ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

SUSCEPTIBILIDADE AO ENTUPIMENTO DE EMISSORES EM SISTEMA DE FERTIRRIGAÇÃO SOB APLICAÇÃO DE FONTES DE NUTRIENTES

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1 RESUMO

Objetivou-se avaliar o grau de entupimento de gotejadores submetidos a aplicação de macro e micronutrientes em diferentes tempos de funcionamento. O experimento foi realizado em uma casa de vegetação instalada na área experimental do IFGoiano – Campus Rio Verde. O delineamento experimental utilizado é em blocos ao acaso, analisado em esquema fatorial 3 × 4, com três repetições; sendo o tratamento 1 (molibdato de amônio, cloreto de magnésio e sulfato de amônio), o tratamento 2 (nitrato de cálcio, ácido bórico e sulfato de zinco) e o tratamento 3 (sulfato de cobre, cloreto de manganês e sulfato de ferro) e quatro tempos de funcionamento (200, 400, 600 e 800 h). Foi utilizado um modelo de tubo gotejador com vazão nominal de 2,3 L h^{-1}, diâmetro nominal 16 mm, pressão de operação 100 a 350 kPa e espaçamento entre emissores de 0,5 m. Depois de tabulados os dados de vazão, foram determinados o grau de entupimento, coeficiente de uniformidade estatístico e o coeficiente de uniformidade absoluto. A aplicação de nitrato de cálcio, ácido bórico e sulfato de zinco proporciona a melhor uniformidade e grau de entupimento.

Palavras-chave: obstrução de gotejadores, sulfato de amônio, nitrato de cálcio, uniformidade de aplicação.

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SUSCEPTIBILITY TO CLOGGING OF DRIPPERS IN FERTIRRIGATION SYSTEMS UNDER APPLICATION OF NUTRIENT SOURCES

Recebido em 04/06/2025 e aprovado para publicação em 12/12/2025
DOI: http://dx.doi.org/10.15809/irriga.2025v30p58-69

2 ABSTRACT

The objective of this study was to evaluate the degree of obstruction of drippers subjected to the application of macro- and micronutrients at different operating times. The experiment was carried out in a greenhouse located in the experimental area of the IFGoiano - Rio Verde Campus. The experimental design used a randomized block, analyzed in a 3 × 4 factorial scheme, with three replications: treatment 1 (ammonium molybdate, magnesium chloride and ammonium sulfate), treatment 2 (calcium nitrate, boric acid and zinc sulfate) and treatment 3 (copper sulfate, manganese chloride and iron sulfate) and four operating times (200, 400, 600 and 800 h). A drip tube model with a nominal flow of 2.3 L h $^{-1}$, a nominal diameter of 16 mm, an operating pressure of 100 to 350 kPa and a spacing between emitters of 0.5 m was used. After the flow data were tabulated, the degree of obstruction, coefficient of statistical uniformity and absolute uniformity coefficient were determined. The application of calcium nitrate, boric acid and zinc sulfate provides the best uniformity and degree of obstruction.

Keywords: dripper obstruction, ammonium sulfate, calcium nitrate, uniformity of application.

3 INTRODUCTION

The large amount of water required for irrigation, the decrease in its availability, and the high cost of energy needed for its application have increased interest in the rational use of this resource (Azevedo *et al.*, 1999; Li *et al.*, 2023).

In the design of localized irrigation systems, the variability between drippers must be considered. Another important point is that the system may present flow disturbances over time depending on water quality and irrigation management (Coelho, 2007; Santos *et al.*, 2022). In chemical terms, water quality for irrigation is determined by the composition and concentrations of salts present and dissolved in it, since these can cause chemical precipitation and consequently clogging of drippers (Cavalcante, 2000; Li *et al.*, 2025).

Chemical clogging results from the precipitation of elements in solution in irrigation water and therefore depends mainly on the pH and conductivity of the water. Several chemical elements, including calcium, magnesium, carbonates, phosphates, and iron, can cause this phenomenon. Consequently, the formation of precipitates creates a deposit that evolves and can even modify the water flow area, inducing a variation in the dripper flow rate (Rizk). *et al.*, 2017; Zhangzhong *et al.*, 2019; Petit *et al.*, 2022).

Small variations in the geometry of the water outlet orifices cause significant differences in the flow rate. This can also occur because of fertigation, as this technique can cause a change in water flow, especially at the emitter end that has the first contact with the fertilizers, indicating a gradual deposition of this material inside it and consequently assuming greater importance than flow rate variations resulting from pressure differences along the line (Vermeiren; Jobling, 1980; Botrel, 1984; Cunha *et al.*, 2014a; Shen). *et al.*, 2022).

Drip irrigation systems are therefore extremely susceptible to clogging, and even with a filtration process to retain solid particles, precipitates can form inside the pipes, causing physical clogging (Ribeiro *et al.*, 2018). Clogging can alter the irrigation rate and thus decrease both the efficiency and uniformity of water application in the irrigation system, representing a bottleneck in the durability of the performance of the drip irrigation system (NiNi; Liu; Chen, 2013; Santos *et al.*, 2022). The objective of this study was to evaluate the degree of clogging of drippers subjected to the application of macro- and micronutrients at different operating times.

4 MATERIALS AND METHODS

The experiment was conducted in a greenhouse installed in the experimental area of IFGoiano – Campus Rio Verde. The greenhouse consists of a 150-micron-thick transparent polyethylene plastic film with closed sides and 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 region's climate is classified according to Köppen and Geiger (1928) as Aw (tropical), with rainfall occurring from October to May and drought occurring from June to September. The average annual temperature varies from 20 to 35 °C, and the rainfall varies from 1,500 to 1,800 mm annually.

The experimental design used was a randomized block design, analyzed in a 3 × 4 factorial scheme, with three replications: treatment 1 (ammonium molybdate, magnesium chloride and ammonium sulfate); treatment 2 (calcium nitrate, boric acid and zinc sulfate); treatment 3 (copper sulfate, manganese chloride and iron sulfate); and four operating times (200, 400, 600 and 800 h).

The following quantities were applied via fertigation in treatment 1: 0.12 g 1000 L^{-1} ^{of} ammonium molybdate, 200 g 1000 L^{-1} of ^{magnesium} chloride, and 200 g 1000 L^{-1} ^{of} ammonium sulfate; in treatment 2: 900 g 1000 L^{-1} ^{of} calcium nitrate, 1.9 g 1000 L^{-1} ^{of} boric acid, and 1.15 g 1000 L^{-1} ^{of} zinc sulfate; and in treatment 3: 0.12 g 1000 L^{-1} ^{of} copper sulfate, 4 g 1000 L^{-1} ^{of} manganese chloride, and 400 g 1000 L^{-1} ^{of} iron sulfate. The irrigation system had a filtration system equipped with a 100-mesh disc filter to remove any solid particles that might have entered the system.

A drip irrigation tubing system with a nominal flow rate of 2.3 L $h^{-1,}$ a nominal diameter of 16 mm, an operating pressure of 100 to 350 kPa, an emitter spacing of 0.5 m, and a length of 7 m for each line of drip irrigation tubing was used.

At the entrance of the drip irrigation lines, a pressure tap was installed, allowing the pressure to be checked at each flow measurement and, if necessary, adjusted to the preestablished value. For this purpose, a Bourdon manometer with a reading range of 0–4 kgf $cm^{-2\ \text{was used}}$. Throughout the test period, water temperature readings were taken in the intake reservoir, with the treatments applied at a water temperature in the range of 25 $^{\circ C}$ (25 $^{\circ C}$ ± 1 °C).

The fertilizer injection time was approximately 1 hour to ensure better fertilizer application on the basis of minimal dilution. For fertilizer injection into the irrigation system, a Venturi injector was chosen, which suctioned the fertilizer after it had been dissolved in a 50 L capacity reservoir tank.

The flow rate was read by pressurizing the system, stabilizing the pressure at 150 kPa (+/- 5 kPa) at the beginning of the line, positioning the collectors under their respective drippers with a three-second delay, and removing the collectors with the same sequence and time delay after 5 minutes of collection. The gravimetric method was used to determine the volume collected from each emitter. Monitoring the flow rate of the drippers allowed us to obtain the average flow rate of the drippers.

After the flow rate data were tabulated, calculations were performed for the uniformity of water application and the degree of clogging, according to equations 1 to 3.

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

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

$$\mathrm{GE} = \left(1 - \frac{q_{\mathrm{usado}}}{q_{\mathrm{novo}}}\right)100 \quad (3)$$

In what way:
CUE - statistical uniformity coefficient (Wilcox; Swailes, 1947), in %;
CUA - absolute uniformity coefficient (Keller; Karmeli, 1975), in %;
GE - degree of clogging, %;
$X_{25\%}$ - average of 25% of the total number of drippers, with the lowest flow rates, in L h $^{-1}$;
$X_{12,5\%}$ - 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 $^{-1}$;
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 using the F test at the 5% probability level, and in cases of significance, regression analysis was performed for the operating times, and the means of the fertigation treatments were compared with each other using Tukey's test at the 5% probability level with the SISVAR® statistical software (Ferreira, 2011).

5 RESULTS AND DISCUSSION

The statistical uniformity coefficient (CUE) at the 200 h operating time was not significantly different between treatments 1 and 2 and was 1% greater than that in treatment 3 (Table 1). At the 400 h operating time, the lowest CUE was observed, with differences of 1.8% and 3.6% for treatments 1 and 2, respectively; between treatments 1 and 2, a difference of 1.78% was observed.

Table 1. Statistical uniformity coefficient (CUE) at different operating times.

Treatments	**Operating time (h)**							
	200		**400**		**600**		**800**	
T1	97.32	the	95.32	b	91.77	b	90.36	b
T2	97.85	the	97.10	the	93.13	the	91.90	the
T3	96.34	b	93.53	w	89.57	w	87.97	w

Treatment 1: $^{\text{ammonium}}$ molybdate, magnesium chloride, and ammonium sulfate; Treatment 2: calcium nitrate, boric acid, and zinc sulfate; and Treatment 3: copper sulfate, manganese chloride, and iron sulfate. Means with the same lowercase letter in the column do not indicate a significant difference according to Tukey's test at the 5% probability level. **Source:** Authors (2025).

Generally, CUE values are slightly lower than the Christiansen uniformity coefficient (CUC) over time. This is because CUE provides more rigorous treatment of water distribution problems that occur along the lateral line (Rodrigues *et al.*, 2013; Shen). *et al.*, 2022).

During the 600-hour operating time, treatment 2 resulted in the highest CUE, with differences of 1.4% and 3.6% compared with treatments 1 and 3, respectively; between treatments 1 and 3, a difference of 2.2% was observed. During the 800-hour operating time, compared with treatments 2 and 3, treatment 1 resulted in intermediate CUE, with differences of 1.5% and 2.4%, respectively; between treatments 2 and 3, a difference of 3.9% was observed.

The obstruction of emitters impairs the overall function of the localized irrigation system, affecting its operating characteristics and requiring more frequent maintenance; in addition, clogging reduces the uniformity of the water distribution in localized irrigation systems (Liu; Huang, 2009; Li *et al.*, 2025).

Water uniformity during the 200 h operating time remained consistently above 95%; thus, no significant difference was observed between treatments for uniformity during this operating time (Table 2). At the 400 h operating time, treatment 3 resulted in the lowest CUA, with differences of 2% and 4.3% compared with treatments 1 and 2, respectively, whereas between treatments 1 and 2, a difference of 2.3% was observed.

Table 2. Absolute uniformity coefficient (CUA) at different operating times.

Treatments	**Operating time (h)**							
	200		**400**		**600**		**800**	
T1	96.46	the	93.97	b	89.54	b	87.24	b
T2	97.02	the	96.28	the	91.46	the	89.47	the
T3	95.90	the	91.95	w	86.73	w	85.84	w

Treatment 1: $^{\text{ammonium}}$ molybdate, magnesium chloride, and ammonium sulfate; Treatment 2: calcium nitrate, boric acid, and zinc sulfate; and Treatment 3: copper sulfate, manganese chloride, and iron sulfate. Means with the same lowercase letter in the column do not indicate a significant difference according to Tukey's test at the 5% probability level. **Source:** Authors (2025)

The CUE and CUA decrease similarly to the CUC, indicating a more stable behavior than that observed in the distribution uniformity coefficient (CUD), which showed more significant differences by overvaluing blockages (Cunha *et al.*, 2014b; Cunha *et al.*, 2024).

During the 600-hour operating time, treatment 2 resulted in the highest CUA (cost per unit), with differences of 1.9% and 4.7% compared with treatments 1 and 3, respectively; between treatments 1 and 3, a difference of 2.8% was observed. During the 800-hour operating time, compared with treatments 2 and 3, treatment 1 resulted in intermediate CUA, with differences of 2.2% and 1.4%, respectively; between treatments 2 and 3, a difference of 3.6% was observed.

Despite the launch of self-compensating drippers on the market, the evaluation of localized irrigation systems remains one of the starting points for successful crops, and well-designed and uniform water application systems are fundamental to the fertigation technique, resulting in increased productivity and crop yield (Nakayama; Bucks, 1991; Santos *et al.*, 2022).

The degree of clogging (GE) at an operating time of 200 h did not significantly differ between treatments, with an average GE of 4.3% (Table 3). At an operating time of 400 h, treatment 3 presented the highest GE, indicating differences of 2.3% and 5.5% compared with treatments 1 and 2, respectively, whereas between treatments 1 and 2, a difference of 3.2% was observed.

Table 3. Degree of clogging (GE) at different operating times

Treatments	Operating time (h)							
	200		400		600		800	
T1	4.28	the	7.32	b	11.14	the	14.51	b
T2	3.90	the	4.16	the	10.17	the	11.88	the
T3	4.67	the	9.62	w	15.60	w	16.39	w

Treatment 1: ammonium molybdate, magnesium chloride, and ammonium sulfate; Treatment 2: calcium nitrate, boric acid, and zinc sulfate; and Treatment 3: copper sulfate, manganese chloride, and iron sulfate. Means with the same lowercase letter in the column do not indicate a significant difference according to Tukey's test at the 5% probability level. **Source:** Authors (2025)

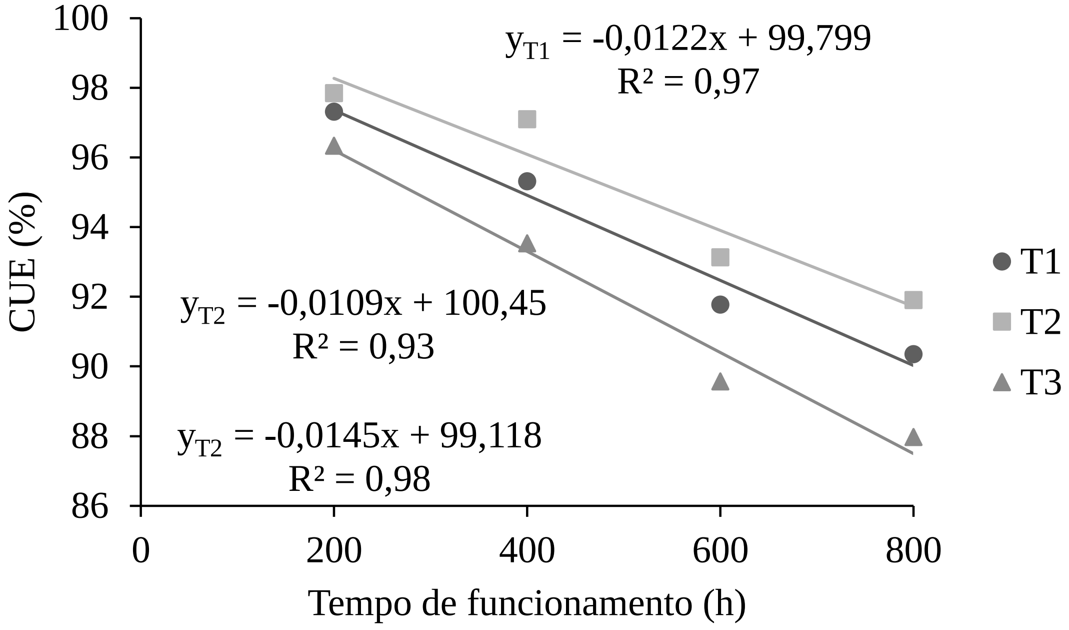
High levels of iron and manganese are the main causes of emitter blockage in localized irrigation systems; thus, the clogging of emitters impairs the overall function of the irrigation system (Busato). *et al.*, 2012; Cunha *et al.*, 2014b; Li *et al.*, 2023).

During the 600-hour operating period, compared with treatment 3, treatments 1 and 2 resulted in the lowest energy efficiency (GE), indicating a difference of 5.4%. During the 800-hour operating period, compared with treatments 2 and 3, treatment 1 resulted in intermediate GEs, with differences of 2.6% and 1.9%, respectively, whereas between treatments 2 and 3, a difference of 4.5% was observed.

For irrigation to be efficient, a localized irrigation system must have a highly uniform water distribution, as this affects water use efficiency and therefore crop yield and the quality of the final product (Dantas Neto *et al.*, 2013; Araújo Neto *et al.*, 2015; Cunha *et al.*, 2024).

The CUE (cost of use) as a function of operating time fit the linear model for treatments 1, 2, and 3, with R^2 $^{\text{above}}$ 93% (Figure 1). The behavior of application uniformity for each treatment as a function of operating time is shown in Figure 1. Considering operating times of 200 and 800 h, reductions in CUE of approximately 7.3%, 6.5%, and 8.7% were observed when treatments 1, 2, and 3 were used in fertigation, respectively.

Figure 1. Statistical uniformity coefficient (CUE) as a function of operating time for treatment 1 (ammonium molybdate, magnesium chloride and ammonium sulfate), treatment 2 (calcium nitrate, boric acid and zinc sulfate) and treatment 3 (copper sulfate, manganese chloride and iron sulfate)



Source: Authors (2025)

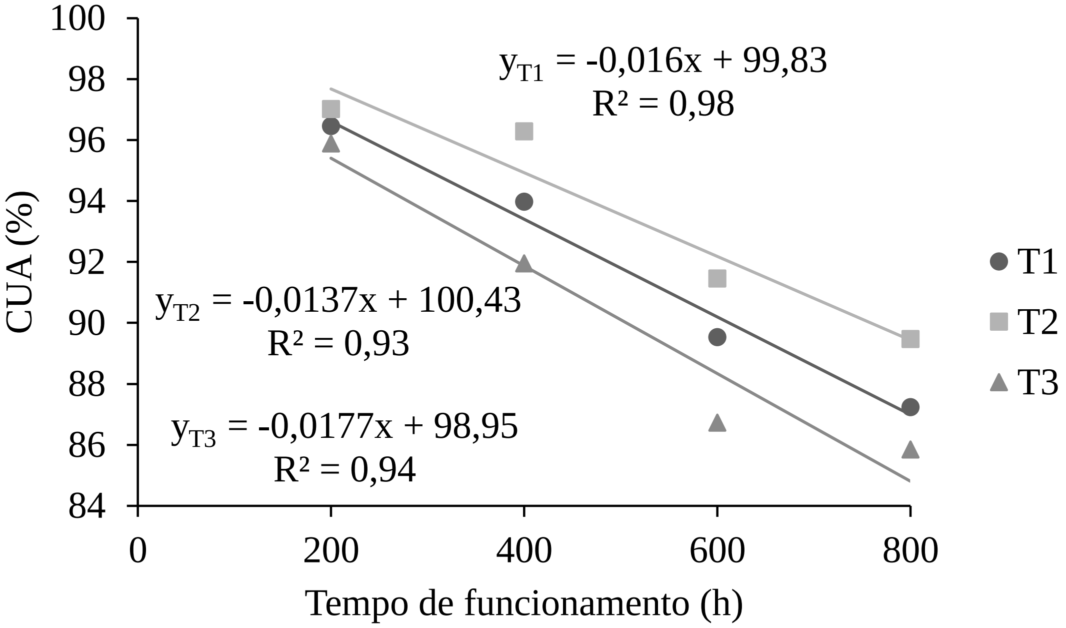
The uniformity of water distribution is essential for assessing localized irrigation systems, both in the initial design phase and in postimplementation performance (Favetta; Botrel, 2001; Li *et al.*, 2025).

The coefficient of use of energy (CUE) decreased by 2.4%, 2.2%, and 2.9% for each 200-hour increase in operating time when irrigation water was applied in treatment 1, treatment 2, and treatment 3, respectively.

Several factors can compromise the uniformity of water application in localized irrigation systems, most notably partial and total clogging and flow imbalance of emitters caused by mineral or organic particles present in the water (Vieira *et al.*, 2004; Cunha *et al.*, 2024).

The coefficient of use of water (CUA) as a function of operating time fit the linear model for treatments 1, 2, and 3, with R² values reaching 98% (Figure 2). The behavior of application uniformity for each treatment as a function of operating time is shown in Figure 2. Considering operating times of 200 and 800 h, reductions in CUA of approximately 9.60, 8.22, and 10.62% were observed when treatments 1, 2, and 3 were used in fertigation, respectively.

Figure 2. Absolute uniformity coefficient (CUA) as a function of operating time for treatment 1 (ammonium molybdate, magnesium chloride and ammonium sulfate), treatment 2 (calcium nitrate, boric acid and zinc sulfate) and treatment 3 (copper sulfate, manganese chloride and iron sulfate)



Source: Authors (2025)

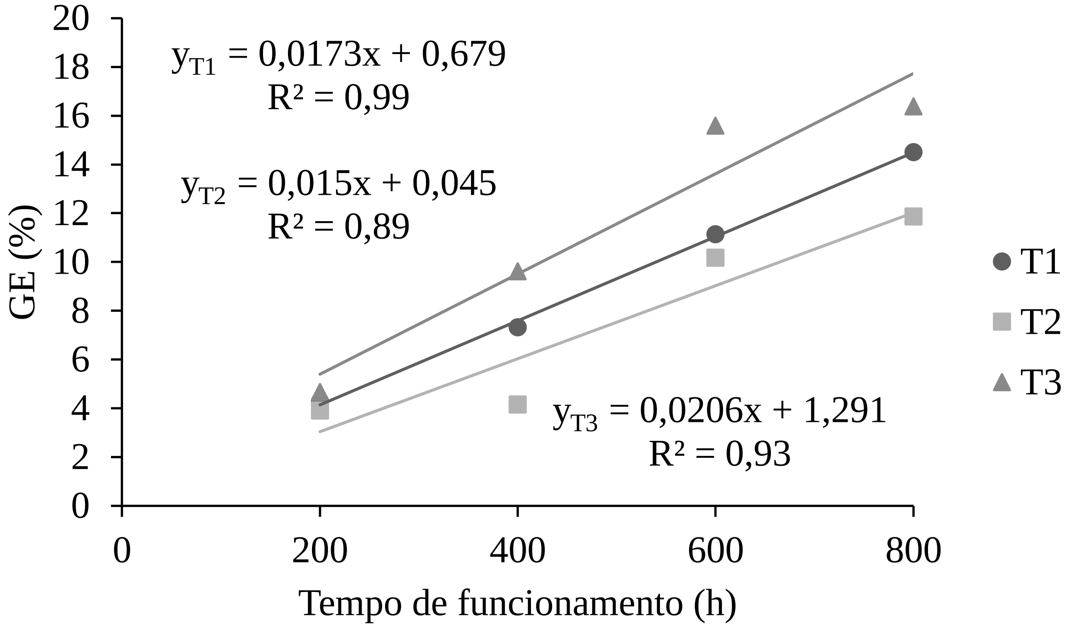
When the uniformity obtained both in the presence and absence of fertigation is considered good, the irrigation system generally functions adequately even under fertigation (Cunha *et al.*, 2014a; Shen). *et al.*, 2022).

The coefficient of use of water (CUA) decreased by 3.2%, 2.7%, and 3.5% for each 200-hour increase in operating time when irrigation water was applied in treatment 1, treatment 2, and treatment 3, respectively.

An analysis of uniformity coefficients is essential for evaluating the performance of any localized irrigation system; therefore, for irrigation to be efficient, the system must exhibit high uniformity in terms of water application (Rodrigues *et al.*, 2013; Santos *et al.*, 2022).

The GE (generic efficiency) as a function of operating time fit the linear model for treatments 1, 2, and 3, with $R^{2\ \text{above}}$ 89% (Figure 3). The behavior of the degree of emitter clogging for each treatment as a function of operating time is shown in Figure 3. Considering operating times of 200 and 800 h, increases in the GE of approximately 10.40, 9.00, and 12.40% are observed when treatments 1, 2, and 3 are used in fertigation, respectively.

Figure 3. Degree of clogging (GE) as a function of operating time for treatment 1 (ammonium molybdate, magnesium chloride and ammonium sulfate), treatment 2 (calcium nitrate, boric acid and zinc sulfate) and treatment 3 (copper sulfate, manganese chloride and iron sulfate)



Source: Authors (2025)

There is a greater propensity for partial and total clogging when fertigation is present; furthermore, the difference between fertigation with and without fertigation over the operating time can be greater than 5.00% (Cunha *et al.*, 2014a; Li *et al.*, 2023).

The GE (generator efficiency) for each 200-hour increase in operating time increased by 3.50%, 3.00%, and 4.10% when irrigation water was applied in treatment 1, treatment 2, and treatment 3, respectively.

6 CONCLUSIONS

The application of calcium nitrate, boric acid, and zinc sulfate provides greater uniformity in terms of water application and a lower degree of clogging.

Fertigation with ammonium molybdate, magnesium chloride, and ammonium sulfate influences the uniformity of distribution and the degree of clogging.

During operating times of 200 to 800 hours, increases in the degree of clogging of up to 12.40% are observed when ammonium molybdate, magnesium chloride and ammonium sulfate (Treatment 1), calcium nitrate, boric acid and zinc sulfate (Treatment 2) and copper sulfate, manganese chloride and iron sulfate (Treatment 3) are used in the fertigation process.

7 ACKNOWLEDGEMENTS

The authors thank the Ministry of Science, Technology and Innovation (MCTI), the Financing Agency for Studies and Projects (Finep), the National Council for Scientific and Technological Development (CNPq), the Coordination for the Improvement of Higher Education Personnel (Capes), the Goiás State Research Support Foundation (FAPEG), the Center of Excellence in Exponential Agriculture

(CEAGRE), and the Federal Institute of Goiás (IF Goiano) for their financial and structural support in this study.

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