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AVALIAÇÃO DA FUNCIONALIDADE E RENDIMENTO DE GOTEJADORES IRRIGANDO COM ÁGUA ENRIQUECIDA COM MACRO E MICRONUTRIENTES

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1 RESUMO

A uniformidade de distribuição é uma informação importante para a avaliação de sistemas de irrigação localizada, como para o acompanhamento do desempenho da irrigação. Objetivou-se avaliar desempenho de gotejadores submetido a aplicação de água com presença de macro e micronutrientes. 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 os coeficientes de uniformidade e o coeficiente de variação de vazão. Os distúrbios de vazão dos gotejadores são mais acentuados quando sob aplicação de sulfato de cobre, cloreto de manganês e sulfato de ferro.

Palavras-chave: ácido bórico, sulfato de zinco, vazão

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EVALUATION OF THE FUNCTIONALITY AND PERFORMANCE OF DRIPPERS IRRIGATING WITH WATER ENRICHED WITH MACRO AND MICRONUTRIENTS

2 ABSTRACT

Distribution uniformity is important information for evaluating localized irrigation systems, as well as for monitoring irrigation performance. The objective of this study was to evaluate the

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performance of drippers submitted to the application of water with presence of macro and micronutrients. The experiment was realized in a greenhouse located in the experimental area of the IFGoiano - Rio Verde Campus. The experimental design used randomized block, analyzed in factorial scheme 3 × 4, with three replications; with treatment 1 (ammonium molybdate, magnesium chloride and ammonium sulfate), treatment 2 (calcium nitrate, boric acid and zinc sulphate) and treatment 3 (copper sulphate, manganese chloride and iron sulphate) and four operating times (200, 400, 600 and 800 h). Used a drip tube model with nominal flow of 2.3 L h^{-1}, nominal diameter 16 mm, operating pressure 100 to 350 kPa and spacing between emitters of 0.5 m. After tabulating the flow data, were determined the coefficient of uniformity and the coefficient of variation of flow. The flow disturbances of the drippers are more pronounced when under the application of copper sulphate, manganese chloride and iron sulphate.

Keywords: boric acid, zinc sulphate, flow

3 INTRODUCTION

Irrigated agriculture represents a great strategy for obtaining global food production. In addition, more than half of the world's population depends on food produced in irrigated areas. Notably, irrigation has several benefits, such as social and ecological aspects, improving the efficiency of the use of water and energy, and maintaining favorable soil moisture conditions for good plant development (Paz; Teodoro; Mendonça, 2000; Mantovani; Bernardo; Palaretti, 2009; Andrade *et al.*, 2022). Localized irrigation systems are a response to the need to look for new irrigation systems that are efficient, reduce the consumption of water resources and, above all, minimize water scarcity problems (Faria; Coelho; Resende, 2004; Lopes *et al.*, 2021).

To evaluate the ideal functioning of the localized irrigation system, an evaluation index called water application uniformity is used. This index characterizes an irrigation system on the basis of the difference in water volume applied by the emitters along the lateral lines. Notably, water application uniformity affects crop yield and is considered one of the most important factors in the dimensioning and operation of irrigation systems (Barreto Filho *et al.*, 2000; Elhussiny *et al.*, 2023).

The uniformity of water distribution in localized irrigation systems can be assessed via methodologies that involve characterizing the flow rate of the drippers in the lateral lines within an irrigated plot (Keller; Karmeli, 1975; Cunha *et al.*, 2018).

Distribution uniformity is important for evaluating localized irrigation systems, both in the design phase and in monitoring performance after implementation, as it is a relevant step for obtaining information related to the efficiency of water use in the irrigation system and the actual functioning of the system (Favetta; Botrel, 2001; Mantovani; Bernardo; Palaretti, 2009; Lopes *et al.*, 2020).

The quality of the water used in irrigated agriculture is of fundamental importance for the performance of irrigation systems and their components, as it can cause serious problems ranging from salts in the soil profile to the clogging of pipes and emitters by the deposition of inorganic particles, resulting in uneven irrigation and a decrease in efficiency (Frigo *et al.*, 2006; Blum, 2003; Mohamed *et al.*, 2019). Therefore, the objective of this study was to evaluate the performance of drippers subjected to the application of water in the presence of macro- and micronutrients.

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

A dripper pipe with a nominal flow rate of 2.3 L h $^{-1}$, nominal diameter of 16 mm, operating pressure of 100 to 350 kPa and spacing between emitters of 0.5 m and the length of each dripper pipe line of 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 approximately 1 h to ensure better fertilizer application, which was based on minimum dilution. To inject the fertilizers into the irrigation system, a Venturi injector was chosen, which sucked the fertilizer after it was dissolved in a reservoir box with a capacity of 50 L.

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 distribution uniformity coefficient (CUD), Hart uniformity coefficient (CUH), HSPA standard efficiency (UDH) and flow variation coefficient (CV), according to equations (1) to (4).

$$CUD = 100\left(\frac{X_{25\%}}{\overline{\overline{X}}}\right) \tag{1}$$

$$CUH = 100\left\{1 - \sqrt{\frac{2}{\pi}\left(\frac{S}{\overline{\overline{X}}}\right)}\right\} \tag{2}$$

$$UDH = 100\left(1 - 1{,}27\frac{S}{\overline{X}}\right) \quad (3)$$

$$CV = \frac{S}{\overline{X}}100 \quad (4)$$

where:
CUD - coefficient of distribution uniformity, in %;
CUH - Hart's coefficient of uniformity, in %;
UDH - HSPA standard efficiency, in %;
CV – coefficient of flow variation, %;
$X_{25\%}$ - average of 25% of the total number of drippers with the lowest 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 $^{-1}$;

The data obtained were subjected to analysis of variance via the F test at the 5% probability level. In cases of significance, regression analysis was performed for the operating times, and the means of the fertigation treatments 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 distribution uniformity coefficient (CUD) at the 200 h operating time did not significantly differ among the treatments in terms of uniformity (Table 1). Considering the initial operating time of nutrient fertigation in a localized drip irrigation system, there was no significant difference in distribution uniformity (Magalhães; Texeira; Ferreyra, 1996; Andrade *et al.*, 2022).

Table 1. Coefficient of distribution uniformity (CUD) at different operating times

Treatments	Operating time (h)							
	200		400		600		800	
T1	96.71	the	93.90	b	89.30	b	88.24	b
T2	97.31	the	96.51	the	91.44	the	90.04	the
T3	96.47	the	92.72	w	87.19	w	86.97	w

[1] 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 same column are not significantly different according to the Tukey test at 5% probability.

At the operating time of 400 h, treatment 3 presented the lowest CUD, indicating differences of 1.2 and 3.8% for treatments 1 and 2, respectively; between treatments 1 and 2, a difference of 2.6% was observed.

The water distribution of an irrigation system mainly depends on the operating time, water quality, spacing, type, size, internal design and working pressure of the emitters (Zhu *et al.*, 2015; Araújo *et al.*, 2020).

For the operating time of 600 h, treatment 2 presented the highest CUD, indicating differences of 2.1 and 4.2% for treatments 1 and 3, respectively; between treatments 1 and 3, a difference of 2.1% was observed. For the operating time of 800 h, treatment 1 presented an intermediate CUD, indicating differences of 1.8 and 1.3% for treatments 2 and 3, respectively; between treatments 2 and 3, a difference of 3.1% was observed.

Fertigation, variations in operating time and pressure losses have important effects on the variation in dripper flow during irrigation because the operating pressure loads of drippers are low (Frizzone *et al.*, 2012; Lopes *et al.*, 2020).

The Hart uniformity coefficient (CUH) at the 200 h operating time was significantly different among all the treatments, with an emphasis on Treatment 2, where the highest uniformity was observed, at approximately 88% (Table 2). At the 400 h operating time, treatment 3 presented the lowest CUH, indicating differences of 3 and 6.7% for treatments 1 and 2, respectively; between treatments 1 and 2, a difference of 3.7% was observed.

Table 2. Hart coefficient of uniformity (CUH) at different operating times

Treatments	Operating time (h)			
	200	400	600	800
T1	86.93 b	82.74 b	77.12 b	75.22 b
T2	88.30 the	86.42 the	79.10 the	77.30 the
T3	84.73 w	79.71 w	74.24 w	72.33 w

[1] 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 same column are not significantly different according to the Tukey test at 5% probability.

The uniformity of the distribution of the irrigation system has an effect on crop yield and is considered one of the most important factors in the operation of irrigation systems (Bernardo; Soares; Mantovani, 2006; Elhussiny *et al.*, 2023).

For the operating time of 600 h, treatment 2 presented the highest CUH, indicating differences of 1.9 and 4.9% for treatments 1 and 3, respectively; between treatments 1 and 3, a difference of 2.9% was observed.

For the operating time of 800 h, treatment 1 presented an intermediate CUH, indicating differences of 2.1 and 2.9% for treatments 2 and 3, respectively; between treatments 2 and 3, a difference of 4.97% was observed.

Typically, reduced uniformity values result in increased energy and water consumption, in addition to large nutrient losses due to surface runoff, deep percolation and, at the same time, water deficit (Martins *et al.*, 2011; Andrade *et al.*, 2022).

The standard efficiency of HSPA (UDH) at an operating time of 200 h did not significantly differ between treatments 1 and 2 and was 1.2% greater than that of treatment 3 (Table 3). At the operating time of 400 h, treatment 3 presented the lowest UDH, indicating differences of 2.3 and 4.5% for treatments 1 and 2, respectively; between treatments 1 and 2, a difference of 2.27% was observed.

Table 3. Standard efficiency of the HSPA (UDH) at different operating times

Treatments	Operating time (h)							
	200		400		600		800	
T1	96.59	the	94.05	b	89.55	b	87.75	b
T2	97.27	the	96.32	the	91.28	the	89.72	the
T3	95.35	b	91.79	w	86.76	w	84.72	w

[1] 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 same column are not significantly different according to the Tukey test at 5% probability.

Among the various factors that affect the distribution uniformity of an irrigation system, special attention must be given to working pressure, operating time and fertigation (Li; Bai; Yan, 2015; Araújo *et al.*, 2020).

For the operating time of 600 h, treatment 2 presented the highest UDH, indicating differences of 1.7 and 4.5% for treatments 1 and 3, respectively; between treatments 1 and 3, a difference of 2.8% was observed.

Cunha *et al.* (2014a) reported that the water application uniformity results of the HSPA standard efficiency method (UDH) and the distribution uniformity coefficient (CUD) demonstrated greater variation throughout the tests.

At the operating time of 800 h, treatment 1 presented an intermediate UDH, indicating differences of 1.9 and 3% for treatments 2 and 3, respectively; between treatments 2 and 3, a difference of 5% was observed.

The flow rate variation coefficient (CV) at the 200 h operating time did not significantly differ among the treatments, with an average CV of 2.8% (Table 4). For the 400 h operating time, treatment 3 presented the highest CV, with differences of 1.79 and 3.57% for treatments 1 and 2, respectively; between treatments 1 and 2, a difference of 1.78% was observed.

Table 4. Flow rate variation coefficient (CV) at different operating times

Treatments	Operating time (h)							
	200		400		600		800	
T1	2.68	the	4.68	b	8.23	b	9.64	b
T2	2.15	the	2.90	the	6.87	the	8.10	the
T3	3.66	the	6.47	w	10.43	w	12.03	w

[1] 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 same column are not significantly different according to the Tukey test at 5% probability.

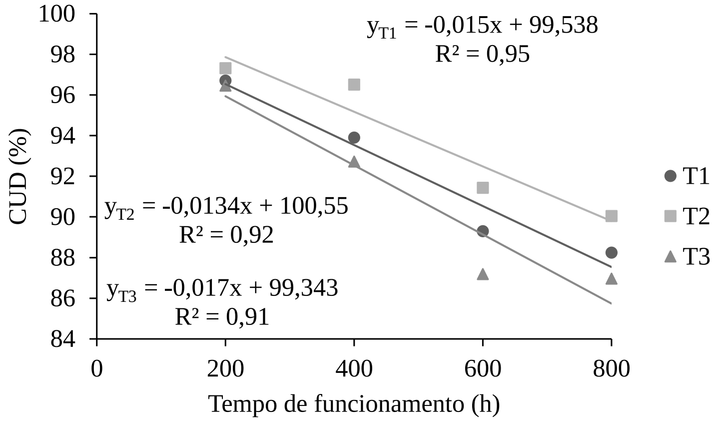
To avoid harming the uniformity of water distribution, the flow variation must be less than 10% throughout the irrigation system (Keller; Karmeli, 1975; Lopes *et al.*, 2021).

For the operating time of 600 h, treatment 2 presented the lowest CV, with differences of 1.36 and 3.56% for treatments 1 and 3, respectively; between treatments 1 and 3, a difference of 2.2% was observed. For the operating time of 800 h, treatment 1 presented an intermediate CV, indicating differences of 1.55 and 2.39% for treatments 2 and 3, respectively; between treatments 2 and 3, a difference of 3.93% was observed.

When a drip irrigation system is used, there is a cumulative increase in the variation in its flow rate, which affects its uniformity (Silva *et al.*, 2015; Mohamed *et al.*, 2019).

The UDC as a function of operating time conformed to the linear model for treatments 1, 2 and 3, with R2 above 91% (Figure 1). Figure 1 shows the behavior of application uniformity for each treatment as a function of operating time. Taking into account operating times of 200 and 800 h, reductions in UDC of approximately 9, 8 and 10.2% were observed when treatments 1, 2 and 3 were used in fertigation, respectively.

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

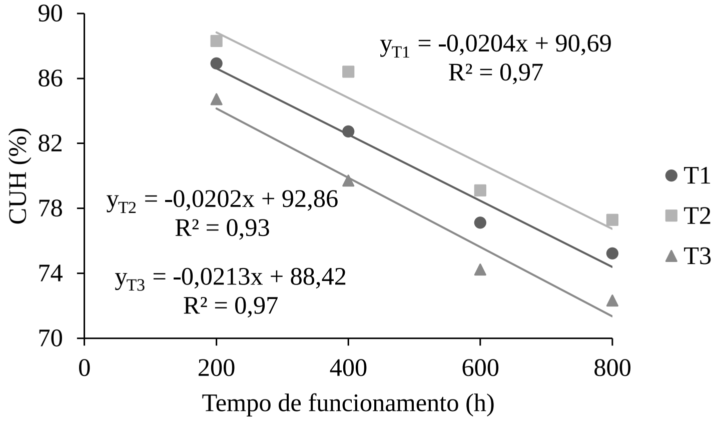


Some authors consider CUD to be the most rigorous for field evaluation of irrigation systems. However, even though CUD is the most rigorous method, it does not adequately identify flow disturbances (Keller; Karmeli, 1974; Cunha *et al.*, 2014b).

The CUD for each 200-h increase in operating time decreased by 3, 2.7, and 3.4% when irrigation water was applied to 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), respectively. In areas under fertigation with different hydraulic loads, there are marked variations in system pressure, causing flow differences that reduce uniformity (Lima *et al.*, 2003; Lopes *et al.*, 2020).

The CUH as a function of the operating time conformed to the linear model for treatments 1, 2 and 3, with R ^{2} values of up to 97% (Figure 2). Figure 2 shows the behavior of the application uniformity for each treatment as a function of the operating time. Taking into account operating times of 200 and 800 h, reductions in the CUH of approximately 12.2, 12.1 and 12.8% were observed when treatments 1, 2 and 3 were used in fertigation, respectively.

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



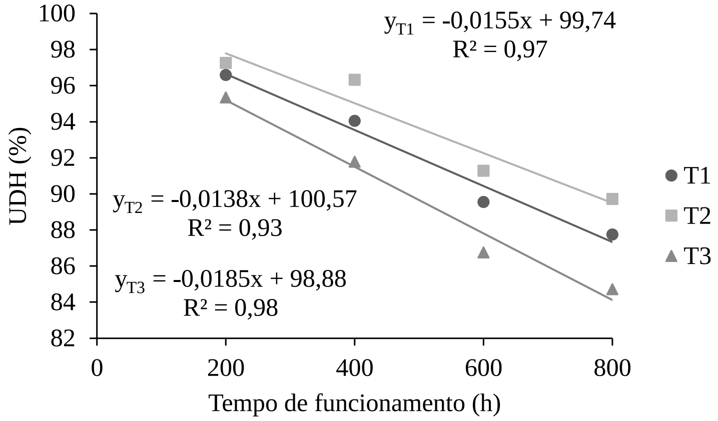
Knowledge of the performance of an irrigation system, especially regarding the uniformity of the distribution of the applied water layer, is essential for making decisions that allow the rational use of water, energy and fertilizers (Colombo *et al.*, 2015; Araújo *et al.*, 2020).

The CUH for each 200 h increase in operating time decreased by 4.1, 4 and 4.3% when irrigation water was applied to Treatments 1 (ammonium molybdate, magnesium chloride and ammonium sulfate), 2 (calcium nitrate, boric acid and zinc sulfate) and 3 (copper sulfate, manganese chloride and iron sulfate), respectively.

Irrigation projects conducted via drip irrigation should present uniformity coefficients above 90%, which is recommended to obtain a good spatial distribution of water and consequently better uniformity in crops (Bernardo; Soares; Mantovani, 2006; Mohamed *et al.*, 2019).

The UDH as a function of operating time conformed to the linear model for treatments 1, 2 and 3, with $R^{2 \text{ values}}$ of up to 98% (Figure 3). Figure 3 shows the behavior of the standard efficiency of the HSPA for each treatment as a function of operating time. Taking into account operating times of 200 and 800 h, reductions in the UDH of approximately 9.3, 8.3 and 11.1% were observed when treatments 1, 2 and 3 were used in fertigation, respectively.

Figure 3. Standard HSPA efficiency 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).

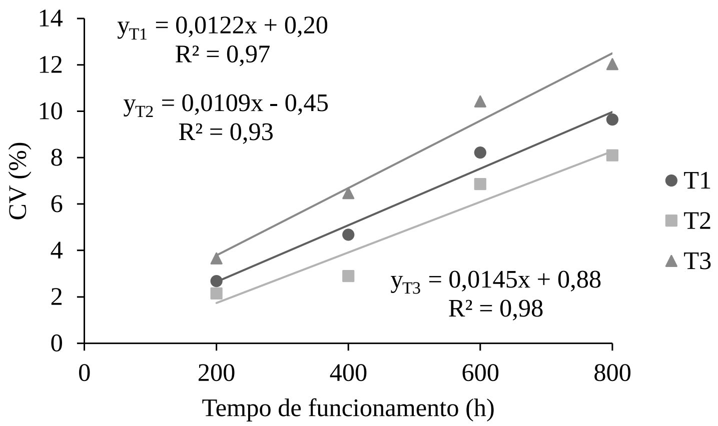


The CUD is most commonly used in the evaluation, as it allows a more restricted measurement, giving greater weight to plants that receive less water. In this sense, the UDH could be more interesting, as it is more restricted and presents better discrimination in a wide variety of flows (López *et al.*, 1992; Frizzone; Dourado Neto, 2003; Cunha *et al.*, 2014a).

The HDU for each 200-h increase in operating time decreased by 3.1, 2.8, and 3.7% when irrigation water was applied to 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), respectively. Shorter operating times and better water quality are vital to ensure adequate irrigation efficiency since such variables can have major impacts on the application and distribution of water and nutrients (Faria *et al.*, 2016).

The CV as a function of operating time conformed to the linear model for treatments 1, 2 and 3, with $^{R2\ values}$ above 93% (Figure 4). Figure 4 shows the behavior of the flow rate variation coefficient for each treatment according to the operating time. Taking into account the operating times of 200 and 800 h, increases in the CV of approximately 7.32, 6.54 and 8.7% were observed when treatments 1, 2 and 3 were used in fertigation, respectively.

Figure 4. Coefficient of variation as a function of operating time for Treatments 1 (ammonium molybdate, magnesium chloride and ammonium sulfate), 2 (calcium nitrate, boric acid and zinc sulfate) and 3 (copper sulfate, manganese chloride and iron sulfate).



The emitters under fertigation conditions cause damage to the emitters only from the point of view of their construction quality, affecting the CVq, with no impediment in the labyrinth structure that would harm the flow (Dalri *et al.*, 2014; Elhussiny *et al.*, 2023).

The CV for each 200 h increase in operating time demonstrated increases of 2.44, 2.18 and 2.9% when irrigation water was applied to Treatments 1 (ammonium molybdate, magnesium chloride and ammonium sulfate), 2 (calcium nitrate, boric acid and zinc sulfate) and 3 (copper sulfate, manganese chloride and iron sulfate), respectively.

6 CONCLUSIONS

Flow disturbances in drippers are more pronounced when copper sulfate, manganese chloride and iron sulfate are applied.

The best flow rate variation coefficients occur when calcium nitrate, boric acid and zinc sulfate are used in fertigation.

The efficiency of drippers is less influenced by the application of calcium nitrate, boric acid and zinc sulfate.

Hart's uniformity coefficient and standard efficiency of HSPA due to fertigation with ammonium molybdate, magnesium chloride and ammonium sulfate indicate intermediate reduction.

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