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ENTUPIMENTO DE EMISSORES SOB APLICAÇÃO DE DIFERENTES FONTES DE NITROGÊNIO

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1 RESUMO

O entupimento de emissores está diretamente relacionado a qualidade da água de irrigação, além disso pode-se observar um agravamento no entupimento devido à prática da fertirrigação, técnica cada vez mais frequente em sistemas de irrigação localizada. Objetivou-se avaliar o grau de entupimento de gotejadores submetidos a aplicação de nitrato de potássio, sulfato de amônio, nitrato de cálcio, nitrato de amônio e ureia. O experimento foi realizado em uma casa de vegetação. O delineamento experimental utilizado é em blocos ao acaso, analisado em esquema fatorial 5 × 4, com três repetições. Os tratamentos consistiram em cinco fontes de N (nitrato de potássio, sulfato de amônio, nitrato de cálcio, nitrato de amônio e ureia) e quatro tempos de funcionamento (200 400, 600 e 800 h). Foi utilizado um modelo de tubo gotejador com vazão nominal de 2 L h^{-1}, diâmetro nominal 16 mm, diâmetro interno 13 mm, pressão de operação 100 a 350 kPa e espaçamento entre emissores de 0,7 m. Depois de tabulados os dados de vazão, foram determinados o coeficiente de uniformidade estatístico, o coeficiente de uniformidade absoluto, coeficiente de variação e o grau de entupimento. A aplicação de nitrato de cálcio provoca o maior grau de entupimento dos gotejadores.

Palavras-chave: fertirrigação, obstrução, uniformidade, sulfato de amônio, nitrato de potássio.

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CLOGGING OF DRIPPERS UNDER THE APPLICATION OF DIFFERENT SOURCES OF NITROGEN

2 ABSTRACT

Emitter clogging is directly related to the quality of irrigation water. Furthermore, clogging can be observed due to the practice of fertigation, an increasingly common technique in localized irrigation systems. The objective of this study was to evaluate the degree of clogging of drippers subjected to the application of potassium nitrate, ammonium sulfate, calcium nitrate, ammonium nitrate and urea. The experiment was carried out in a greenhouse. The experimental

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design used was randomized blocks, analyzed in a 5 × 6 factorial scheme, with three replications. The treatments consisted of five N sources (potassium nitrate, ammonium sulfate, calcium nitrate, ammonium nitrate and urea) and four operating times (200, 400, 600 and 800 h). A dripper pipe model with a nominal flow rate of 2 L h^{-1}, nominal diameter of 16 mm, internal diameter of 13 mm, operating pressure of 100 to 350 kPa and spacing between emitters of 0.7 m was used. After the flow data were tabulated, the statistical uniformity coefficient, absolute uniformity coefficient, coefficient of variation and degree of clogging were determined. The application of calcium nitrate caused the greatest degree of clogging in the drippers.

Keywords: fertigation, clogging, uniformity, ammonium sulfate, potassium nitrate.

3 INTRODUCTION

Irrigation in agriculture should be understood as a technique that provides conditions for genetic material to express its full productive potential in the field. Furthermore, irrigation is a very effective instrument for increasing profitability (Hernandez, 1994; Silva; Silva, 2005). ; Kumar; Ashoka, 2020).

The search for better irrigation water management involves increasing the efficiency of irrigation water use and reducing losses, which can be achieved by drip irrigation, which is considered an effective method for reducing water application and increasing water use efficiency by applying water directly to the root zones of each plant, particularly in areas with low rainfall and high irrigation water costs (Sinha; Shasikant, 2021).

Localized irrigation systems are technologies in which techniques such as the fertigation of soluble fertilizers via irrigation water can be used, with high uniformity of application and assuming economic and environmental importance in agricultural activities (Borssoi *et al.*, 2012; Hakiruwizera *et al.*, 2024).

The uniformity of water application affects crop productivity and yield and the cost of irrigation. Irrigated areas with low uniformity of water distribution can lead to problems such as nutrient leaching, soil saturation, increased incidence of disease, water deficit and uneven harvesting (Paulino *et al.*, 2009; Coelho *et al.*, 2018).

Uniformity coefficients are the main parameters used in the evaluation of irrigation systems since they express the functioning of the system and the quality of irrigation and are decisive in the planning and operation of irrigation systems. Furthermore, the analysis of uniformity coefficients is essential for evaluating the performance of any irrigation system (Souza *et al.*, 2006; Rodrigues *et al.*, 2013; Banjare; Sinha, 2020).

Emitter clogging is directly related to the quality of irrigation water, which includes factors such as the quantity of suspended particles, chemical composition and microbial population; in addition, an increase in emitter clogging can also be observed due to the practice of fertigation, a technique that is increasingly common in localized irrigation systems (Ribeiro *et al.*, 2005; Coelho, 2007). Notably, to evaluate the irrigation system, several parameters are determined in the field, such as the flow rate, irrigation time and uniformity of water application; these are basic criteria for decision-making regarding the diagnosis of the system (Paulino *et al.*, 2009; Gultekin, 2007). *et al.*, 2022).

The evaluation of localized irrigation systems should therefore be a routine procedure for detecting failures in a timely manner in solution (Salgado *et al.*, 2021). Additionally, the need to conserve water resources and reduce production costs, especially energy and inputs, demonstrates the importance of evaluating the uniformity of application and the degree of clogging of irrigation systems, mainly to obtain a uniform and efficient application of water (Rezende *et al.*, 2002; Sinha; Shasikant, 2021). The objective of this study was to evaluate the degree of clogging of drippers subjected to the application of potassium nitrate, ammonium sulfate, calcium nitrate, ammonium nitrate, and urea.

4 MATERIALS AND METHODS

The experiment was carried out in a greenhouse installed in the experimental area of IFGoiano – Campus Rio Verde. The greenhouse consists of a 150-micron transparent polyethylene plastic film covering and closed sides, with a shade cloth with 30% interception. The geographic coordinates of the installation site are 17°48'28" S and 50°53'57" W, with an average altitude of 720 m above sea level. The climate of the region is classified according to Köppen and Geiger (1928) as Aw (tropical), with rain from October to May and dry from June to September. The average annual temperature ranges from 20 to 35 °C, and precipitation ranges from 1,500 to 1,800 mm per year.

The experimental design used was randomized blocks, analyzed in a 5 × 4 factorial scheme, with three replications. The treatments consisted of five N sources (potassium nitrate, ammonium sulfate, calcium nitrate, ammonium nitrate and urea) and four operating times (200, 400, 600 and 800 h). An equal nitrogen dose was applied to all the treatments, equivalent to a recommendation of 100 kg ha $^{-1}$ of N.

A drip tube model with a nominal flow rate of 2 L h $^{-1}$, nominal diameter of 16 mm, internal diameter of 13 mm, operating pressure of 100 to 350 kPa and spacing between emitters of 0.7 m was used.

A pressure gauge was installed at the inlet of the drip lines, allowing the pressure to be checked at each flow measurement and, if necessary, adjusted to the preestablished pressure. For this purpose, a Bourdon pressure gauge with a reading range of 0–4 kg cm$^{-2 \text{ was used}}$. During the entire test period, water temperature readings were taken in the collection tank, with treatments being applied with water temperatures in the range of 25 $^{\circ C}$ (25 $^{\circ C}$ ± 1 °C).

The fertilizer injection time was 2 hours to ensure better application of nitrogen sources, on the basis of minimum dilution. A Venturi injector was used to inject the fertilizers into the irrigation system, which sucked the fertilizer after it had dissolved in a 50 L reservoir tank. Table 1 shows the characteristics of the potassium nitrate, ammonium sulfate, calcium nitrate, ammonium nitrate, and urea used in fertigation.

Table 1. Nutrient concentrations of the nitrogen sources used in fertigation

Nitrogen sources [1]	**Nutrient concentration (g kg $^{-1}$)**			
	N	**S**	**Here**	**K_2O**
Ammonium sulfate	200	240	-	-
Calcium nitrate	140	-	280	-
Potassium nitrate	130	-	-	460
Ammonium nitrate	340	-	-	-
Urea	450	-	-	-

[1] Adapted from Frizzone and Botrel (1994); Vitti, Boaretto and Penteado (1994); Sousa *et al.* (2011).

The procedure for performing the flow reading consisted of pressurizing the system, stabilizing the pressure at 150 kPa (+/- 5 kPa) at the beginning of the line, positioning the collectors under the respective drippers with a three-second time lag, and removing the collectors with the same sequence and time lag after 5 min of collection. The gravimetric method was used to determine the volume collected from each emitter. Monitoring the dripper flow rate allowed the average dripper flow rate to be obtained.

After the flow data were tabulated, calculations were performed for the uniformity of water application, coefficient of variation and degree of clogging, according to equations (1) to (4).

$$CUE = 100\left(1 - \frac{S}{\overline{X}}\right) \quad (1)$$

$$CUA = 50\left(\frac{X_{25\%}}{\overline{X}} + \frac{\overline{X}}{X_{12,5\%}}\right) \quad (2)$$

$$CV = \frac{S}{\overline{X}}100 \quad (3)$$

$$\mathrm{GE} = \left(1 - \frac{\mathrm{q_{usado}}}{\mathrm{q_{novo}}}\right)100 \quad (4)$$

where:

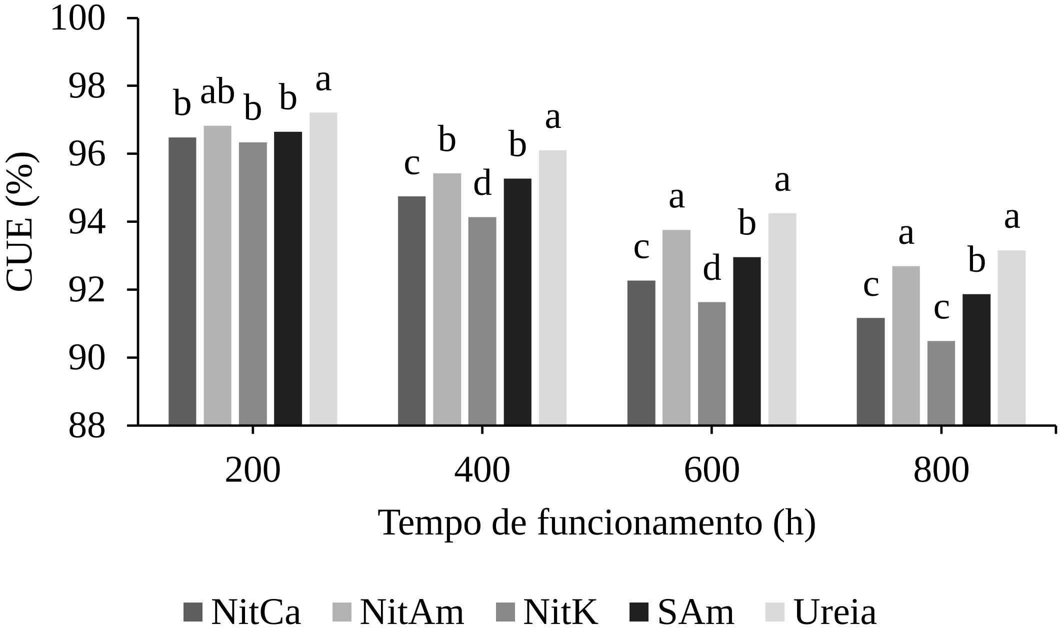
CUE - statistical uniformity coefficient, in %;
CUA - absolute uniformity coefficient, in %;
CV - coefficient of flow variation, %;
GE - degree of clogging, %;
$X_{25\%}$ - average of 25% of the total number of drippers with the lowest flow rates, in L h $^{-1}$; and
$X_{12,5\%}$ - average of 12.5% of the total number of drippers with the highest flow rates, in L h $^{-1}$;
X_i - flow rate of each dripper, in L h $^{-1}$;
$\overline{X}$ - average flow rate of the drippers, in L h $^{-1}$;
S - standard deviation of the flow rate of the drippers used, L h $^{-1}$;
q_{new} - flow rate of the new dripper, L h $^{-1}$;
q_{used} - flow rate of the dripper used, L h $^{-1}$;

The data obtained were subjected to analysis of variance via the F test at the 5% probability level, and in cases of significance, regression analysis was performed for the operating times and for the nitrogen sources. The means were compared with each other via the Tukey test at the 5% probability level via SISVAR® statistical software (Ferreira, 2011).

5 RESULTS AND DISCUSSION

The statistical uniformity coefficient (CUE) at an operating time of 200 h for calcium nitrate (NitCa), potassium nitrate (NitK) and ammonium sulfate (SAm) did not significantly differ (Figure 1). At an operating time of 200 h, urea resulted in CUE values of 0.73, 0.87 and 0.56% for calcium nitrate, potassium nitrate, and ammonium sulfate, respectively.

Figure 1. Statistical uniformity coefficient (CUE) for nitrogen sources (calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea)) and operating times. Means with the same lowercase letter in the same column are not significantly different according to the Tukey test at 5% probability.



Source: Authors (2024).

In addition to environmental factors, the water source and the implementation of fertigation can significantly influence the uniformity of application; thus, there is a need for the periodic maintenance of irrigation systems (Drumond *et al.*, 2006; Kumar; Ashoka, 2020).

The statistical uniformity coefficient (CUE) at the 400 h operating time for ammonium nitrate and ammonium sulfate did not significantly differ. At the 400 h operating time, the highest CUE was also verified when the urea N source was used for fertigation, followed by ammonium nitrate and ammonium sulfate, potassium nitrate, calcium nitrate and potassium nitrate. At the 400 h operating time, the greatest difference in CUE was observed between the urea N source and potassium nitrate, indicating a difference of approximately 2%.

Cunha *et al.* (2014a) reported that, in general, the CUC presented the greatest sensitivity with respect to uniformity, identifying 62.5% of flow disturbances, followed by the CUE, which distinguished approximately 56.25% of the changes that occurred in the flow.

The statistical uniformity coefficient (CUE) at the 600 h operating time for urea and ammonium nitrate did not significantly differ; therefore, the best CUE (>93.75%) was verified for these N sources. At the 600 h operating time, the CUE of the ammonium sulfate N source was 0.69% and 1.33%

greater than the CUE of the calcium nitrate and potassium nitrate N sources, respectively. Raphael *et al.* (2018) reported a lower value of application uniformity, but these were located in the same excellent class, with a uniformity coefficient of 93%.

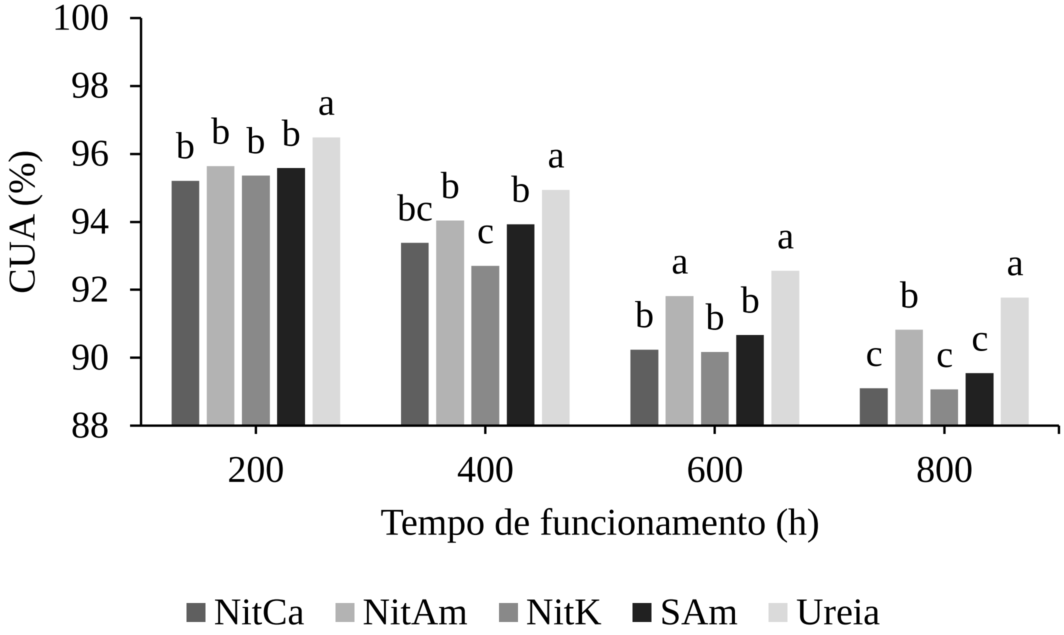
The statistical uniformity coefficient (CUE) at the operating time of 800 h for urea and ammonium nitrate did not significantly differ; therefore, for these N sources, the best CUE was verified (>92.60%), and no significant difference was detected between the N sources of calcium nitrate (NitCa) and potassium nitrate (NitK). At an operating time of 600 h, the CUE of the N source of urea was 2.00, 2.67 and 1.29% greater than the CUE of the N sources of calcium nitrate (NitCa), potassium nitrate (NitK) and ammonium sulfate (SAm), respectively.

The use of irrigation systems with high application efficiency enables better effectiveness of fertigation practices and pesticide application (Nascimento; Feitosa; Soares, 2017).

The N sources of urea and ammonium nitrate provided the best CUE values at nearly all operating times (200, 400, 600 and 800 h), with the highest values of water application uniformity (>90.82%). In general, there was greater nonuniform distribution when potassium nitrate (NitK) was used in fertigation. Dariman *et al.* (2021) reported a uniformity of water application in a drip irrigation system above 90%, which is within the same range obtained in this study.

The absolute uniformity coefficient (AUC) at the 200 h operating time showed practically no significant differences in uniformity between the N sources, thus revealing better values in the AUC, only in relation to the urea N source, which was approximately 1.30, 0.85, 1.13 and 0.91% greater than the N sources of calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK) and ammonium sulfate (SAm), respectively (Figure 2).

Figure 2. Absolute uniformity coefficient (AUC) for nitrogen sources (calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea)) and operating times. Means with the same lowercase letter in the same column are not significantly different according to the Tukey test at 5% probability.



Source: Authors (2024).

The high values of the uniformity coefficient obtained indicate good performance of the drip irrigation system under the application of fertilizers via irrigation water (Geleta, 2019).

During the 400 ha operating period, the urea N source presented a CUA 2.2 3% higher than that observed in the potassium nitrate N source, whereas the CUA during this operating period did not significantly differ between the ammonium nitrate (NitAm) and ammonium sulfate (SAm) N sources.

The joint analysis of uniformity coefficients is essential for evaluating the performance of any irrigation system, avoiding problems such as underestimation or overestimation of the average uniformity value, ensuring a deeper knowledge of the system, and reducing waste and expenses (Cunha *et al.*, 2013; Rodrigues *et al.*, 2013; Alves *et al.*, 2022).

The CUA at the operating time of 600 h for urea and ammonium nitrate did not significantly differ; therefore, the best CUA (>91.80%) was verified for these N sources. Calcium nitrate (NitCa), potassium nitrate (NitK) and ammonium sulfate (SAm) also did not significantly differ, indicating an average distribution uniformity of 90.36%.

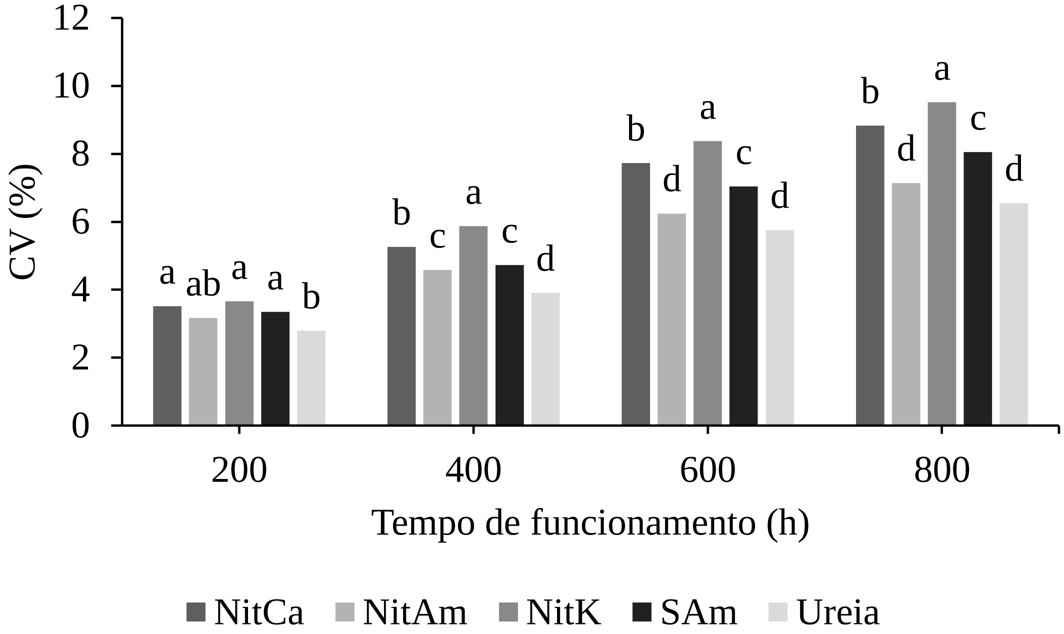
Cunha *et al.* (2014a) reported that the CUA was more sensitive when the dripper was in a superficial condition and presented the greatest sensitivity with respect to uniformity, as it managed to identify more than 60% of flow disturbances.

The CUA values during the 800 h operating time for calcium nitrate (NitCa), potassium nitrate (NitK) and ammonium sulfate (SAm) did not significantly differ, indicating an average distribution uniformity of 89.24%. At the 800 h operating time, the amount of CUA detected in the urea N source was approximately 1.00% greater than the amount of CUA detected in the ammonium nitrate N source.

Solving the problem of low water application uniformity is extremely important because uniformity levels in this range can reduce crop productivity (Contreras *et al.*, 2020).

The coefficients of variation (CVs) at the 200 h operating time for calcium nitrate (NitCa), potassium nitrate (NitK) and ammonium sulfate (SAm) did not significantly differ, with an average CV of 3.51%. At the 200 h operating time, the CV of the urea N source was 0.73, 0.87 and 0.56% lower than the CVs of the calcium nitrate (NitCa), potassium nitrate (NitK) and ammonium sulfate (SAm) N sources, respectively (Figure 3).

Figure 3. Coefficient of variation (CV) for nitrogen sources (calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea)) and operating times. Means with the same lowercase letter in the same column are not significantly different according to the Tukey test at 5% probability.



Source: Authors (2024).

Localized irrigation systems are subject to variations in flow, mainly due to the clogging of drippers, impairing the overall functioning of the irrigation system, which affects its operating characteristics and interferes with distribution uniformity (Batista *et al.*, 2013; Veeranna; Mishra; Patel, 2017).

The coefficients of variation (CVs) at the 400 h operating time for ammonium nitrate and ammonium sulfate did not significantly differ, indicating an average CV of 4.65%. At the 400 h operating time, the CVs for the urea N source were approximately 1.40, 0.70, 2.00 and 0.83% lower than the CVs for the N sources of calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK) and ammonium sulfate (SAm), respectively.

Coefficient of variation values lower than or close to 10% indicate good quality in irrigation system emitters (Cararo, 2004; Alves *et al.,* 2022).

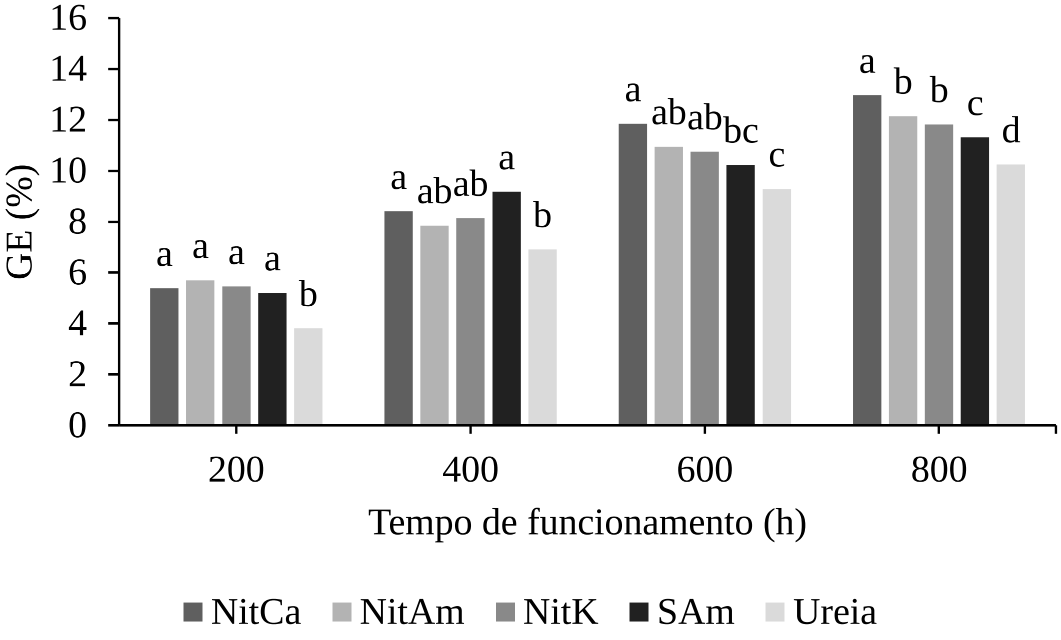
The coefficients of variation (CVs) at an operating time of 600 h for urea and ammonium nitrate did not significantly differ, indicating an average CV of approximately 6.00%. At an operating time of 600 h, the CV of the urea N source was 1.98%, 2.62% and 1.29% lower than the CVs of the calcium nitrate (NitCa), potassium nitrate (NitK) and ammonium sulfate (SAm) N sources, respectively. The same behavior was verified for the CV at an operating time of 800 h, with the lowest CV verified in the urea and ammonium nitrate N sources, among which there was no significant difference, indicating an average CV of 6.84%.

Alves *et al.* (2022) evaluated a localized irrigation system under fertigation and reported that the relative flow, flow variation coefficient and degree of clogging during the initial operation time were 8.44%, 94.40% and 6.86%, respectively.

The degree of clogging (GE) during the 200 h operating time for calcium nitrate

(NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK) and ammonium sulfate (SAm) did not significantly differ, indicating an average CV of approximately 5.50%. At the 200 h operating time, the GEs verified in the urea N source were 1.58, 1.89, 1.65 and 1.40% lower than the GEs verified in the calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK) and ammonium sulfate (SAm) N sources, respectively (Figure 4).

Figure 4. Degree of clogging (GE) for various nitrogen sources (calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea)) and operating times. Means with the same lowercase letter in the same column are not significantly different according to the Tukey test at 5% probability.



Source: Authors (2024).

The uneven application of water in drip irrigation systems due to emitter clogging and flow rate variation has become a major problem, limiting the widespread use of drip irrigation systems (Cunha *et al.*, 2014b; Hakiruwizera *et al.*, 2024).

The degree of clogging (GE) during the 400 h operating time for calcium nitrate (NitCa) and ammonium sulfate (SAm) did not significantly differ, indicating an average CV of approximately 8.80%. At the 400 h operating time, the GEs of the urea N source were 1.50% and 2.27% lower than the GEs of the calcium nitrate (NitCa) and ammonium sulfate (SAm) N sources, respectively. At the 600 h operating time, the amount of GE verified in the urea N source was approximately 2.60% lower than the amount of GE verified in the calcium nitrate (NitCa) N source.

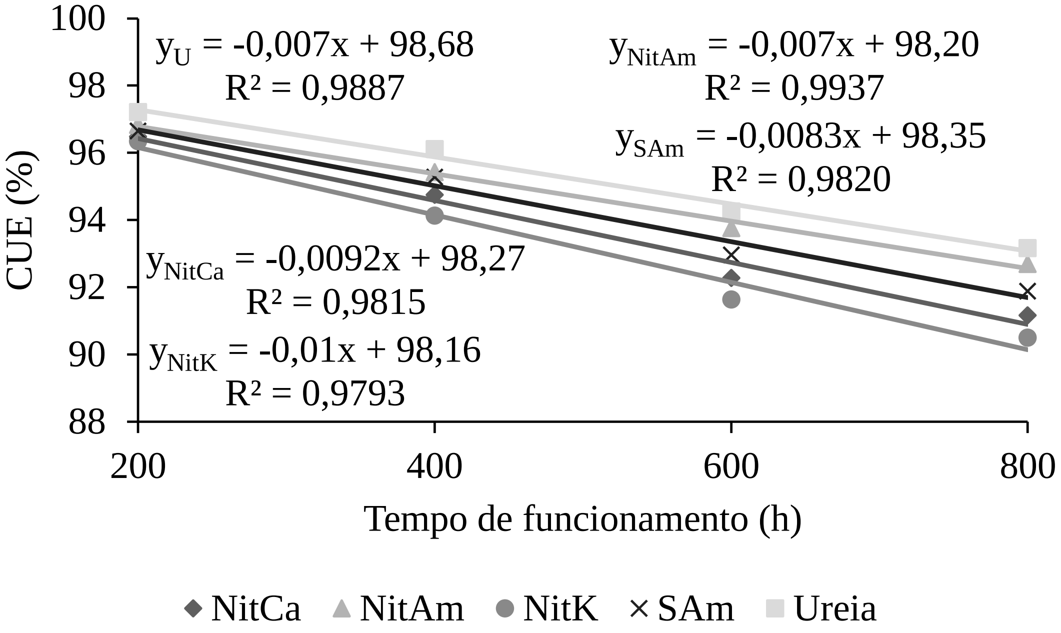
Veeranna, Mishra, and Patel (2017) reported that emitter clogging is a severe obstacle to the widespread application of drip irrigation technology.

The degree of clogging (GE) during the 800 h operating time for ammonium nitrate (NitAm) and potassium nitrate (NitK) did not significantly differ, indicating an average CV of approximately 12%. At the 800 h operating time, the GEs of the urea N source were 2.73, 1.91, 1.58 and 1.07% lower than the GEs of the calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK) and ammonium sulfate (SAm) N sources, respectively.

Clogging can be partial, reducing application uniformity, or total, completely interrupting the functioning of the system, causing serious problems for crops (Cararo, 2004; Kumar; Ashoka, 2020).

The CUE fit a linear model, with an average R2 of 98.50%, indicating that on average, 1.50% of the CUE variations are not explained by the variation in operating time (Figure 5).

Figure 5. Statistical uniformity coefficient (CUE) as a function of operating time for calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea).



Source: Authors (2024).

Compared with the operating times of 200 and 800 h, reductions in CUE of approximately 4.20, 4.20, 4.98, 5.52 and 6.00% were observed when the N sources urea (Urea), ammonium nitrate (NitAm), ammonium sulfate (SAm), calcium nitrate (NitCa) and potassium nitrate (NitK) were used in fertigation, respectively.

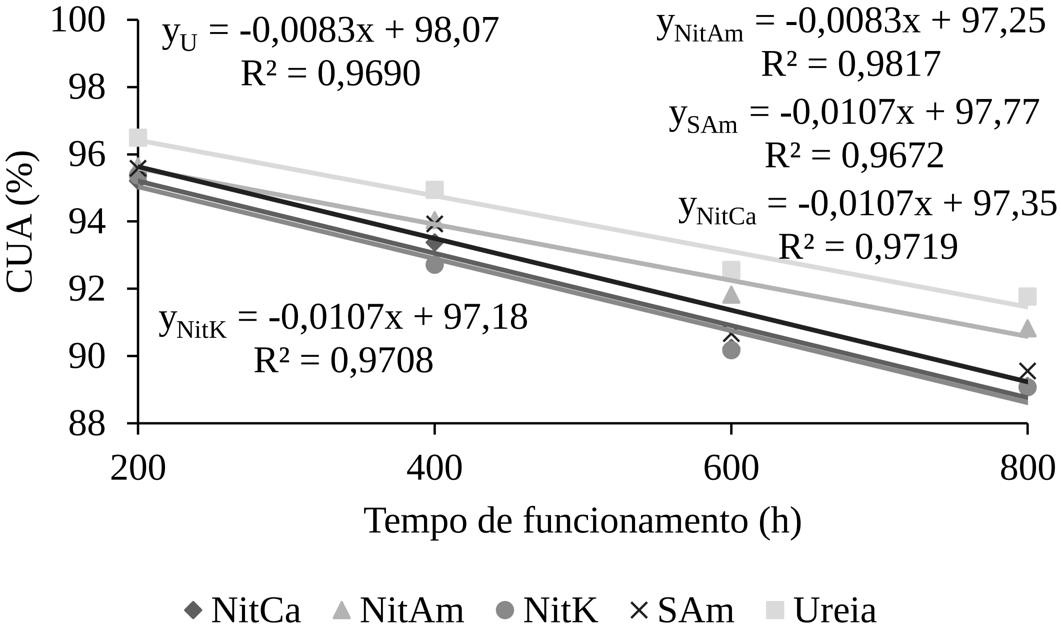
The coefficient of uniformity of water distribution and application efficiency are the main parameters used, as they express the quality of irrigation and are decisive in the operation of these systems (Oliveira; Villas Bôas, 2008; Gultekin *et al.*, 2022).

The CUE for each 200 h increase in operating time decreased by 1.40, 1.40, 1.66, 1.84 and 2.00% when the N sources urea (urea), ammonium nitrate (NitAm), ammonium sulfate (SAm), calcium nitrate (NitCa) and potassium nitrate (NitK) were applied via irrigation water, respectively.

When performing fertigation, Sales and Sánchez-Román (2019) reported that even after some crops, drippers presented values of the Christiansen uniformity coefficient (CUC), distribution uniformity coefficient (CUD) and statistical uniformity coefficient (CUE), which are classified as good and, in most cases, excellent.

The CUA fit a linear model, with an average R2 of 97.21%, indicating that, on average, 2.79% of the CUA variations were not explained by the variation in operating time (Figure 6).

Figure 6. Absolute uniformity coefficient (AUC) as a function of operating time for calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea).



Source: Authors (2024).

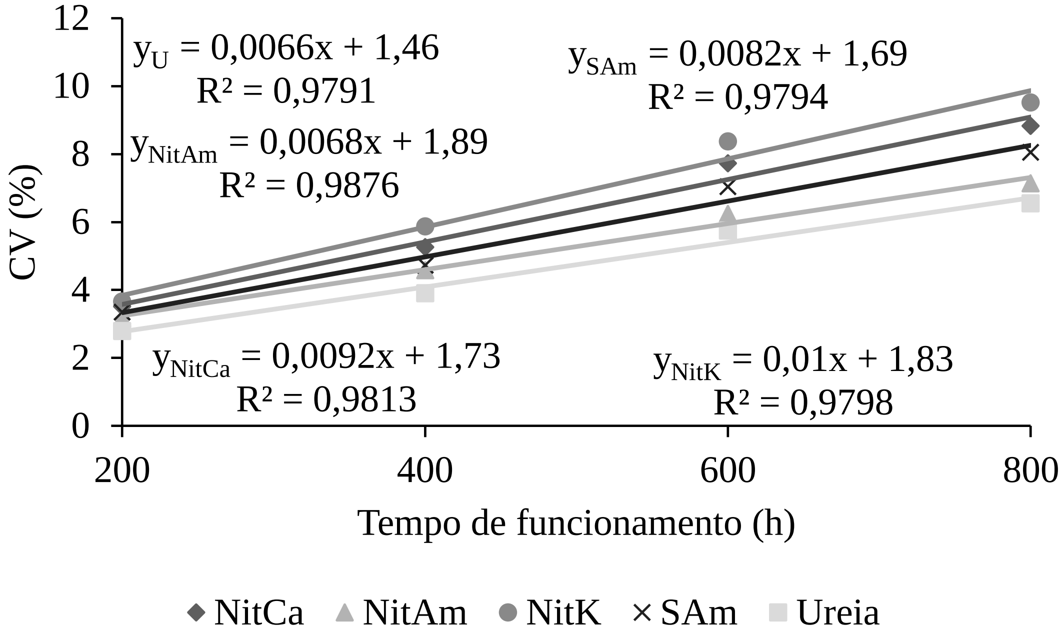
Compared with the operating times of 200 and 800 h, reductions in CUA of approximately 4.98, 5.00, 6.42, 6.40 and 6.42% were observed when the N sources urea (Urea), ammonium nitrate (NitAm), ammonium sulfate (SAm), calcium nitrate (NitCa) and potassium nitrate (NitK) were used in fertigation, respectively.

The uniformity of fertilizer application can be influenced by the variation in the concentration of the solution in the mixing tank since the mixture may not be homogeneous. Furthermore, the main problem that can arise with the application of fertilizer is clogging, which has a high impact on the uniformity of application (Rolston; Miller; Schulbach, 1986; Burt; O'Connor; Ruehr, 1995; Cunha *et al.*, 2014b).

The CUA for each 200 h increase in operating time decreased by 1.66, 1.68, 2.14, 2.12 and 2.14% when the N sources urea (urea), ammonium nitrate (NitAm), ammonium sulfate (SAm), calcium nitrate (NitCa) and potassium nitrate (NitK) were applied via irrigation water, respectively. The probable cause of the decrease in water application uniformity is pressure loss or variation, but more likely, it is related to partial clogging of the emitters by silt and clay, algae or chemical precipitates (Hakiruwizera *et al.*, 2024).

The CV fit a linear model, with an average R^2 of 98.14%, indicating that, on average, 1.86% of the CV variations were not explained by the variation in operating time (Figure 7).

Figure 7. Coefficient of variation (CV) as a function of operating time for calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea).



Source: Authors (2024).

When the operating times of 200 and 800 h were compared, increases in CVs of approximately 3.96, 4.08, 4.92, 5.52 and 6.00% were observed when N sources of urea (urea), ammonium nitrate (NitAm), ammonium sulfate (SAm), calcium nitrate (NitCa) and potassium nitrate (NitK) were used in fertigation, respectively.

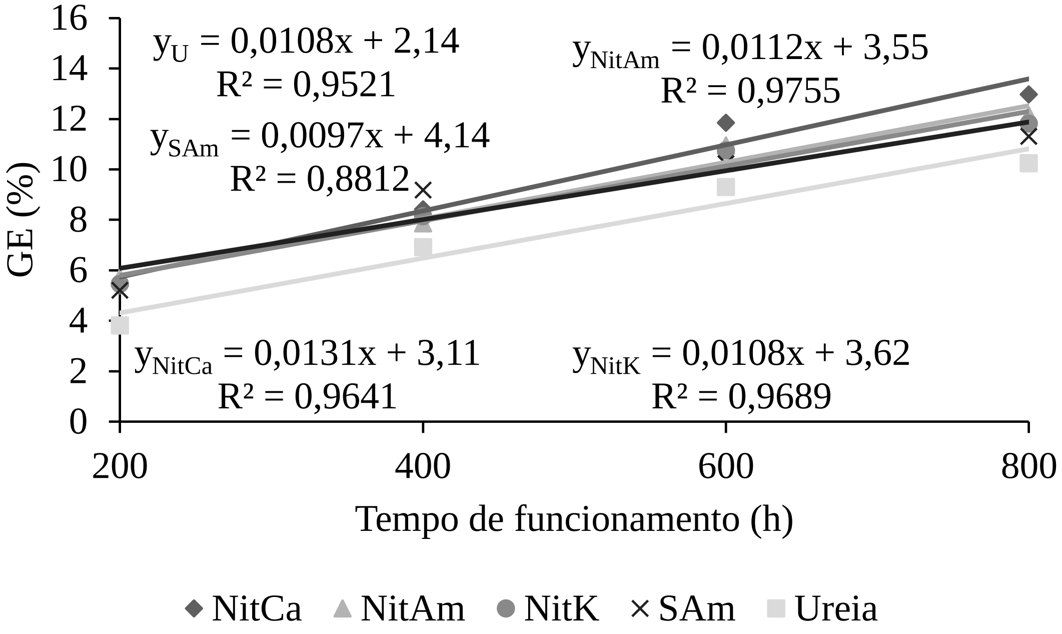
The CV is highly sensitive to highly discrepant values, in this case, zero flow, and is an important parameter for identifying partial and total clogging of emitters (Faria; Coelho; Resende, 2004; Sales; Sánchez-Román, 2019).

The CV for each 200 h increase in operating time increased by 1.32, 1.36, 1.64, 1.84 and 2.00% when N was applied via irrigation water to the N sources urea (urea), ammonium nitrate (NitAm), ammonium sulfate (SAm), calcium nitrate (NitCa) and potassium nitrate (NitK), respectively.

A well-designed localized irrigation system allows for water distribution uniformity above 90%; however, with its intensive use, there is a reduction in distribution uniformity and an increase in flow variation over time (Teixeira, 2006; Contreras *et al.*, 2020).

The GE fit a linear model, with an average R2 of 94.84%, indicating that, on average, 5.16% of the GE variations were not explained by the variation in operating time (Figure 8).

Figure 8. Degree of clogging (GE) as a function of operating time for calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea).



Source: Authors (2024).

Compared with the operating times of 200 and 800 h, increases in the GE of approximately 6.48, 6.72, 5.82, 7.86 and 6.48% were observed when the N sources urea (urea), ammonium nitrate (NitAm), ammonium sulfate (SAm), calcium nitrate (NitCa) and potassium nitrate (NitK) were used in fertigation, respectively. The results obtained regarding the degree of clogging corroborate those obtained by some authors, who attributed the formation of chemical precipitates as the cause of dripper clogging, which consequently reduces the flow of water applied (Nascimento, 2015; Hakiruwizera *et al.*, 2024).

The GE for each 200 h increase in operating time increased by 2.16, 2.24, 1.94, 2.62 and 2.16% when water was applied via irrigation water to the N sources urea (urea), ammonium nitrate (NitAm), ammonium sulfate (SAm), calcium nitrate (NitCa) and potassium nitrate (NitK), respectively.

6 CONCLUSIONS

The maximum nonuniformity of water application for the N sources of calcium nitrate, ammonium nitrate, potassium nitrate, ammonium sulfate and urea was observed at the longest operating time (800 h), indicating a decrease of up to 2.14% for each increase of 200 h in operating time.

The greatest degree of clog among the drippers decreased in the order of N source: calcium nitrate, ammonium nitrate, potassium nitrate, ammonium sulfate and urea.

The greatest flow disturbances are observed in the N sources of potassium nitrate, calcium nitrate and ammonium sulfate, which have coefficients of variation above 8.00%.

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