Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga
ISSN 1983-2125 (online)

http://dx.doi.org/10.1590/1983-21252023v3712327rc

Scientific Article

Performance of drip tapes applying reverse osmosis reject from the carnaúba wax industry

Desempenho de fitas gotejadoras aplicando rejeito da osmose reversa da indústria de cera de carnaúba

Antonio D. da S. Teixeira[1]*, Rafael O. Batista[2], Laio A. L. de Paiva[1], Ricardo A. Rodrigues Filho[1], Silvanete S. da Silva[3], Layla B. L. Reges[1], Poliana M. da C. Bandeira[4], Wellyda K. B. de Lavôr[1]

[1]Department of Agricultural and Forestry Sciences, Universidade Federal Rural do Semi-Árido, Mossoró, RN, Brazil. [2]Department of Engineering and Environmental Sciences, Universidade Federal Rural do Semi-Árido, Mossoró, RN, Brazil. [3]Universidade Federal Rural de Pernambuco, Belo Jardim, PE, Brazil. [4]Department of Agricultural Engineering, Universidade Federal de Viçosa, Viçosa, MG, Brazil.

ABSTRACT - Water scarcity and the search for alternative water reuse are challenges faced in the Brazilian semi-arid region. The objective of this study was to predict the risk of clogging of drippers based on water quality attributes and to analyze the effects of industrial residual water and supply water on their hydraulic performance. Two experimental benches were set up in a completely randomized design, in split-split plots, with three replicates. Plots contained the types of water (supply water and reverse osmosis reject), subplots contained the types of non-pressure-compensating drippers (NST - 1.6 L h^{-1}, NSL - 1.6 L h^{-1} and NDT - 1.7 L h^{-1}) and sub-subplots contained the evaluation times of the distribution uniformity coefficient and relative flow rate (0, 20, 40, 60, 80, 100, 120, 140 and 160 hours). At times 0, 80 and 160 hours, the attributes pH, electrical conductivity, total suspended solids, total dissolved solids, calcium, magnesium, iron and manganese were characterized in both types of water. The data were subjected to descriptive analysis, ANOVA and Tukey test at 5% probability level. In residual water, the attributes that represented a risk of clogging for drippers were pH, electrical conductivity, magnesium and total dissolved solids, while in supply water only pH represented risk. The interaction between types of water and operating time significantly affected both hydraulic performance indicators, but there was no significant effect of the dripper type factor.

Keywords: *Copernicia prunifera*. Emitters. Reuse. Distribution uniformity. Clogging.

RESUMO - A escassez hídrica e a busca por alternativas de reúso da água são desafios enfrentados no semiárido brasileiro. Objetivou-se, com este trabalho, predizer o risco de obstrução de gotejadores por atributos de qualidade da água e analisar os efeitos das águas residual de indústria e de abastecimento no desempenho hidráulico de gotejadores. Para isso, foram montadas duas bancadas experimentais, onde o delineamento utilizado foi o inteiramente casualizado em parcelas subsubdivididas com três repetições. Tendo nas parcelas os tipos de água (água de abastecimento e rejeito da osmose reversa), nas subparcelas os tipos de gotejadores não autocompensantes (NST - 1,6 L h^{-1}, NSL - 1,6 L h^{-1} e NDT - 1,7 L h^{-1}) e nas subsubparcelas os tempos de avaliação do coeficiente de uniformidade de distribuição e da vazão relativa (0, 20, 40, 60, 80, 100, 120, 140 e 160 horas). Nos tempos 0, 80 e 160 horas efetuou-se a caracterização dos atributos pH, condutividade elétrica, sólidos suspensos totais, sólidos dissolvidos totais, cálcio, magnésio, ferro e manganês nos dois tipos de água. Os dados foram submetidos à análise descritiva, ANOVA e teste de Tukey à 5% de probabilidade. Na água residual os atributos que representaram risco de obstrução para gotejadores foram o pH, condutividade elétrica, magnésio e sólidos dissolvidos totais, enquanto na água de abastecimento somente o pH. A interação tipos de águas e tempo de operação afetou significativamente os dois indicadores de desempenho hidráulico, entretanto não houve efeito significativo do fator tipos de gotejadores.

Palavras-chave: *Copernicia prunifera*. Emissores. Reúso. Uniformidade de distribuição. Obstrução.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

Received for publication in: October 25, 2023.
Accepted in: March 7, 2024.

***Corresponding author:**
<diego.lopx@gmail.com>

INTRODUCTION

Carnauba (*Copernicia prunifera* (Miller) H. E. Moore) is a xerophytic palm tree of the Arecacea family native to the northeastern region of Brazil, whose leaves are used for extraction of wax, a raw material for the chemical, electronic, cosmetic, food and pharmaceutical industries (FREITAS et al., 2019). The industrial sector stands out not only for the consumption of water in large quantities, but mainly for the volume and quality of residual water returned to the environment (SMOL; ADAM; PREISNER, 2020). The highest water consumption in the industry occurs in cooling towers and boilers, which specifically generate residual water (FAYYAZ et al., 2023).

Conceptually, residual water, unlike wastewater, is that which does not have contact with the product and remains after being used in processing, containing no residues from the production process (MATOS; MATOS, 2017). Reverse osmosis is widely adopted in industrial residual water treatment, with a focus on the reuse of quality water for various purposes; this type of treatment meets water quantity and quality requirements for a variety of urban, environmental and industrial applications (LOH et al., 2021; OLIVEIRA et al., 2020).

Regarding the application of residual water for agricultural/forestry use, drip irrigation systems stand out for their high water use efficiency (> 90%), enabling water, nutrient and labor savings, reducing losses, controlling weed growth, reducing soil salinization and increasing crop yield (ALMEIDA et al., 2022; AMARAL et al., 2022). However, the biggest barrier to the adoption and extensive use of drip irrigation with residual water, wastewater or water of inferior quality is the clogging of the emitters, which can significantly affect the hydraulic performance indicators distribution uniformity coefficient and relative flow rate of the irrigation system (CUNHA et al., 2017; DURAN-ROS et al., 2022; MARQUES et al., 2018; MESQUITA et al., 2016; PAIVA et al., 2024; VALE et al., 2020; ZHANGZHONG et al., 2016).

Emitter clogging can be caused by physical, chemical, or biological agents; physical clogging is caused by suspended inorganic particles, organic materials, and microbiological debris, and these materials can be combined with biological mucilages; chemical problems are caused by total dissolved solids when they form precipitates; and biological clogging is caused by algae and bacterial mucilages (SHEN et al., 2022; MUNIZ et al., 2023; VALE et al., 2021; ZHANG et al., 2017).

In view of the above, the objective of this study was to predict the risk of clogging of drippers by water quality attributes and to analyze their hydraulic performance when applying reverse osmosis reject from the carnauba wax industry and supply water.

MATERIAL AND METHODS

Site used to conduct the experimental tests

This study was carried out in the vicinity of the Laboratory of Rural Constructions and Ambience (LCRA) of the Federal Rural University of the Semi-Arid Region (UFERSA), in Mossoró, RN, Brazil, located at the geographic coordinates 5°12’13.14” South latitude and 37°19’26.93” West longitude.

Experimental design

The experiment was conducted in a completely randomized design with split-split plots in three replicates. Plots are represented by supply water (SW) and reverse osmosis reject (ROR); subplots comprised three types of non-pressure-compensating drippers (NST - 1.6 L h^{-1}, NSL - 1.6 L h^{-1}, NDT - 1.7 L h^{-1}), and sub-subplots contained nine times of evaluations of hydraulic performance indicators (0, 20, 40, 60, 80, 100, 120, 140, 160 hours).

Origin of the waters used in the tests

The reject used in the experiment was acquired from a carnauba wax industry in the state of Ceará, which uses well water treatment by reverse osmosis; one part is destined for cooling equipment in the internal process, and the other part (reject) is discarded. Supply water (control) came from the public network of the municipality of Mossoró, RN, managed by the Water and Sewage Company of Rio Grande do Norte (CAERN).

Assembly of experimental benches

Two drip units were assembled, one using supply water as control and the other using reverse osmosis reject. Both units were used to test three types of drip tapes, with each subunit representing one type of dripper.

The experimental bench had 1.0 x 8.0 m dimensions (width x length), with an area of 8.0 m², as shown in Figure 1. For support, nine pairs of 1.50 m high columns were installed, in a total of 18 columns per bench, made of white PVC pipes, DN 100 mm, filled with reinforced concrete. Column height varied from 1.00 m to 1.20 m, with a slope of 0.025 m/m and an average spacing of 1.02 m between pairs of columns. These columns support nine mixed wood rafters (5 x 5 cm) and eight fiber cement tiles (2.44 m x 0.50 m x 4 mm). The inclination of the tiles allows the recirculation of the types of water tested in the drip units.

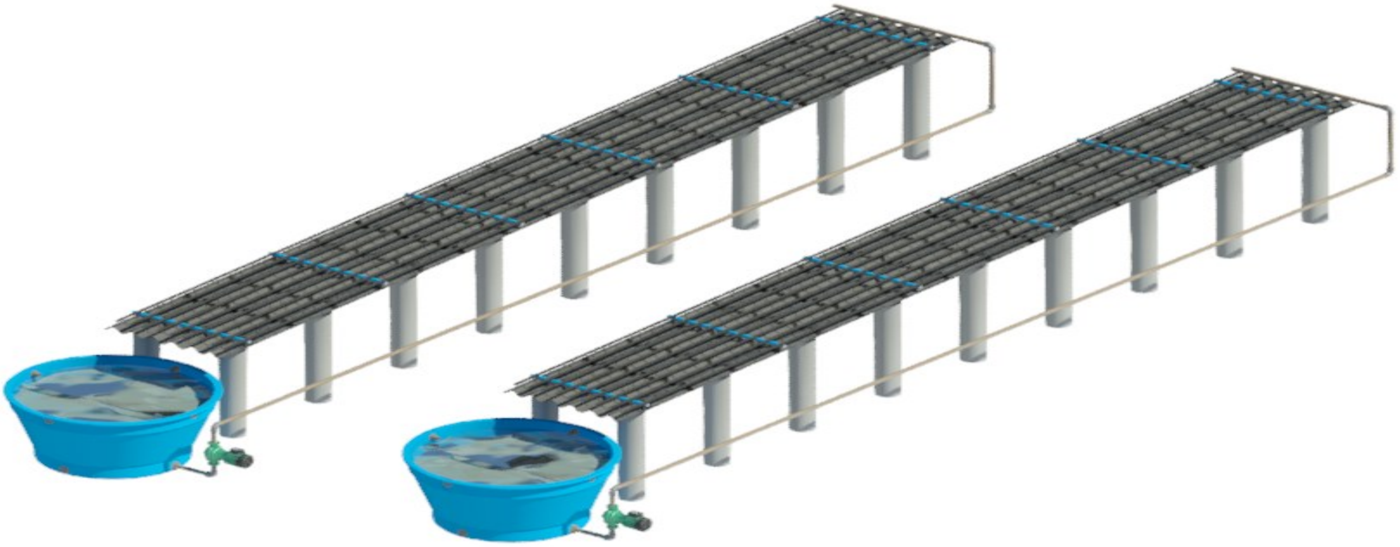


Figure 1. Schematic of the two experimental benches equipped with three drip subunits.

On the two experimental benches, two drip units were mounted with the following devices: 1) 0.31 m^3 water tank; 2) 0.5 hp motor pump; 3) Disc filter with 130 µm openings; 4) Point for measuring the operating pressure using a glycerin-filled pressure gauge; 5) Point for collecting samples of the tested waters; 6) PVC main line; 7) PVC submain line; 8) Nine 16 mm connectors and nine rubber seals; and 9) Nine 8-m-long lateral lines, three lines of each type of drip tape (Table 1); and 10) Nine end plugs for the lateral lines and nine end closures.

Table 1. Technical characteristics of non-pressure-compensating drip tape emitters used in drip units.

Specifications	Dripper model		
	NST	NSL	NDT
Nominal flow rate (L h^{-1})	1.60 [a]	1.60 [a]	1.70 [a]
Pressure compensation device	No [a]	No [a]	No [a]
Flow rate x pressure equation	v = 0.53. $P^{0.48}$ [a]	v = 0.57. $P^{0.45}$ [a]	v = 0.56. $P^{0.46}$ [a]
Filtering area (mm^2)	34 [a]	17 [a]	6 [b]
Labyrinth length (mm)	23 [a]	13 [a]	44 [b]
Manufacturing coefficient of variation (%)	7 [a]	7 [a]	5 [a]
Recommended pressure range (kPa)	60 -100 [a]	65-100 [a]	50-300 [a]
Spacing between drippers (m)	0.3 [a]	0.3 [a]	0.2 [a]

Note: [a]Technical information searched in manufacturers' catalogues. [b]Dimensions obtained using a digital caliper.

Water quality analysis

At the operating times of 0, 80 and 160 hours, samples of the two types of water were collected downstream of the disc filter for physicochemical analysis, following the recommendations of the Standard Methods for the Examination of Water and Wastewater (BAIRD; EATON; RICE, 2017).

In the Laboratory of Soil, Water and Plant Analysis (LASAP) and Multiuser Laboratory of Soil, Water and Plant Analysis of the Semi-Arid Region (LASAPSA), both belonging to UFERSA, the following physicochemical attributes of the two types of water were obtained: hydrogen potential (pH) and electrical conductivity (EC), using a pH meter and a benchtop conductivity meter, respectively; calcium (Ca^{2+}) and magnesium (Mg^{2+}), obtained by the titration method; iron (Fe) and manganese (Mn), determined by atomic absorption spectrophotometry; and total suspended solids (TSS) and total dissolved solids (TDS), quantified by the gravimetric method.

Monitoring the hydraulic performance of the drip units

In each lateral line, 16 emitters were identified with white ink to fix and facilitate the collection of the flow from the same drippers throughout the experimental period. To obtain the flow rate of the drippers, the volume of water for each emitter was collected in a 200 mL plastic container for three minutes, and the volume was later quantified in a 100 mL graduated cylinder, with a precision of 1 mL; then, the volume was divided by time and multiplied by a conversion factor of 0.06 to convert the flow rate from mL $minute^{-1}$ to L h^{-1}. Then, the volumes collected in each lateral line were converted into flow rate (V), using Equation 1.

$$Q = 0.06.\left(\frac{vol}{t}\right) \quad (1)$$

Where:
Q - Dripper flow rate obtained over the experimental period, L h^{-1};
vol - Volume collected for three minutes and quantified in a graduated cylinder, mL;
t - Fluid collection time, minutes; and
0.06 - Conversion factor.

Over the experimental period of 160 hours, nine evaluations of emitter flow rate were carried out every 20 hours, at 0, 20, 40, 60, 80, 100, 120, 140 and 160 hours. These V values were then used to estimate two hydraulic performance indicators: 1) Distribution Uniformity Coefficient (DU) and 2) Relative flow rate (Qr). Equations 2 and 3 describe the hydraulic performance indicators DU and Qr, respectively.

$$DU = 100.\left(\frac{Q_{25\%}}{Q_m}\right) \quad (2)$$

$$Qr = \left(\frac{Q_{act}}{Q_{0h}}\right) \quad (3)$$

Where:
DU - Fluid distribution uniformity coefficient, %;
$Q_{25\%}$ - Mean of the 25% lowest dripper flow rates, L h^{-1};
Q_m - Mean dripper flow rate, L h^{-1};
Qr - Relative flow rate, decimal;
Q_{act} - Actual dripper flow rate, L h^{-1}; and
Q_{0h} - Initial dripper flow rate, L h^{-1}.

The classification proposed by Merriam and Keller (1978) was used for DU values: DU values above 90% are excellent; DU values between 80 and 90% are good; DU values between 70 and 80% are regular; and DU values below 70% are poor. The classification presented by Cararo et al. (2006) was used for Qr values: Qr = 1 indicates absence of clogging, Qr > 1 represents clogging that causes increase in flow rate, and Qr < 1 is associated with clogging that leads to reduction in flow rate.

The drip units operated for an average of six hours per day until reaching the total operating time of 160 hours, and the operating pressure was maintained throughout the experimental period at 100 ± 10 kPa. The operating pressure was maintained at this value by cleaning the filter element once a day and by adjusting the gate valve located downstream of the motor pump two to four times during the daily operation.

Statistical analysis

Data of the physicochemical attributes of the two types of water were subjected to descriptive analysis, and mean and standard deviation were calculated. Data of the two hydraulic performance indicators were subjected to analysis of variance by the F test ($p < 0.05$), and the means were compared by Tukey test ($p < 0.05$). Statistical analyses were performed using he SISVAR program Version 5.6 (FERREIRA, 2019). ANOVA was performed following the recommendations of Vieira (2006).

RESULTS AND DISCUSSION

Predicting the risk of dripper clogging by assessing irrigation water quality

Descriptive statistics in presented Table 2, highlighting the mean and standard deviation, throughout the experimental period, specifically at 0, 80 and 160 hours, when the water quality indicators pH, electrical conductivity (EC), calcium (Ca^{2+}), magnesium (Mg^{2+}), manganese (Mn^{+}), iron (Fe^{+}), total suspended solids (TSS) and total dissolved solids (TDS) were evaluated in laboratories.

Table 2. Physicochemical attributes of supply water (SW) and reverse osmosis reject from the carnauba wax industry (ROR) and their respective means and standard deviations.

Attributes	Operating time (h)						Descriptive statistics	
	0		80		160		Mean and standard deviation and clogging risk classification	
	SW	ROR	SW	ROR	SW	ROR	SW	ROR
pH	9.16	8.95	8.52	8.98	8.30	8.70	8.66(S) ±0.45	8.88(S) ±0.15
EC (dS m^{-1})	0.71	1.76	0.56	1.56	0.49	1.55	0.59(B) ±0.11	1.62(M) ±0.12
Ca^{2+} ($mmol_c$ L^{-1})	0.70	3.70	1.00	2.50	0.80	3.40	0.83(B) ±0.15	3.20(L) ±0.62
Mg^{2+} ($mmol_c$ L^{-1})	1.20	3.90	1.66	2.53	0.80	1.80	1.22(B) ±0.43	2.74(M) ±1.07
Mn (mg L^{-1})	0.004	0.012	0.003	0.156	0.004	0.001	0.004(B) ±0.0006	0.06(L) ±0.086
Fe (mg L^{-1})	0.055	0.120	0.060	0.078	0.023	0.008	0.046(B) ±0.020	0.07(L) ±0.056
TSS (mg L^{-1})	8.0	14.0	4.0	30.0	6.0	14.0	6.0(B) ±2.0	19.0(L) ±9.0
TDS (mg L^{-1})	112	1086	101	205	144	661	119(B) ±22	651(M) ±441

Note: L - Low; M - Moderate; and S - Severe.

In the studies conducted by Bucks, Nakayama and Gilbert (1979) and Capra and Scicolone (1998), the strong relationship between irrigation water quality and dripper clogging is evident. For this reason, these authors proposed attributes and standards that allow predicting this risk as low, moderate, and severe, according to the laboratory results of the attributes.

Regarding the pH attribute, the mean values were 8.66 and 8.88 in SW (control) and ROR, respectively, both representing a severe risk of clogging in drippers (pH > 8.0); in this case, with pH > 7.5 and high Ca^{2+} or Mg^{2+} contents or high hardness, calcium or magnesium carbonate may precipitate in the filter, tubing, or emitter (BUCKS; NAKAYAMA; GILBERT, 1979). The mean pH values of SW and ROR in the present study were higher than the mean pH found in SW by Paiva et al. (2024), who observed a moderate risk of clogging (7.0 < pH < 8.0), and the mean pH in ROR obtained by Oliveira et al. (2020), who also observed a moderate risk of clogging.

In SW, the mean EC was 0.59 dS m^{-1}, with a low risk of emitter clogging (EC < 1.0 dS m^{-1}) according to Capra and Scicolone (1998). In ROR, the mean EC was 1.62 dS m^{-1}, representing a moderate risk (1.0 dS m^{-1} ≤ EC ≤ 4.5 dS m^{-1}). Compared to other studies, the mean EC value of SW in the present study is identical to that reported by Paiva et al. (2024), and the mean EC value of ROR in the present study is similar to the mean EC of 1.64 dS m^{-1} obtained by Oliveira et al. (2020). In both comparisons, the risks of clogging due to EC were identical to those of the present study.

The average Ca^{2+} content in SW was 0.83 $mmol_c$ L^{-1}, while in ROR, the mean concentration was 3.20 $mmol_c$ L^{-1}. Both types of water are classified as having a low risk of emitter clogging (Ca^{2+} < 12.50 $mmol_c$ L^{-1}) (CAPRA; SCICOLONE, 1998). The mean Ca^{2+} content in this study is higher than the mean Ca^{2+} in SW (0.50 $mmol_c L^{-1}$) obtained by Vale et al. (2020) and similar to the mean Ca^{2+} content of 3.30 $mmol_c L^{-1}$ found by Souza et al. (2022) in ROR. For both comparisons, the risks of clogging due to Ca^{2+} were low, as in the present study.

In the control (SW), the mean Mg^{2+} content was 1.22 $mmol_c L^{-1}$, having a low risk of emitter clogging (< 2.00 $mmol_c L^{-1}$) according to Capra and Scicolone (1998); this average Mg^{2+} content in SW was higher than the content of 0.38 $mmol_c L^{-1}$ quantified by Vale et al. (2020), but also having a low risk of clogging. In ROR, the mean Mg^{2+} content was 2.74 $mmol_c L^{-1}$, so the risk of clogging was classified as moderate (2.0 $mmol_c L^{-1} \leq Mg^{2+} \leq 7.3$ $mmol_c L^{-1}$). Regarding ROR, the Mg^{2+} values in the present study are lower than the content of 11.9 $mmol_c L^{-1}$ found by Souza et al. (2022), for which the risk of clogging was also higher and classified as severe.

In SW and ROR, the mean contents of Mn and Fe were 0.004 and 0.046 mg L^{-1} and 0.06 and 0.07 mg L^{-1}, respectively. The mean contents of Mn and Fe in SW and ROR represent a low risk of clogging (Mn < 0.7 mg L^{-1} and Fe < 0.5 mg L^{-1}) according to the classification presented by Capra and Scicolone (1998). The chemical elements Mn and Fe can cause clogging problems in emitters both by the formation of low-solubility precipitates and by the emergence of mucilage-producing bacteria (BUCKS; NAKAYAMA; GILBERT, 1979).

According to Muniz et al. (2023), waters with higher contents of these chemical elements are the most susceptible to Fe and Mn precipitation, as redox reactions occur at pH values higher than 7.0 with the presence of oxygen. Also according to the aforementioned authors, Equations 4 and 5 present the oxidation reactions of Fe and Mn by the action of oxygen, forming low-solubility precipitates that cause clogging of drippers.

$$4Fe(HCO_3)_2 + O_2 + 2H_2O \rightarrow 4FeOH_3 + 8CO_2 \quad (4)$$

$$2Mn(HCO_3)_2 + O_2 + 2H_2O \rightarrow 2Mn(OH)_4 + 4CO_2 \quad (5)$$

The mean TSS values in the control (SW) and ROR were 6 and 19 mg L^{-1}, respectively, and both types of water have a low risk of dripper clogging (TSS < 50 mg L^{-1}) (BUCKS; NAKAYAMA; GILBERT, 1979). In the study conducted by Vale et al. (2021), the mean TSS value was higher (10 mg L^{-1}), but the risk of clogging in relation to TSS was also low. It is worth noting that Loganathan, Chelme-Ayala, and El-Din (2015) found TSS values below 2 mg L^{-1} in ROR, which are lower than those of the present study, also representing a low risk of clogging. It should be emphasized that physical clogging of drippers is caused by TSS (sand, silt, clay, and organic matter) in irrigation water (BUCKS; NAKAYAMA; GILBERT, 1979), but this risk was not observed in the present study.

In the control (SW) and ROR, the mean TDS values were 110 and 651 mg L^{-1}, respectively. In relation to SW, the mean value of TDS was lower than the limit of 500 mg L^{-1} established by Bucks, Nakayama and Gilbert (1979), so the risk of clogging was classified as low. For Vale et al. (2021), the SW used in the control drip units had a mean TDS content of 298 mg L^{-1} and also a low risk of clogging.

On the other hand, for ROR, the mean TDS content had a moderate risk of clogging (500 mg L^{-1} < TDS < 2000 mg L^{-1}). TDS include inorganic salts and organic matter, which are pollutants with negative impacts on aquatic ecosystems and water for human use (PENG et al., 2020). TDS content is a crucial indicator of chemical clogging of drippers (MIRZAEE; ZAKERINIA; FARASATI, 2021). There is a strong correlation between the chemical clogging indicators TDS, pH, and EC in irrigation water (MUNIZ et al., 2023).

Hydraulic performance of drippers operating with reverse osmosis reject from the carnauba wax industry and supply water as control

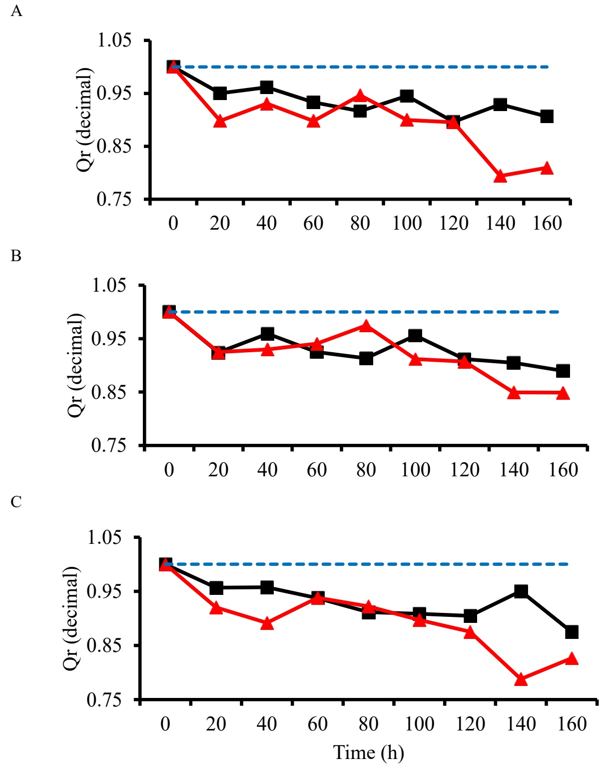
The results presented in Figure 2 show the evolution of the hydraulic performance indicator Qr during the operating period of the NST, NSL and NDT drip units.

Initially (0 h), the two types of water did not cause any change in Qr, with mean values equal to 1.00. However, at 160 h, there was a reduction in Qr values. In SW and ROR, the final Qr values in the NST, NSL and NDT drip units were 0.91 and 0.89, 0.88 and 0.81, and 0.85 and 0.83, respectively. Zhang et al. (2017) stated that a dripper is considered obstructed when Qr < 0.75, which did not occur in the present study. These results coincide with those of Mesquita et al. (2016), who also obtained Qr < 1 after 20 hours of operation in drip units equipped with non-pressure-compensating emitters (1.65 L h^{-1}), when applying landfill leachate diluted in supply water in a 1:3 ratio for 160 hours.

In the NST drip unit (Figure 2A) operating with ROR, there was a 19% reduction compared to the initial Qr, which can be justified by the fact that it had the second longest labyrinth length (Table 1) and by the higher risk of chemical clogging caused by ROR compared to SW (Table 2). In this drip unit, when operating with SW, a 9% decrease in Qr was observed when comparing the final (160 hours) and initial (0 hours) times. A reduction of less than 15% was detected in the Qr of the NSL drip unit when applying ROR, while the Qr reduction in the NSL drip unit operating with SW was 11% (Figure 2B). In the NDT drip unit (Figure 2C), applying SW, there was a 12% reduction compared to the initial Qr, probably due to the longer labyrinth length (Table 1) and the risk of precipitate formation (ZHANGZHONG et al., 2016) caused by the high pH value (Table 2); however, in the NDT drip unit applying ROR, this Qr reduction was 17%.

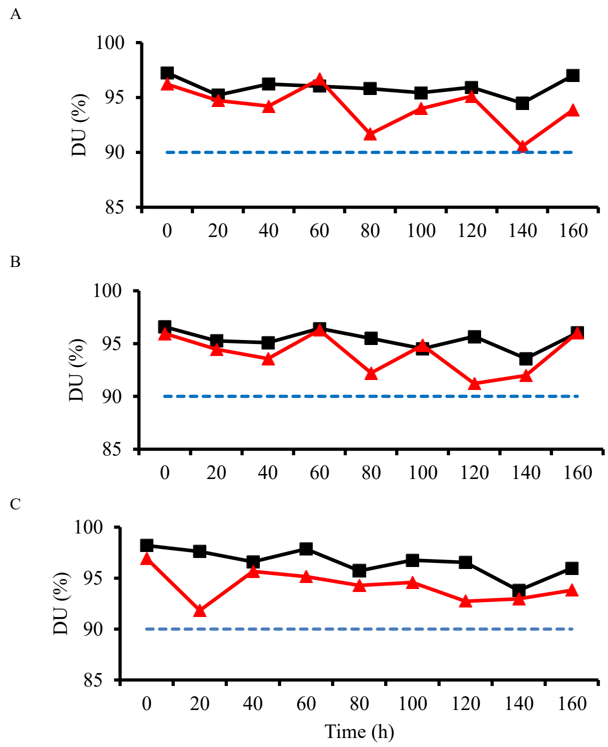
Analysis of the Qr results, at the end of the experiment, showed low reduction in flow rate. This finding can be related to the TSS values found in this experiment, for both SW and ROR, and the risk of clogging was low for this attribute, according to the classification of Bucks, Nakayama and Gilbert (1979). In general, the ROR showed a greater reduction in Qr compared to SW, probably due to the higher values of the attributes pH, EC, Mg^{2+}, and TDS (SHEN et al., 2022).

The results of the distribution uniformity coefficient (DU) for the NST, NSL and NDT drip units in operation with SW and ROR are presented in Figure 3.



Note: Classification of Qr = 1 (▬ ▬ ▬)

Figure 2. Relative flow rate (Qr), over the operating time, of the drip units with NST (A), NSL (B) and NDT (C) emitters applying supply water (━■━) and reverse osmosis reject from the carnauba wax industry (━▲━).



Note: Classification of DU as excellent (▬ ▬ ▬)

Figure 3. Variation of the distribution uniformity coefficient (DU), over the operating time, of the drip units with NST (A), NSL (B) and NDT (C) emitters applying supply water (━■━) and reverse osmosis reject from the carnauba wax industry (━▲━).

Figure 3A illustrates the DU results of the NST drip unit applying SW, and its initial and final values were 97.24% and 97%, respectively. However, when ROR was applied, the initial and final values were 96.21% and 93.87%, respectively. There were reductions of 0.25% and 2.46% in the DU of NST when operating with SW and ROR, respectively. In the study conducted by Vale et al. (2020) with dilutions of produced water from oil exploration, the same types of drip tapes showed DU reductions of 2.20 and 72.92% also at the operating time of 160 hours.

Figure 3B shows the DU results of the NSL drip unit operating with SW. The initial DU was 96.59% and the final DU was 96.03%. In the ROR system, the initial and final values were 95.95% and 96.03%, respectively, with a reduction of 0.58% in the DU of the SW system and an increase of 0.08% in the ROR system due to the random unclogging process (CUNHA et al., 2017). Marques et al. (2018) obtained similar results when using drip tapes with SW, while in the drip tapes that applied dilutions of dairy effluents, the DU classification ranged from excellent to good throughout the experimental period.

The DU results for the NDT drip unit are presented in Figure 3C. For the SW system, the initial DU was 98.20% and the final DU was 95.97%, with a reduction of 2.27%. In the ROR system, the initial DU was 96.93%, but at the end, it was 93.82%, representing a reduction of 3.21%. These results differ from those reported by Vale et al. (2020), who observed that the NDT drip unit applying SW showed no reduction in DU at the final time (160 h), while the dilutions of produced water from oil exploration in SW showed reductions in DU ranging from 3.16% to 9.78% at the same evaluation time.

The results showed that all types of drip tapes had DU values classified as excellent (DU > 90%), indicating high uniformity in the distribution of water by the drippers used in the study. Such high uniformity is related to the low risk of dripper clogging, mainly due to low values of TSS (Table 2), one of the most relevant physical attributes in the clogging process (DURAN-ROS et al., 2022).

Table 3 presents the summary of the analysis of variance for the variables relative flow rate (Qr) and distribution uniformity coefficient (DU) in the split-split-plot scheme.

Table 3. Summary of the analysis of variance for the variables relative flow rate (Qr) and distribution uniformity coefficient (DU) in the split-split-plot scheme.

Sources of variation	Degrees of freedom	Mean square	
		Qr	DU
Types of water (TW)	1	0.0344^{ns}	149.68^{ns}
Residual (a)	2	0.0025	8.12
Types of dripper (TD)	2	0.0016^{ns}	6.90^{ns}
TD x TW	2	0.0034^{ns}	2.12^{ns}
Residual (b)	4	0.0023	8.16
Operating time (T)	8	0.0317**	24.30**
T x TW	8	0.0080**	3.34^{ns}
T x TD	16	0.0004^{ns}	1.69^{ns}
T x TW x TD	16	0.0007^{ns}	3.96^{ns}
Residual (c)	102	0.0010	3.73
CVplot (%)		5.39	3.00
CVsubplot (%)		5.22	3.01
CVsub-subplot (%)		3.45	2.03
Overall mean		0.92	95.02%

Note: ** and ^{ns} Significant at 1% probability level and not significant at 5% probability level by the F-test. CV - Coefficient of variation.

For the Qr and DU variables, the types of water x types of drippers x operating time interaction was not significant ($p < 0.05$). However, the interaction between types of water and operating time was significant ($p < 0.01$) only for Qr. The operating time factor was also significant ($p < 0.01$) for Qr and DU. However, these variables showed that the factor types of drippers, the interaction between types of drippers and types of water, and the interaction between types of drippers and operating time were not significant ($p < 0.05$). It is worth pointing out that the coefficients of variation of the sub-subplots were 3.45% and 2.03% for the Qr and DU variables, respectively.

Table 4 shows the mean values of the variables relative flow rate (Qr) and distribution uniformity coefficient (DU) for the type of dripper factor considering each level of operating time and type of water.

Analysis of the Qr means followed by at least one lowercase letter in the columns of Table 4 showed that: at the SW level, the Qr of the NST, NSL and NDT drip subunits did not differ ($p < 0.05$) for any of the operating times of the present study, while at the ROR level, the Qr of the NSL drip subunit differed ($p < 0.05$) from the Qr of the NDT drip subunit, only at the operating time of 140 hours. By establishing a comparison between the Qr means followed by at least one uppercase letter in the rows, it was found that: at the operating time of 20 hours, the Qr of the NST drip subunit at the SW level differed ($p < 0.05$) from the Qr at the ROR level; at the operating time of 40 hours, the mean Qr of the NDT drip subunit differed ($p < 0.05$) between SW and ROR levels; at the operating times of 80 and 100 hours, the Qr of the NSL drip subunit at the SW level differed ($p < 0.05$) from the Qr at the ROR level; at 140 hours, the mean Qr values of the NST, NSL, and NDT drip subunits differed ($p < 0.05$) when comparing the SW and ROR levels; and at the operating time of 160 hours, the mean Qr values of the NST and NDT drip units at the SW level differed ($p < 0.05$) from the Qr means at the ROR level.

Table 4. Mean values of the variables relative flow rate (Qr) and distribution uniformity coefficient (DU) for the type of dripper factor (TD) considering each level of operating time (T) and type of water (TW).

T (hours)	TD	TW*			
		Qr (decimal)		DU (%)	
		SW	ROR	SW	ROR
0	NST	1.00aA	1.00Aa	97.24aA	96.21aA
	NSL	1.00aA	1.00aA	96.59aA	95.95aA
	NDT	1.00aA	1.00aA	98.20aA	96.93aA
20	NST	0.95aA	0.90aB	95.23aA	94.72aA
	NSL	0.92aA	0.92aA	95.27aA	94.46aA
	NDT	0.96aA	0.92aA	97.61aA	91.81aB
40	NST	0.96aA	0.93aA	96.22aA	94.21aA
	NSL	0.96aA	0.93aA	95.10aA	93.58aA
	NDT	0.96aA	0.89aB	96.61aA	96.66aA
60	NST	0.93aA	0.90aA	96.03aA	96.67aA
	NSL	0.93aA	0.94aA	96.43aA	96.29aA
	NDT	0.94aA	0.94aA	97.86aA	95.15aA
80	NST	0.92aA	0.94aA	95.81aA	91.68aB
	NSL	0.92aB	0.97aA	95.49aA	92.23aB
	NDT	0.92aA	0.95aA	95.73aA	94.28aA
100	NST	0.94aA	0.90aA	95.43aA	93.98aA
	NSL	0.96aA	0.91aB	94.52aA	94.85aA
	NDT	0.92aA	0.90aA	96.76aA	94.47aA
120	NST	0.90aA	0.90aA	95.93aA	95.11aA
	NSL	0.91aA	0.91aA	95.67aA	91.23bB
	NDT	0.91aA	0.88aA	96.54aA	92.73abB
140	NST	0.93aA	0.80abB	94.49aA	90.55aB
	NSL	0.90aA	0.85bB	93.58aA	91.99aA
	NDT	0.93aA	0.79aB	93.81aA	92.98aA
160	NST	0.90aA	0,81aB	97.01aA	93.87aB
	NSL	0.89aA	0.85aA	96.52aA	94.30aA
	NDT	0.88aA	0.83aB	95.98aA	93.82aA

Note: SW - Supply water; ROR - Reverse osmosis reject. * Means followed by at least one lowercase letter in the columns and one uppercase letter in the rows do not differ from each other at 5% probability level, by the Tukey test.

By fixing the means of DU followed by at least one lowercase letter in the columns, it is possible to observe that: at the SW level, the means of DU of the NST, NSL and NDT drip subunits did not differ ($p < 0.05$) at the nine operating times studied; at the ROR level, the mean DU of the NST drip subunit differed ($p < 0.05$) from the mean DU of the NSL drip subunit only at the operating time of 120 hours. A comparison of the means of DU followed by at least one uppercase letter in the rows showed that: at the operating time of 20 hours, the mean DU of the NDT drip subunit at the SW level differed ($p < 0.05$) from the mean DU at the ROR level; at the operating time of 80 hours, the mean DU of the NST and NSL drip subunits at the SW level differed ($p < 0.05$) from the mean DU at the ROR level; at 120 hours, the mean DU values of the NSL and NDT drip subunits differed ($p < 0.05$) when comparing the SW and ROR levels; and at the operating times of 140 and 160 hours, the mean DU of the NST drip subunit at SW levels differed ($p < 0.05$) from the mean DU at the ROR level.

CONCLUSIONS

In residual water, the attributes that represented a risk of clogging for drippers were pH, electrical conductivity, magnesium and total dissolved solids, while in the control only pH represented risk.

There was a slight decrease in the hydraulic performance indicators relative flow rate and distribution uniformity coefficient with the increase in operating time, especially in the drip units that operated with reverse osmosis reject.

The interaction between types of water and operating time significantly affected the two hydraulic performance indicators.

There was no significant effect of the types of drippers on the changes in the two hydraulic performance indicators.

REFERENCES

ALMEIDA, I. A. et al. Dripper clogging: emphasis on the problem and how to minimize impact. **Revista Brasileira de Engenharia de Biossistemas**, 16: 1095, 2022.

AMARAL, M. A. C. M. et al. Dripper clogging by soil particles entering lateral lines directly during irrigation network assembly in the field. **Agricultural Water Management**, 273: 107884, 2022.

BAIRD, R. B.; EATON, A. D.; RICE, E. W. **Standard methods for the examination of water and wastewater**. 23. ed. Washington: APHA, AWWA, WPCR, 2017. 1504 p.

BUCKS, D. A.; NAKAYAMA, F. S.; GILBERT, R. G. Trickle irrigation water quality and preventive maintenance. **Agricultural Water Management**, 2: 149-162, 1979.

CAPRA, A.; SCICOLONE, B. Water quality and distribution uniformity in drip/trickle irrigation systems. **Journal of Agricultural Engineering Research**, 70: 355-365, 1998.

CARARO, D. C. et al. Analysis of clogging in drip emitters during wastewater irrigation. **Applied Engineering in Agriculture**, 22: 251-257, 2006.

CUNHA, M. E. et al. Obstrução de gotejadores operando com efluente de laticínios diluído. **Revista Brasileira de Agricultura Irrigada**, 11: 1517-1527, 2017.

DURAN-ROS, M. et al. Effect of different filter media on emitter clogging using reclaimed effluents. **Agricultural Water Management**, 266: 107591, 2022.

FAYYAZ, S. et al. Life cycle assessment of reverse osmosis for high-salinity seawater desalination process: Potable and industrial water production. **Journal of Cleaner Production**, 382: 135299, 2023.

FERREIRA, D. F. SISVAR: A computer analysis system to fixed effects split plot type designs: Sisvar. **Brazilian Journal of Biometrics**, 37: 529-535, 2019.

FREITAS, C. A. S. et al. Carnauba wax uses in food-A review. **Food Chemistry**, 291: 38-48, 2019.

LOGANATHAN, K.; CHELME-AYALA, P.; EL-DIN, M. G. Treatment of basal water using a hybrid electrodialysis reversal-reverse osmosis system combined with a low-temperature crystallizer for near-zero liquid discharge. **Desalination**, 363: 92-98, 2015.

LOH, W. H. et al. Reverse osmosis concentrate treatment by microbubble ozonation-biological activated carbon process: Organics removal performance and environmental impact assessment. **Science of The Total Environment**, 798: 149289, 2021.

MARQUES, B. C. D. et al. Uniformidade da distribuição de efluente em unidades gotejadoras aplicando diluições da água residuária de laticínios. **IRRIGA**, 23: 592-608, 2018.

MATOS, A. T.; MATOS, M. P. **Disposição de águas residuárias no solo e em sistemas alagados construídos**. 1.ed. Viçosa, MG: Ed. UFV, 2017. 371 p.

MERRIAM, J. L.; KELLER, J. **Farm irrigation system evaluation**: a guide for management. Logan: Utah State University, 1978. 271 p.

MESQUITA, F. O. et al. Desempenho de gotejadores aplicando percolado de aterro sanitário diluído. **IRRIGA**, 21: 156-156, 2016.

MIRZAEE, M. M.; ZAKERINIA, M.; FARASATI, M. The effects of phytoremediation of treated urban wastewater on the discharge of surface and subsurface drippers (Case study: Gorgan wastewater treatment plant in northern Iran). **Cleaner Engineering and Technology**, 4: 100210, 2021.

MUNIZ, G. L. et al. Risk evaluation of chemical clogging of irrigation emitters via geostatistics and multivariate analysis in the northern region of Minas Gerais, Brazil. **Water**, 15: 790, 2023.

OLIVEIRA, A. M. et al. Disposal of waste brine from desalination in Eutrophic Red Argisol and Fluvic Neosol in the western Potiguar region, Brazil. **Desalination and Water Treatment**, 195: 213-221, 2020.

PAIVA, L. A. L. et al. Canonical correlation between clogging agents and performance of drippers operating with aquaculture effluents. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 28: e274127, 2024.

PENG, J. et al. Removal of total dissolved solids from wastewater using a revolving algal biofilm reactor. **Water Environment Research**, 92: 766-778, 2020.

SHEN, Y. et al. Physical, chemical and biological emitter clogging behaviors in drip irrigation systems using high-sediment loaded water. **Agricultural Water Management**, 270: 107738, 2022.

SMOL, M.; ADAM, C.; PREISNER, M. Circular economy model framework in the European water and wastewater sector. **Journal of Material Cycles and Waste Management**, 22: 682-697, 2020.

SOUZA, A. C. M. et al. Economic analysis and development of the Nile Tilapia cultivated in the nursery using reject brine as water support. **Water, Air, & Soil Pollution**, 233: 8, 2022.

VALE, H. S. M. et al. Distribution uniformity in drip units applying dilutions of treated water produced by oil exploration. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 24: 394-401, 2020.

VALE, H. S. M. et al. Flow rate changes of drippers with dilutions of treated water produced by oil exploration in the Brazilian semiarid region. **Australian Journal of Crop Science**, 15: 796-805, 2021.

VIEIRA, S. **Análise de Variância:** (ANOVA). São Paulo, SP: Atlas, 2006. 206 p.

ZHANGZHONG, L. et al. Chemical clogging of emitters and evaluation of their suitability for saline water drip irrigation. **Irrigation and Drainage**, 65: 439-450, 2016.

ZHANG, C. et al. Analysing the correlations of long-term seasonal water quality parameters, suspended solids and total dissolved solids in a shallow reservoir with meteorological factors. **Environmental Science and Pollution Research**, 24: 6746-6756, 2017.