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Scientific Article

Effect of using saline water on dripper clogging

Efeito do uso de águas salinas no entupimento de gotejadores

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ABSTRACT - Drip irrigation and the agricultural use of brackish water mitigate water scarcity in semi-arid regions and food insecurity. The objective of this study was to evaluate the clogging behavior in three types of non-pressure-compensating emitters applying dilutions of brackish water. The study was carried out in Mossoro, RN, Brazil. On a bench, three dripping units were installed in a split-split-plot scheme, in a completely randomized design with three replicates. Plots comprised three dilutions of brackish water (BW) in supply water (SW) (D1 - 100% of SW; D2 – 50% of SW plus 50% of BW; and D3 - 100% of BW), subplots comprised three types of non-pressure-compensating drippers (NJ - NaanDanJain, SL – StreamLine and ST - Super Typhoon), and sub-subplots comprised evaluation times (0, 20, 40, 60, 80, 100, 120, 140 and 160 h). Every 80 h and 20 h of operation, the physical and chemical characteristics of the dilutions and the clogging indices (DUC) and relative flow rate reduction (RQR) were determined, respectively. The pH, EC, DUC and RQR were subjected to MANOVA and post-hoc test. The SL-D3 combination had greater clogging, reducing the DUC from 93% to 68%; the combinations least affected by clogging were SL-D1 and NJ-D2, both ending the tests with a DUC of 90%. There was a statistically significant variation in the DUC and RQR coefficients over the periods from 0 to 160 h and from 80 to 160 h, with no statistically significant variation from 0 to 80 h.

Keywords: Clogging. Uniformity of application. Dilution. Irrigation Efficiency.

RESUMO - A irrigação por gotejamento e o uso agrícola de águas salobras mitigam a escassez hídrica em regiões semiáridas e a insegurança alimentar. Objetivou-se com o presente trabalho, avaliar o comportamento do entupimento em três tipos de emissores não autocompensantes aplicando diluições de água salobra. O estudo foi realizado em Mossoró-RN, Brasil. Em bancada, foram instaladas três unidades gotejadoras em esquema de parcelas subsubdivididas, no delineamento inteiramente casualizado com três repetições. Tendo nas parcelas, as três diluições de água salobra (AS) em água de abastecimento (AB) (D1 - 100% de AB; D2 – 50% de AB mais 50% de AS; e D3 - 100% de AS); nas subparcelas três tipos de gotejadores não autocompensantes (NJ – NaanDanJain, SL – StreamLine e ST - Super Typhoon); e nas subsubparcelas os tempos de avaliação (0, 20, 40, 60, 80, 100, 120, 140 e 160 h). A cada 80 h e 20h de operação, foram determinadas as características físicas e químicas das diluições e os índices de obstrução (CUD) e redução de vazão relativa (RVR), respectivamente. O pH, CE, CUD e RVR foram submetidos à MANOVA e teste post-hoc. A combinação SL-D3 apresentou maior obstrução, reduzindo o CUD de 93% para 68%; as combinações menos afetadas pelo entupimento foram SL-D1 e NJ-D2, ambas finalizando os ensaios com CUD de 90%. Houve uma variação estatisticamente significativa dos coeficientes CUD e RVR ao longo dos tempos de 0 a 160 h e de 80 a 160 h, não existindo variação estatisticamente significativa de 0 a 80 h.

Palavras-chave: Obstrução. Uniformidade de aplicação. Diluição. Eficiência da Irrigação.

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INTRODUCTION

Water scarcity and geopolitical conflicts are factors that explain the rise in food prices and, consequently, the increase in global food insecurity (ABAY et al., 2023). It should also be noted that agriculture is the sector that consumes the most water, accounting for more than 70% of global withdrawals, which continue to increase (FAO, 2020).

For this reason, optimization of water use is a strategic goal of the Sustainable Development Goals (SDGs), established by the 2030 Agenda. The adoption of more efficient technologies, such as drip irrigation, has the potential to contribute directly to the achievement of at least six SDGs: poverty eradication (SDG 1), zero hunger and sustainable agriculture (SDG 2), health and well-being (SDG 3), clean water and sanitation (SDG 6), decent work and economic growth (SDG 8), and responsible consumption and production (SDG 12) (ABDELZAHER; AWAD, 2022).

In this context, a prominent technique is drip irrigation, which has become a water-saving technology due to its excellent application efficiency (VALE et al., 2020; XU; ZHANG, 2020), in addition to being considered a solution to the water conflict between agricultural and ecological needs in arid and semi-arid regions (HAN et al., 2023).

Drip irrigation is carried out using emitters that have a low flow rate and operate at low pressure, allowing the use of smaller motor pumps and pipes with a smaller nominal diameter (LILI et al., 2021). Among other advantages, drip irrigation also results in significant savings in electricity and reduced operating costs. In addition, the localized application of water minimizes losses due to evaporation and deep percolation. These characteristics make the method highly efficient, especially in regions with water scarcity.

In this context, the emitter is the main and most sensitive component of drip irrigation due to its narrow flow path, sized from 0.5 to 1.2 mm to meet energy dissipation requirements (YUNKAI et al., 2019). Therefore, the performance of this device directly affects the quality of water application by drip irrigation systems (FERNANDES et al., 2014; MARQUES et al., 2016; COSTA et al., 2019).

Alternating the use of fresh and brackish water in drip irrigation is an excellent strategy to overcome brackish water-induced salt stress problems (ZHANG et al., 2022). However, inadequate use of brackish water in agriculture leads to worsening of soil salinization (WANG et al., 2023). The main ions present in groundwater are the Na^+, Ca^{2+} and Mg^{2+} cations and the Cl^- and SO_4^{2-} anions (YASUOR; YERMIYAHU; BEN-GAL, 2020).

In another study with brackish water, it was found that calcium and magnesium carbonates were the main responsible for emitter clogging, and the highest values of electrical conductivity and operating time led to an increase in chemical fouling (LILI et al., 2019).

In arid and semi-arid regions, water scarcity drives the use of inferior-quality water in irrigation, including brackish water; however, dripper clogging appears as a barrier to this tool of water resources management. In this context, studying an alternative to mitigate clogging, such as dilution, and selecting emitters resistant to clogging caused by higher-salinity water can assist in the discovery of new options. The objective of this study was to evaluate the clogging behavior in three types of non-pressure-compensating emitters applying brackish water dilutions. The hypothesis is that: the dilution of brackish water mitigates clogging of emitters, enabling better hydraulic performance indices in drip irrigation.

MATERIAL AND METHODS

Experimental area description

The present study was conducted in the dry season from October 10 to 29, 2022, with an average air temperature of 29.30±0.56 ºC, in the experimental area of water reuse located next to the Laboratory of Rural Constructions and Environment (LCRA) of the Federal Rural University of the Semi-Arid Region (UFERSA) in Mossoró, RN, Brazil (5º12’13.33”S and 37º19’26.78” W).

Types and quality of water used in experimental tests

In the experiment, two types of water were used: 1) Water from the public supply network with lower salinity; and 2) Brackish water with higher salinity. The supply water came from the public network managed by the Water and Sewage Company of Rio Grande do Norte (CAERN), where there is a mixture of water from deep wells in the municipality of Mossoró, RN, with surface water from the Engenheiro Armando Ribeiro Gonçalves Dam in the municipality of Açu, RN; this water receives treatment that includes chlorination, which helps to mitigate the biological risk of clogging in the drippers. Brackish water came from an artesian well located in the Aquaculture Sector of UFERSA in Mossoró, RN, where no treatment is carried out.

In the experimental tests, three types of water were used: 1) D1 (control) - 100% supply water (SW), which receives treatment from CAERN in the dry period of 2022, with the free residual chlorine in the water (0.5 and 2.0 mg L^{-1}) helping to mitigate the biological risk of clogging; 2) D2 – 50% SW with 50% brackish water (BW) from the artesian well of UFERSA in Mossoró, RN, with salinity between 500 and 30000 mg L^{-1}, in which free residual chlorine is reduced (0.25 and 1.0 mg L^{-1}), but also mitigates clogging of biological origin; and 3) D3 – 100% BW with salinity between 500 and 30000 mg L^{-1} and without dilution in SW, and chlorination representing a possible condition of irrigation in the semi-arid region of Rio Grande do Sul.

Samples were collected at the operating times of 0, 80 and 160 h and the following attributes were analyzed: pH, EC, K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, CO_3^{2-}, HCO_3^-, TSS, TDS, Hardness and SAR (Table 1). Collection of samples and analyses were carried out following the recommendations of EMBRAPA (PARRON; MUNIZ; PEREIRA, 2011). The analyses were carried out at the Soil, Water and Plant Analysis Laboratory (LASAP/UFERSA) and at the Multiuser Laboratory of Soil, Water and Plant Analysis of the Semi-arid Region (LASAPSA/UFERSA).

Table 1. Physicochemical characteristics of dilutions of brackish water (BW) in supply water (SW) used in the drip units.

Time X dilution	pH	EC	K^+	Na^+	Ca^{2+}	Mg^{2+}	Cl^-	CO_3^{2-}	HCO_3^-	TSS	TDS	Hard	SAR
		dSm^{-1}	-------------------			$mmol_cL^{-1}$			--------------------	---------	mg L^{-1}	---------	$(mmol_cL^{-1})^{0.5}$
0hD1	8.40	0.60	0.30	5.80	0.90	0.50	2.40	0.60	3.90	0	85	70	6.90
0hD2	8.30	3.50	0.60	19.90	12.80	12.80	26.00	0.60	4.70	4	456	1280	5.60
0hD3	8.10	5.50	0.80	29.00	19.30	20.60	37.60	0.60	5.60	28	837	1995	6.50
80hD1	9.10	0.50	0.30	4.30	0.60	1.00	3.40	0.40	2.30	0	96	80	4.80
80hD2	8.80	3.40	0.90	22.90	13.60	18.80	36.00	0.60	2.80	4	1121	1620	5.70
80hD3	8.90	5.00	1.20	35.30	21.10	28.60	56.00	1.00	3.20	28	1747	2485	7.10
160hD1	8.10	0.60	0.60	5.50	0.60	0.60	2.70	0.50	3.10	2	108	57	7.30
160hD2	8.00	4.30	4.30	19.90	15.40	16.80	27.20	0.40	3.60	26	1199	1610	5.00
160hD3	7.90	5.20	5.20	32.40	33.00	27.30	57.00	0.80	4.20	50	4475	3015	5.90

Note: EC – Electrical conductivity; TSS – Total suspended solids; TDS – Total dissolved solids; Hard – Hardness; SAR – Sodium adsorption ratio; D1 - 100% SW plus 0% BW; D2 – 50% SW plus 50% BW; and D3 – 0% SW plus 100% BW.

Experimental design and assembly of experimental benches

The experiment was set up in a completely randomized design in a split-split-plot scheme with three replicates. Plots comprised three dilutions of brackish water (BW) without treatment in supply water (SW) with treatment given by CAERN (D1 - 100% SW; D2 – 50% SW plus 50% BW; and D3 - 100% BW), subplots comprised three types of non-pressure-compensating drippers (NJ – NaanDanJain of 1.7 L h^{-1}, SL – StreamLine of 1.6 L h^{-1} and ST – Super Typhoon of 1.6 L h^{-1} in Table 1), and sub-subplots comprised evaluation times (0, 20, 40, 60, 80, 100, 120, 140 and 160 h).

The experimental tests were conducted using three benches with dimensions of 1 m wide by 8 m long, totaling a surface area of 8.0 m^2 (VALE et al., 2020). Each bench consisted of a plastic reservoir with a capacity of 0.31 m^3, a ball valve with a diameter of 32 mm, a motor pump with a power of 0.5 cv, a disc filter with a filtration degree of 130 µm, two water sample collection points, two analog glycerin-filled pressure gauges for readings from 0 to 400 kPa, one main line with a diameter of 32 mm and 10 m in length, a submain line with a diameter of 50 mm and 1 m in length, and nine lateral lines with a diameter of 16 mm and 8 m in length, with three lateral lines of each of the non-pressure-compensating emitters, with a spacing of 0.10 cm between them (Figure 1 and Table 2).

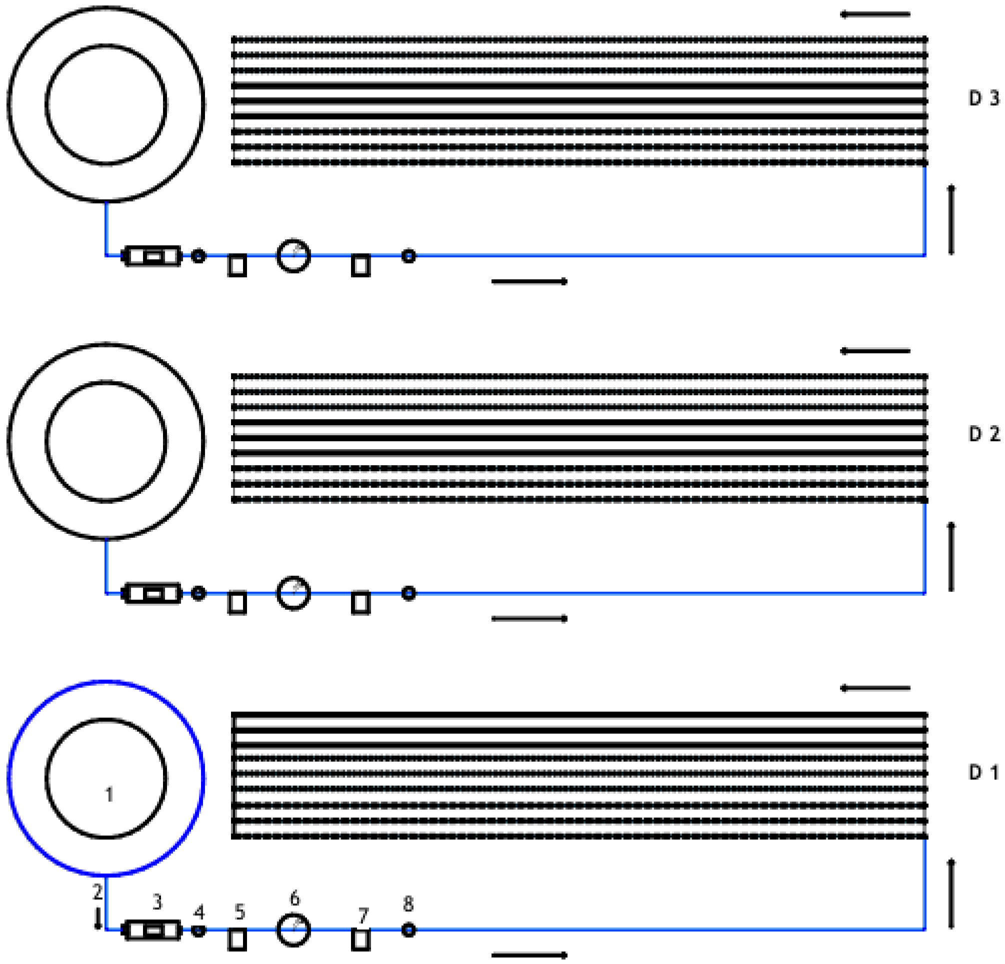
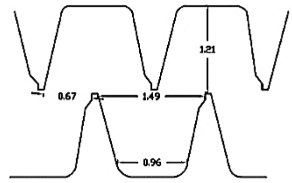
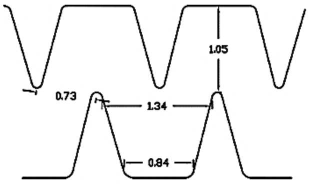
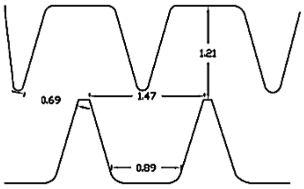


Figure 1. Schematic diagram of the three experimental benches highlighting: (1) 0.31 m^3 plastic reservoir, (2) 32 mm diameter ball valve, (3) 0.5 cv motor pump, (4) and (8) Glycerin-filled pressure gauges (0 to 400 kPa), (6) 130 µm disc filter, (5) and (7) Points for water sample collection, irrigation lines with non-pressure-compensating emitters. Treatments: D1 - 100% SW; D2 – 50% SW plus 50% BW; and D3 - 100% BW.

Table 2 shows the hydraulic characteristics, dimensions and images of the non-pressure-compensating emitters and their respective labyrinths used in the experimental tests with dilutions of BW in SW. It can be observed that the ST and NJ emitters have a larger dimension in the orthogonal direction to the flow path (1.21 mm) compared to the SL emitter (1.05 mm); similarly, the ST and NJ drippers had greater separation, in the lower wall of the labyrinth, 0.89 and 0.96 mm, respectively, while the SL emitter had a dimension of 0.84 mm.

Table 2. Characteristics and images of the emitters used in the experimental tests.

Emitters	Nominal flow rate [1] (L h^{-1})	K[1] (dimensionless)	x[1] (dimensionless)	Spacing between emitters [1] (m)
NJ	1.70	0.56	0.46	0.20
SL	1.60	0.57	0.45	0.30
ST	1.60	0.53	0.48	0.30

Emitters	Labyrinth dimensions [2] mm	Emitter images [3]
NJ		
SL		
ST		

Note: K – Emitter discharge coefficient; x – Emitter flow rate exponent [1] Information obtained from the catalogs of the manufacturers Netafim and NaanDanJain. [2] Vector-based measurements obtained by scanning electron microscopy at the Center for Research in Plant Sciences of the Semi-Arid Region (CPVSA) of UFERSA using an Olympus DP72 camera coupled to an Olympus BX51 optical microscope. [3] Images extracted from the catalogs of the manufacturers Netafim and NaanDanJain.

Evaluation of emitter performance

On the lateral lines of the drip units that applied dilutions of BW in SW, 16 emitters were marked and their flow rate was measured every 20 h during 160 h of operation of the experimental benches, which corresponds to the irrigation carried out in one melon cultivation cycle in the semi-arid region of Rio Grande do Norte, at a working pressure of 80 kPa, widely used in the region, with nine moments of flow rate evaluation for each type of dripper.

Flow rate was obtained as the ratio between the volume of water applied by the emitter, in L, and the test time of 0.05 h.

The criteria used to evaluate emitter clogging were the distribution uniformity coefficient (DUC) and the relative flow rate reduction (RQR), both in percentage, and represented by Equations 1 and 2, respectively.

$$\mathrm{DUC} = 100.\frac{q_{1/4}}{q} \qquad (1)$$

$$\mathrm{RQR} = 100.\left(\frac{q_i - q_c}{q_i}\right) \qquad (2)$$

Where:
DUC – Distribution uniformity coefficient, in %;
$q_{1/4}$ - Average value of the 25% lowest flow rates of the emitters, in L h^{-1};
$\bar{q}$ - Average flow rate of the emitters, in L h^{-1};
RQR - Relative flow rate reduction, in %;
q_i - Initial flow rate, in L h^{-1}; and
q_c - Current flow rate, in L h^{-1}.

Regarding DUC, Merrian and Keller (1978) proposed the following classification: DUC < 70% is poor; 70 ≤ DUC < 80 is fair; 80 ≤ DUC < 90 is good, and finally, DUC ≥ 90% is excellent. RQR values greater than 0 indicate a reduction in the flow rate of the emitters, while RQR values lower than 0 express an increase in the flow rate (MESQUITA et al., 2016).

Statistical analysis

The following variables were used in the statistical analyses: times, emitters, dilutions, flow rate (Q) of the drippers, distribution uniformity coefficient (DUC), relative flow rate reduction (RQR), pH and electrical conductivity (EC) of the waters. The statistical analyses comprised: obtaining of Pearson's correlation matrix (where r values of -1 and +1 represent the greatest correlation, and those close to zero are related to the absence of correlation, with the classification proposed by Schober, Boer and Schwarte (2018) being used in the interpretation of r values: Insignificant for $0.00 \leq r < 0.10$; Weak correlation for $0.10 \leq r \leq 0.39$; Moderate correlation for $0.40 \leq r \leq 0.69$; 4) Strong correlation for $0.70 \leq r \leq 0.89$; and Very strong correlation for $0.90 \leq r \leq 1.00$); multivariate analysis of variance (MANOVA); and the post-hoc tests (Wilks' lambda, Pillai-Bartlett, Lawley–Hotelling and Roy's Largest Root) using statistical analyses of the Python 3.12 programming language through the NumPy, Pandas, Seaborn and Matplotlib packages. Graphs of the hydraulic performance indices RQR and DUC were created with the statistical packages of Python 3.12; the Seaborn package was used to obtain the graphs, while the Matplotlib package allowed fitting the curves in the graphs.

RESULTS AND DISCUSSION

Physicochemical quality of brackish water dilutions in supply water used in drip units

The quality of the types of water used to supply the experimental benches shows temporal variations in their physicochemical characteristics (Table 1). These variations in water quality can be attributed to four factors: 1) Oscillation in the quality of SW, as it alternates mixtures of water from deep wells in the municipality of Mossoró, RN, with surface water from the Engenheiro Armando Ribeiro Gonçalves Dam in the municipality of Açu, RN; 2) Recirculation and replacement of water in the benches, where evaporation, O_2 incorporation and CO_2 escape contribute to increasing the values of some attributes, and the replacement of water reduced the values of other attributes; 3) Carrying out the experiment in the dry season, which led to an increase in the concentration of ions, especially in groundwater; and 4) Incorporation of particles and ions carried by the wind to the surfaces of the benches.

The pH values of the dilutions, over time, ranged from 7.90 to 9.10 (Table 1). Thus, according to Bucks, Nakayama and Gilbert (1979), the three dilutions represent a severe risk (pH > 7.50) of dripper clogging, due to the formation of calcium carbonate precipitates (LILI et al., 2019). A different result was reported by Oliveira et al. (2014), as the supply water had a risk of dripper clogging classified as low. Particularly, SW has a high pH of 8.40, with a severe risk of clogging, already at the initial time (0h), probably because the experiment was conducted in the dry season, when the concentration of ions in groundwater increases due to greater anthropogenic demand and absence of recharge by rainfall. Next, SW at 80 h showed an increase in pH to 9.1, probably due to CO_2 escape and concentration of ions through evaporation, both in the recirculation process. And finally, in SW at 160 h the pH value decreases to 8.10 possibly due to the process of replacing SW with a lower pH value. In the study conducted by Vale et al. (2020) using SW on the same experimental benches, a high pH of 8.70±0.27 was detected in the dry period from August 26 to October 5, 2018, corroborating the results of the present study. According to Morais et al. (2020), the formation of calcium carbonate precipitate is intensified as water temperature increases and at pH values higher than 8.0.

In relation to EC, there was an oscillation of 0.5 to 5.5 dS m^{-1} (Table 1) in the dilutions, with the lowest values occurring in dilution D1 (0.50 to 0.60 dS m^{-1}), higher than the EC value of the supply water studied by Oliveira et al. (2014). Therefore, according to the criterion of Capra and Scicolone (1998), the risk of dripper clogging increased with the increase in salinity, being low for EC < 1.0 dS m^{-1}, moderate for 1 dS m^{-1} ≤ EC ≤ 4.5 dS m^{-1} and severe for EC > 4.5 dS m^{-1}. The EC increased with the increase of brackish water in the supply water. The D1 proportion remained around 0.50–0.60 dS m^{-1}, while D2 and D3 reached 4.3–5.2 dS m^{-1} at 160 h. This rise in salinity increases the risk of precipitation of salts, especially carbonates and sulfates, which can clog the labyrinths of the drippers. Gradual accumulation of these precipitates may explain the reduction in DUC and the increase in RQR observed in the tests (Figure 2).

K^+ concentrations ranged from 0.30 to 5.20 mmol$_c$ L^{-1} (Table 1) in the three dilutions over time. Guan et al. (2018) found that potassium sulfate concentrations > 10 g L^{-1} intensified dripper clogging, due to the increase in EC and the formation of precipitates.

Ca^{2+} and Mg^{2+} concentrations ranged from 0.60 to 33.00 mmol$_c$ L^{-1} and from 0.50 to 28.60 mmol$_c$ L^{-1} in the three dilutions over time (Table 1), respectively. According to Capra and Scicolone (1998), for the Ca^{2+} attribute the risk of dripper clogging was low (Ca^{2+} < 12.50 mmol$_c$ L^{-1}) in dilution D1, while in dilutions D2 and D3 the risk of clogging was moderate (12.50 mmol$_c$ L^{-1} ≤ Ca^{2+} ≤ 22.50 mmol$_c$ L^{-1}), except in D3 at 160 h, which had a severe risk of clogging (Ca^{2+} > 22.50 mmol$_c$ L^{-1}). In relation to Mg^{2+}, the risk of clogging was low in dilution D1 (Mg^{2+} < 2.00 mmol$_c$ L^{-1}) and severe in dilutions D2 and D3 (Mg^{2+} > 7.30 mmol$_c$ L^{-1}) according to the criteria of Capra and Scicolone (1998). In this context, Lili et al. (2016) point out that the main process that led to the chemical clogging of drippers applying saline water is the formation of $CaCO_3$, which occurred because the electrolytic hydroxyl ions increased with the increase in pH, promoting the chemical reaction and leading to an increase in the formation of $CaCO_3$.

In the three dilutions, the concentrations of carbonate (CO_3^{2-}) and bicarbonates (HCO_3^-) were 0.40 to 1.00 mmol$_c$ L^{-1} and 2.30 to 5.60 mmol$_c$ L^{-1} (Table 1), respectively. Regarding CO_3^{2-}, the values are within the range of 0 to 1 mmol$_c$ L^{-1} proposed by Ayers and Westcot (1999) considered normal for irrigation water; however, high temperatures and high pH values can lead to the formation of carbonate precipitates. The authors also stated that HCO_3^- concentrations higher than 5.0 mmol$_c$ L^{-1} caused severe clogging, especially when the pH value of the irrigation water was high.

Ca^{2+} and Mg^{2+} concentrations were much higher in the D2 and D3 proportions and increased over time, as well as carbonates and bicarbonates. In the D3 proportion at 160 h, the concentrations of Ca^{2+} (33.0 mmol$_c$ L^{-1}) and Mg^{2+} (27.3 mmol$_c$ L^{-1}) and alkalinity (HCO_3^- of 4.2 mmol$_c$ L^{-1}) possibly provided favorable conditions for the precipitation of carbonates ($CaCO_3$, $MgCO_3$), which are deposits that adhere to the internal surfaces of the drippers. This explains the decrease in DUC and the increase in RQR, which occurred progressively from 80 h onwards (Figure 2).

Regarding the attributes TSS and TDS, their values ranged from 0 to 50 mg L^{-1} and from 85.00 to 4475 mg L^{-1} (Table 1), respectively. According to the classification of Bucks, Nakayama and Gilbert (1979), the risks of clogging associated with the TSS attribute were low (TSS < 50 mg L^{-1}), except in D3 at 160 h, which had a moderate risk of clogging (50 mg L^{-1} ≤ TSS ≤ 100 mg L^{-1}). TSS and TSS increase dramatically with the higher proportion of brackish water. In the D3 proportion, TDS increased from 837 mg L^{-1} (0 h) to 4475 mg L^{-1} (160 h), and TSS increased from 28 to 50 mg L^{-1}. This reflects the increased load of solids entering the drippers, increasing the likelihood of physical clogging by sediment, especially in the narrower sections of the labyrinths. However, TDS showed a different behavior, with the risk of clogging considered low (TDS < 500 mg L^{-1}) in dilution D1, low and moderate (500 mg L^{-1} ≤ TDS ≤ 2000 mg L^{-1}) in dilution D2, and moderate and severe (TDS > 2000 mg L^{-1}) in dilution D3, according to the classification of Bucks, Nakayama and Gilbert (1979).

Hardness levels ranged from 57 to 3015 mg L^{-1} (Table 1) in the three dilutions throughout the experimental period. According to Mirzaee, Zakerinia and Farasati (2021), water with hardness values higher than 300 mg L^{-1} is classified as very hard water and increases the risk of particle sedimentation inside the drippers, especially with the increase in temperature and alkalinity, which makes the environment conducive to dripper clogging.

SAR ranged from 4.8 to 7.3 (mmol$_c$ L^{-1})$^{0.5}$ (Table 1) in the proportions and at the operating times of 0, 80 and 160 h. Regarding the assessment of the risks of dripper clogging based on water quality attributes, SAR is an essential indicator due to the effects of carbonate sediments under alkaline conditions (MIRZAEE; ZAKERINIA; FARASATI, 2021).

Occurrence of chemical clogging in drippers applying dilutions of brackish water

Figure 2 shows the behavior of the clogging detection coefficients RQR and DUC for the ST, SL and NJ emitters applying dilutions of brackish water and supply water for 160 h.

Figure 2A shows that DUC values for the ST emitter are classified as excellent from 0 h to 100 h in the three dilutions studied. At 120 h, the DUC of dilutions D1 and D2 remained excellent, while for D3 the DUC decreased considerably and was classified as good. At 140 h, DUC again was excellent for the three dilutions, and good in the three dilutions at 160 h. In turn, the RQR values were within the range of 0 to 40% throughout the experimental period.

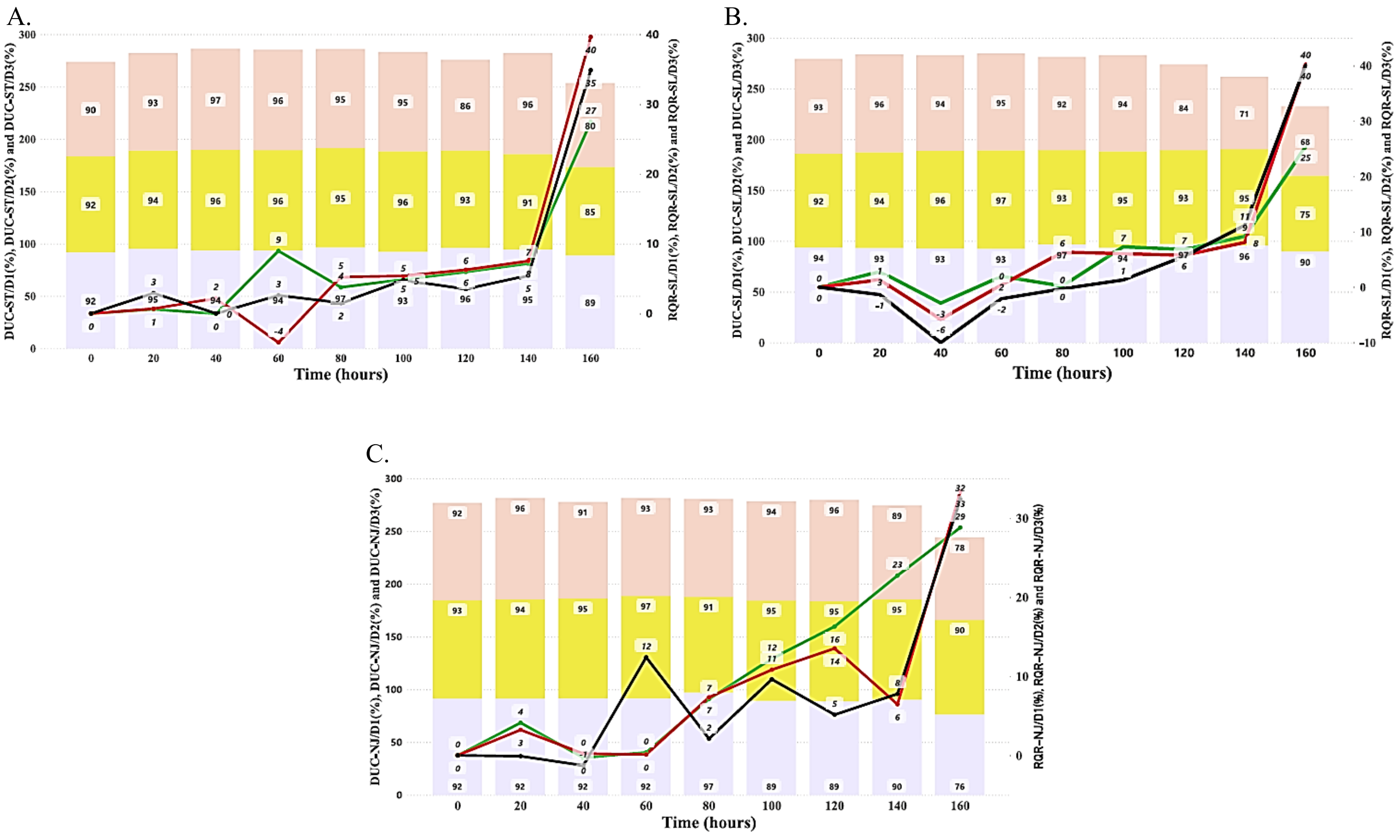


Figure 2. Behavior of the clogging detection coefficients RQR and DUC for ST (A), SL (B) and NJ (C) emitters operating with brackish water and supply water dilutions for 160 h.

As for the SL emitter (Figure 2B), from 0 h to 100 h the DUC values were excellent in the three dilutions. At 120 and 140 h, the DUC values were excellent in dilutions D1 and D2, and for D3 the DUC values were classified as good and fair, respectively.

Finally, at 160 h, the DUC value was excellent in D1, fair in D2 and poor in D3. Regarding the RQR, the process of flow rate reduction predominated throughout the experimental period; both dilution D2 and dilution D3 had the highest values of RQR (40%), while dilution D1 had the lowest RQR (25%).

Negative RQR values were observed at 40 h, indicating processes of increased flow rate. The variation in flow rate over time highlights the clogging and unclogging processes that occur in drip irrigation systems, which are caused by different reasons, such as changes in working pressure (MESQUITA et al., 2016), changes in water quality (SHI et al., 2022), increase in temperature (MORAIS et al., 2020), movement of lateral lines at the time of evaluation (YUNKAI et al., 2015), among other causes.

Figure 2C shows that the NJ emitter maintained the DUC values classified as excellent up to 80 h in the three dilutions. From 100 to 120 h, this emitter showed excellent DUC values in dilutions D2 and D3 and DUC values classified as good in dilution D1.

At 140 h, dilutions D1 and D2 showed excellent DUC values, but in dilution D3 the value was classified as good. Finally, at 160 h, D2 obtained an excellent DUC value, while in D1 and D3 the DUC value was fair. Regarding the RQR coefficient, the values ranged from 0% to 33%, in the interval between 0 h and 40 h, in which the behavior of the results was quite similar. The greatest variations were observed in dilutions D2 and D3, while D1 showed the most stable behavior over time.

The DUC and RQR values obtained by Lili et al. (2021) showed a slow and sharp downward trend under saline water conditions; DUC values were within the range of 85 to 90% over 168 h of system operation and with an EC of 6.0 dS m^{-1} and an RQR of 30 to 50% for the same conditions.

In another study, drip irrigation systems that operated for 700 h with wastewater had DUC values of 70% and 10% at 400 h and 700 h, respectively, i.e., showing a trend of reduction in DUC over time, while the RQR results tended to increase for all types of emitters tested (YUNKAI et al., 2015).

The SL-D3 combination resulted in greater susceptibility to clogging, going from an initial DUC of 93% to 68%, and this is the type of dripper among those tested in the present study that had the smallest internal dimensions of its labyrinth. On the other hand, the combinations least susceptible to clogging, having higher DUC values at the end of the experiment, were NJ-D2 (90%), SL-D1 (90%) and ST-D1 (89%).

Regarding RQR, the greatest susceptibilities to clogging occurred in the combinations ST-D2, SL-D2 and SL-D3, with a value of 40% at the end of the tests. Conversely, the SL-D1 combination was the least susceptible to clogging and had an RQR of 25%.

These variations in both DUC and RQR result from clogging processes, due to the application of water with lower quality by the drippers, with pH > 8.0 and HCO_3^- levels greater than 5 $mmol_c\ L^{-1}$ being water quality attributes that increase the probability of chemical clogging (SHI et al., 2022).

EC values in dilution D3 greater than 4.5 dS m^{-1} may have influenced the formation of fouling within the labyrinths, consequently altering the values of DUC and RQR. Other quality attributes that influenced the clogging of emitters were Ca^{2+}, Mg^{2+} and TDS.

Multivariate analysis of variance (MANOVA) and the post -hoc test

Table 3 presents the input values to generate the MANOVA results, with the independent variables being times, emitters and dilutions. The dependent variables were: mean flow rate (Q) of the drippers, DUC and RQR. At 0 h, the ST-D2 emitter started with the highest average flow rate, while SL-D3 had the lowest flow rate; the ST emitter has the largest internal dimensions of the labyrinth and SL has the smallest dimensions.

Table 3. Input data for MANOVA.

Time	Emitter	Dilution	Q	DUC	RQR	pH	EC
0	SL	D 1	1.19	93.92	0.00	8.44	0.59
0	NJ	D 1	1.3	91.58	0.00	8.44	0.59
0	ST	D 1	1.42	92.03	0.00	8.44	0.59
0	SL	D 2	1.17	92.2	0.00	8.26	3.53
0	NJ	D 2	1.29	93.12	0.00	8.26	3.53
0	ST	D 2	1.43	91.54	0.00	8.26	3.53
0	SL	D 3	1.13	93.08	0.00	8.1	5.49
0	NJ	D 3	1.28	92.09	0.00	8.1	5.49
0	ST	D 3	1.4	90.11	0.00	8.1	5.49
80	SL	D 1	1.18	96.79	0.21	9.1	0.48
80	NJ	D 1	1.21	97.24	7.14	9.1	0.48
80	ST	D 1	1.37	96.71	3.75	9.1	0.48
80	SL	D 2	1.09	92.87	6.34	8.8	3.38
80	NJ	D 2	1.2	90.76	7.35	8.8	3.38
80	ST	D 2	1.35	94.74	5.25	8.8	3.38
80	SL	D 3	1.13	91.68	-0.29	8.9	4.95
80	NJ	D 3	1.25	92.58	2.12	8.9	4.95
80	ST	D 3	1.38	94.51	1.52	8.9	4.95
160	SL	D 1	0.89	89.83	25.34	8.1	0.63
160	NJ	D 1	0.93	76.29	28.82	8.1	0.63
160	ST	D 1	1.03	88.89	27.46	8.1	0.63
160	SL	D 2	0.7	74.69	40.33	7.99	4.31
160	NJ	D 2	0.86	89.79	33.46	7.99	4.31
160	ST	D 2	0.86	84.6	39.64	7.99	4.31
160	SL	D 3	0.68	68.15	40.07	7.88	5.20
160	NJ	D 3	0.87	78.23	32.42	7.88	5.20
160	ST	D 3	0.91	79.85	34.88	7.88	5.20

At the end of the experiment (160 h), ST-D1 ended with the highest flow rate and SL-D3 with the lowest. Regarding DUC, at the beginning of the experiment SL-D1 obtained the highest value and ST-D3, the lowest. At the end of the experiment, SL-D3 had the lowest value, while the highest value was observed in NJ-D2.

RQR was 0 for all drippers at the beginning of the experiment, while the highest value at the end of the study was observed in SL-D2. Regarding pH, there was a tendency to decrease over time, while salinity varied as a function of dilution.

Table 4 shows the Pearson's correlation matrix of the variables time, emitters, dilutions, flow rate, DUC, RQR, pH and EC. In this table, there are six correlations equal to or greater than 0.70 (VICINI et al., 2018), classified as strong to very strong by the criterion of Schober, Boer and Schwarte (2018).

Table 4. Pearson's correlation matrix of the variables time, emitters, dilutions, flow rate, DUC, RQR, pH and EC.

Variables	Times	Emitters	Dilutions	Q	DUC	RQR	pH	EC
Times	1							
Emitters	0	1						
Dilutions	0.00	0.00	1					
Q	-0.81	0.41	-0.10	1				
DUC	-0.62	0.12	-0.27	0.79	1			
RQR	0.89	0.00	0.05	-0.90	-0.82	1		
pH	-0.27	0.00	-0.25	0.58	0.69	-0.63	1	
EC	0.05	0.01	0.97	-0.18	-0.31	0.15	-0.34	1

Note: Q – Flow rate of the drippers; DUC – Distribution Uniformity Coefficient; RQR – Relative flow rate reduction; and EC – Electrical conductivity.

The correlation between the variables time and Q was strong and negative (-0.81), that is, when time increases, the Q values decrease due to clogging of the drippers. In relation to the variables time and RQR, the correlation was strong and positive (0.89), indicating that the RQR values increase over time, also caused by clogging of the drippers, which reduces the flow rate.

The correlation was very strong and positive (0.97) between the variables dilutions and EC, as the increase in the proportion of brackish water in the dilutions in supply water increases salinity. According to Lili et al. (2021), this is a water quality attribute that causes dripper clogging.

It was also observed that the correlation between the variables Q and DUC was strong and positive (0.79), so high DUC values occur without a reduction in Q values due to dripper clogging. However, the correlation between the variables Q and RQR was very strong and positive (0.90), because the increase in RQR due to dripper clogging leads to a reduction in Q

Finally, there was a strong and negative correlation (-0.82) between DUC and RQR, indicating that the reduction in DUC values leads to an increase in RQR due to clogging of the emitters.

Table 5 presents the results of the multivariate analysis of variance (MANOVA) using the Wilks' lambda, Pillai-Bartlett, Lawley–Hotelling, and Roy's Largest Root tests.

Table 5. Multivariate analysis of variance (MANOVA) highlighting the results of Wilks' lambda, Pillai-Bartlett, Lawley–Hotelling, and Roy's Largest Root tests.

Dependent variable	Independent variable	Tests	Value	NumDF	DenDF	F Value	Pr > F
pH + EC + DUC + RQR	Time	Wilks' lambda	0.00	8.00	42.00	138.34	0.0000**
		Pillai-Bartlett	1.90	8.00	44.00	103.61	0.0000**
		Lawley–Hotelling	73.41	8.00	27.78	187.87	0.0000**
		Roy's Largest Root	62.66	4.00	22.00	344.61	0.0000**
	Dilution	Wilks' lambda	0.01	8.00	42.00	46.36	0.0000**
		Pillai-Bartlett	1.07	8.00	44.00	6.35	0.0000**
		Lawley–Hotelling	87.68	8.00	27.78	224.41	0.0000**
		Roy's Largest Root	87.59	4.00	22.00	481.76	0.0000**
	Emitter	Wilks' lambda	0.94	8.00	42.00	0.17	0.9939^{na}
		Pillai-Bartlett	0.06	8.00	44.00	0.17	0.9933^{na}
		Lawley–Hotelling	0.07	8.00	27.78	0.17	0.9936^{na}
		Roy's Largest Root	0.07	4.00	22.00	0.36	0.8346^{ns}

Note: DF – Degree of freedom; ** Significant at 0.1% probability level. ^{ns} Not significant at 0.1% probability level.

The Pillai-Bartlett test was significant (Pillai-Bartlett = 1.90; F(8, 00; 44.00) = 103.61; $p < 0.001$), indicating that there were statistical differences in the variations in the levels reached for the dependent variables pH, EC, DUC and RQR as a function of the independent variable time.

Similarly, when the same dependent variables were contrasted with the dependent variable dilution, the aforementioned test was also significant (Pillai-Bartlett = 1.07; F (8.00; 44.00) = 6.35; $p < 0.001$), thus representing a statistically significant association of dilution, which represents salinity levels, with the variables DUC, RQR, EC and pH.

Finally, when the dependent variables were explored with the independent variable emitter, the test was not significant (Pillai-Bartlett = 0.06; F (8.00; 44.00) = 0.17; $p > 0.001$) i.e., there is no statistical difference between the types of emitters and the dependent variables analyzed.

Table 6 explains whether there was a statistically significant variation in the dependent variables (RQR, DUC, pH, and EC) as a function of the independent variables (time and dilution). For this purpose, the test creates two groups (group 1 and group 2) and calculates the p-value for each combination of dependent and independent variables used in the experiment.

Table 6. Post hoc test.

Dependent variable	Group1	Group2	Avg. Diff.	P-value	Reject
RQR	0 h	160 h	33.60	0.00	True
	0 h	80 h	3.71	0.10	False
	160 h	80 h	-29.89	0.00	True
DUC	0 h	160 h	-11.04	0.00	True
	0 h	80 h	2.02	0.63	False
	160 h	80 h	13.06	0.00	True
pH	0 h	160 h	-0.28	0.00	True
	0 h	80 h	0.67	0.00	True
	160 h	80 h	0.94	0.00	True
	D 1	D 2	-0.20	0.59	False
	D 1	D 3	-0.25	0.43	False
	D 2	D 3	-0.06	0.90	False
EC	0 h	160 h	0.24	0.90	False
	0 h	80 h	-0.20	0.90	False
	160 h	80 h	-0.44	0.90	False
	D 1	D 2	3.24	0.00	True
	D 1	D 3	4.71	0.00	True
	D 2	D 3	1.47	0.00	True

Note: $p \leq 0.05$.

It can be inferred that, in order to obtain acceptable values of both RQR and DUC, preventive measures should be taken, such as injecting chemicals to unclog the emitters in the irrigation system from 100 h, because from 0 h to 160 h, the values of RQR and DUC showed statistically significant variation, while from 0 am to 80 pm, there was no variation; however, from 80 am to 160 h, there are variations in the hydraulic performance indices.

As a result of the post hoc test, it was found that the DUC and RQR coefficients have a statistically significant variation with the evaluation times in the intervals of 0 h to 160 h and 80 to 160 h, not occurring in the time interval of 0 h to 80 h, for which the result was not significant.

Regarding the pH variable, there was a statistically significant variation throughout the experimental period, but dilutions had no influence on this variability. EC was not influenced by evaluation times, although there is a statistically significant relationship with dilutions.

CONCLUSIONS

The emitters used worked similarly with the three dilutions used, according to the clogging indices DUC and RQR.

Evaluation time and the dilutions used had significant effects on the variables pH, EC, DUC and RQR.

There were changes in RQR and DUC in the time interval from 0 h to 160 h and from 80 h to 160 h, while DUC and RQR did not vary significantly from 0 h to 80 h.

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