation system were classified as excellent (>90%) according to the methodology proposed by Keller and Karmeli (1974) and Bralts (1986). In this study, Hermes *et al.* (2015) reported that the distribution uniformity coefficient of the irrigation system for most drippers supplied with diluted wastewater was classified as excellent. However, drippers from different manufacturers may present different CUD values when wastewater from a sewage treatment plant is applied than those obtained from drippers that use only supply water. Therefore, it is necessary to plan and monitor fertigation with this water in drip systems (GOMES *et al.*, 2020).

There was a difference between the sources used only at 0% and 25% D (Figure 1B), where the ARS source provided increases in the CUD value of 2.8% and 2.17%, respectively. The water distribution uniformity coefficient is one of the main parameters used because it expresses the quality of irrigation and is decisive in the operation of these irrigation systems (OLIVEIRA; VILLAS BÔAS, 2008). According to López *et al.* (1992), the CUD is the most widely used method for determining uniformity because it allows for a more accurate measurement, giving greater weight to plants that receive less water. The results of this study for the CUD (>90%) reflect the good operating and conservation conditions of the system operating with wastewater from fish and pig farming.

For Qr, each 25% increase in dilution resulted in increases of 1.40 and 0.17% for the ARP and ARS sources, respectively, in which the 75% dilution presented estimated values of 87.63 and 102.28%, respectively (Figure 2A). This behavior may be the result of the removal of solids from inside the drippers in the larger volumes of water supplied to the system, thus leading to the attenuation of clogging and an increase in relative flow (BATISTA; OLIVEIRA; OLIVEIRA *et al.*, 2014). Leite (1995) and Costa (2000) reported that oscillations in relative flow correspond to variations in the degree of clogging such that the random unclogging of emitters directly reflects the increase in dripper flow.

Figure 2. Breakdown of the dilution × wastewater sources interaction (fish farming – ARP and pig farming – ARS) for the relative flow rate (Qr) of the drip irrigation system; after 470 hours, Rio Verde, Goiás.

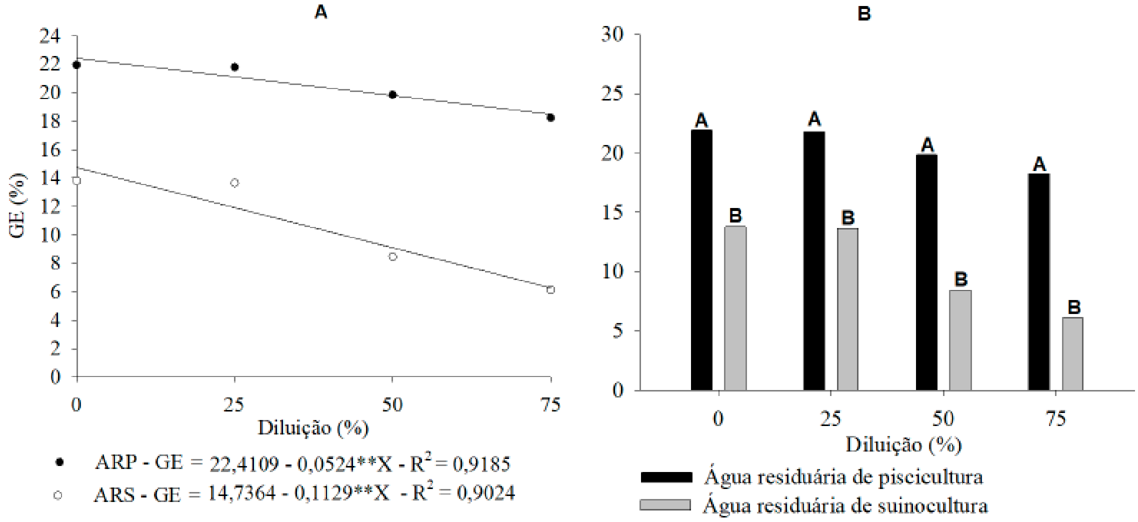


Source: Author (2021)

There was a difference between the sources used at D values of 0%, 25%, 50% and 75% (Figure 2B), in which the ARS source provided increases of 8.75%, 8.75%, 12.25% and 13%, respectively, in the Qr of the drippers compared with the ARP source. Batista *et al.* (2013b) reported that swine wastewater provides a low risk of dripper clogging by observing CUD values above 90% up to an operating time of 60 hours, regardless of the amount of supply water used after applying the wastewater.

In the evaluated system, the GE fit a decreasing linear regression model such that for each 25% increase in dilution, there was a reduction of 1.31 and 2.82% for ARP and ARS, respectively, with the 75% dilution promoting the least pronounced GE, estimated at 18.48 and 6.26% for ARP and ARS, respectively (Figure 3A). These results corroborate the studies by Marques *et al.* (2018), who reported that the dilution of wastewater in supply water minimized dripper clogging. Higher proportions of supply water in wastewater can promote the removal of biofilms developed by bacterial colonies and solids that promote emitter clogging (FERNANDES *et al.*, 2014). Emitter clogging is the main problem in surface and subsurface drip irrigation systems, leading to reduced plant growth and economic losses (ALMEIDA, 2019).

Figure 3. Breakdown of the dilution × wastewater sources interaction (fish farming – ARP and pig farming – ARS) for the degree of clogging (GE) of the drip irrigation system, after 470 hours, Rio Verde, Goiás.

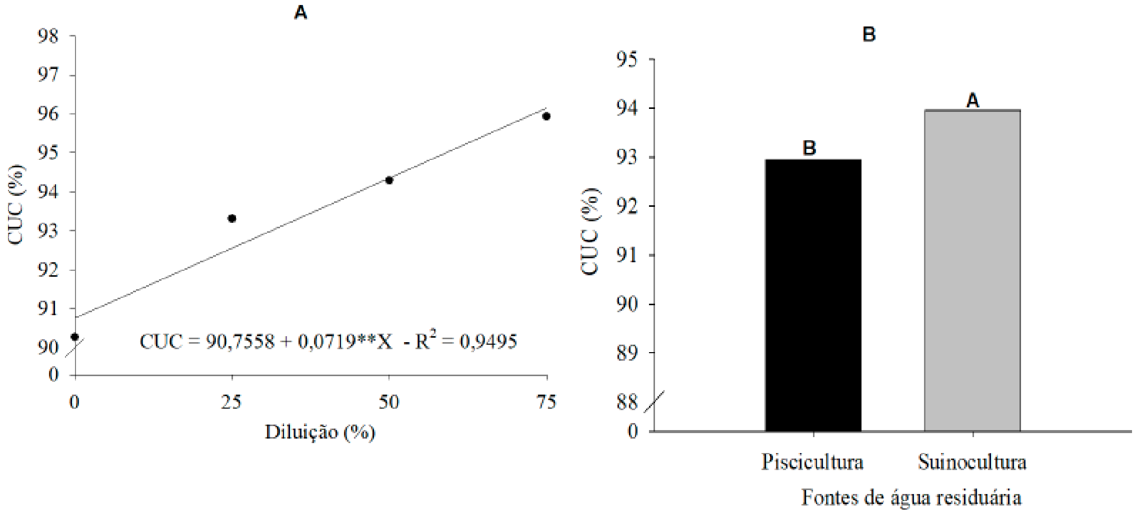


Source: Author (2021)

There was a difference between the sources used at D values of 0%, 25%, 50% and 75% (Figure 3B), in which the ARP source provided a higher GE of the emitters on the order of 8.14, 8.14, 11.4 and 12.09%, respectively, compared with the ARS source. The reduction in clogging in drippers supplied with swine wastewater due to the percentage increase in dilution can be attributed to the low concentration of dissolved oxygen in this *raw effluent* (Table 2), which reduces the production of byproducts of microbial activity and, consequently, the formation of biofilms, which, according to Carmo *et al.* (2016), is the main obstacle to localized irrigation.

The first-degree polynomial equation was used to estimate the CUC as a function of dilution, in which the highest value of this coefficient was obtained at the 75% dilution, which was equal to 96.14% (Figure 4A). Fernandes *et al.* (2017) evaluated the performance of a drip irrigation system operating with wastewater dilutions and reported that there was a linear increase in CUC as the percentage of wastewater in the total irrigation depth decreased. The increase in the CUC of the drippers may be due to the release of gelatinous material from the dripper obstruction (CUNHA *et al.*, 2006). When evaluating a drip fertigation system with wastewater, Juchen, Suszek and Vilas Boas *et al.* (2013) reported that the uniformity coefficient (CUC) was between 89% and 97%.

Figure 4. Christiansen uniformity coefficient (CUC) as a function of dilution (A) and wastewater source (B), after 470 hours, Rio Verde, Goiás.



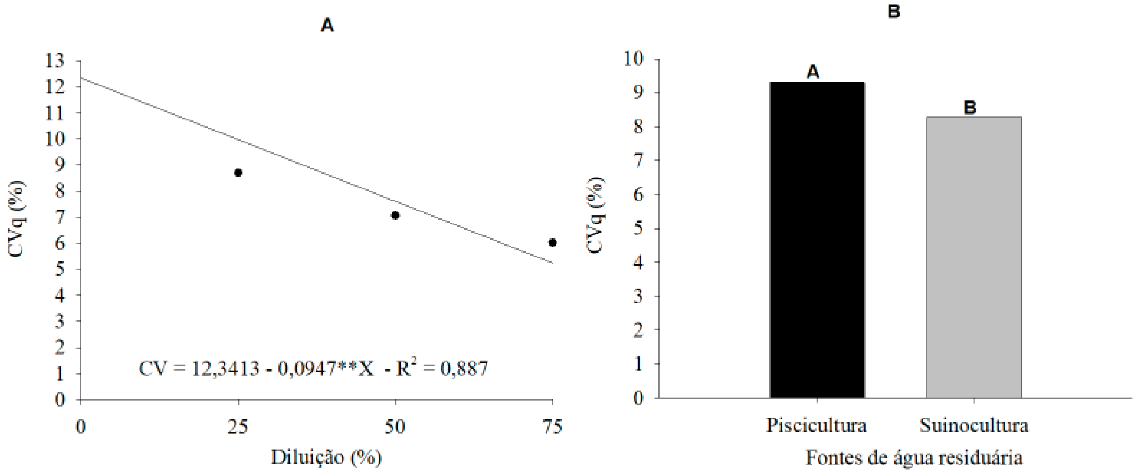
Source: Author (2021)

The wastewater sources influenced the CUC, with the ARS (93.96%) providing a CUC of the drippers that was 1.03% greater than that obtained from the ARP source (92.93%) (Figure 4B). According to the CUC values of this study, the drip irrigation system has an excellent classification (>90%), considering the proposal of ASAE (1996) and Mantovani (2001).

When treated domestic sewage wastewater was used, Sales *et al.* (2019) reported that even after cultivation, the CUC, CUD, and CUE values of drippers were classified as good, and in most cases, excellent. Therefore, on the basis of the drip system performance coefficients, it is possible to apply wastewater, provided that it is properly treated and diluted.

The drippers presented a decreasing CVq with each 25% increase in dilution on the order of 2.36%, with the lowest CVq value found at 75% dilution, estimated at 5.24% (Figure 5A). CVq values lower than or close to 10% indicate good quality in the irrigation system emitters (CARARO, 2004). The flow coefficient of variation values found in the present study were close to those reported by Mulu and Alamirew (2012), in which the flow variation was a maximum of 9%.

Figure 5. Coefficients of variation (CVq) of the drip irrigation system as a function of dilution (A) and wastewater source (B), after 470 hours, Rio Verde, Goiás.



Source: Author (2021)

The sources influenced the CVq value (Figure 5B), with the ARP source (9.30%) showing a variation that was 1.03% greater than that of the ARS source (8.27%). The higher CVq may be related to the lower quality of the applied effluent; this greater variation in flow is mainly due to the greater propensity of the ARP source to cause emitter clogging, as the ARP source tends to provide higher emitter GEs than the ARS source does (Figure 3).

The joint analysis of uniformity coefficients is essential for evaluating the performance of any irrigation system (SANTOS *et al.*, 2013; RODRIGUES *et al.*, 2013). The evaluation of the irrigation system prevents problems such as underestimation or overestimation of the average flow value, variation (CVq) and uniformity, ensuring a deeper knowledge of the system and reducing waste and expenses (CUNHA *et al.*, 2013; CUNHA *et al.*, 2014).

6 CONCLUSIONS

Regardless of the wastewater source, higher dilutions provide higher Christiansen uniformity coefficients, distribution uniformity, and relative flow and lower coefficients of variation and degrees of clogging.

When pig farm wastewater was used, the drip irrigation system presented a higher Christiansen uniformity coefficient after 470 hours of operation.

The highest coefficient of variation and degree of clogging of the drippers are obtained when fish farming wastewater is used as a source.

The use of a drip irrigation system with diluted wastewater from pig and fish farming during 470 hours of operation does not compromise the uniformity of distribution.

7 ACKNOWLEDGMENTS

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