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EFICIÊNCIA E DESEMPENHO DE UM SISTEMA DE IRRIGAÇÃO POR GOTEJAMENTO SOB EFEITO DE FERTIRRIGAÇÃO COM FONTES DE NITROGÊNIO

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1 RESUMO

Os sistemas de irrigação por gotejamento podem apresentar alterações na vazão em decorrência de problema relacionados a obstrução de emissores e podem ocorrer geralmente com maior contundência quando aplica-se via água de irrigação fertilizantes. Objetivou-se avaliar a influência da fertirrigação com fontes de nitrogênio em um sistema de irrigação localizada por gotejamento. 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 5 × 6, 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 seis tempos de funcionamento (100, 200, 300, 400, 500 e 600 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, foram determinadas a vazão, a vazão relativa, o coeficiente de uniformidade de Hart e a eficiência padrão da HSPA. O desempenho dos gotejadores é principalmente afetado pela aplicação de nitrato de potássio.

Palavras-chave: ureia, sulfato de amônio, uniformidade, obstrução.

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EFFICIENCY AND PERFORMANCE OF AN DRIP IRRIGATION SYSTEMS UNDER THE EFFECT OF FERTIGATION WITH NITROGEN SOURCES

2 ABSTRACT

Drip irrigation systems may experience changes in flow due to problems related to emitter obstructions, which can generally occur more severely when fertilizers are applied via irrigation water. The objective of this study was to evaluate the influence of fertigation with nitrogen sources in a drip irrigation system. The experiment was performed in a greenhouse located in

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the experimental area of the IFGoiano - Rio Verde Campus. The experimental design used was a randomized block design with a 5 × 6 factorial scheme and three replications. The treatment consisted of five sources of N (potassium nitrate, ammonium sulfate, calcium nitrate, ammonium nitrate and urea) and six operating times (100, 200, 300, 400, 500 and 600 h). A drip tube model with a nominal flow 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 data were tabulated, the flow, relative flow, Hart uniformity coefficient and HSPA standard efficiency were determined. The performance of drippers is affected mainly by the application of potassium nitrate.

Keywords: urea, ammonium sulfate, uniformity, obstruction.

3 INTRODUCTION

One of the irrigation systems undergoing notable expansion is the drip irrigation system, which offers advantages such as water and energy savings, with the possibility of fertigation (SOUSA *et al.*, 2011; AVELINO NETO; SANDRI; SILVA, 2019).

This method has been widely used because of its characteristics of small flow and high-frequency applications, application of fertilizers via irrigation water, and high efficiency, enabling efficient control of the irrigation depth (BERNARDO; SOARES; MANTOVANI, 2008; MELO *et al.*, 2019). However, drip irrigation systems may present changes in flow due to problems related to obstruction of emitters, which is due to the small holes for water passage, and can generally occur with greater force when fertilizers are applied via irrigation water, which can form precipitates, causing system nonuniformity, variation in irrigation efficiency and flow disturbances (BARROS *et al.*, 2009; BUSATO; SOARES, 2010; CUNHA *et al.*, 2016).

Changes in flow are related to the obstruction process, whose main culprit is water quality, since the problem does not affect all drippers equally and is also dependent on the manufacturing coefficient of variation (RIBEIRO; COELHO; TEIXEIRA, 2010; ALVES *et al.*, 2020). The increase or decrease in flow can be caused either by partial or total clogging of the emitters, which are generally related to the decrease in flow; however, in some models, the opposite may occur (CUNHA *et al.*, 2013; TAMBO; THEBALDI; LIMA, 2020).

The nonuniformity of water application causes the system to apply water to a fraction of the area with excess water, which is lost through percolation and carries some of the nutrients present in the application zone and another fraction in deficit, in which the infiltrated water is stored in the root zone but in a quantity lower than the needs of the plant (VIEIRA *et al.*, 2020). Therefore, to evaluate the conditions under which a drip irrigation system operates, performance parameters, such as the flow rate, water application uniformity, water application efficiency, percentage of the area adequately irrigated and irrigation time (ANDRADE *et al.*, 2021), must be defined on the basis of field evaluations.

One of the main parameters used in the evaluation of an irrigation system is the uniformity of water application over the irrigated area, which is associated with irrigation efficiency, since the uniformity of water application distribution by the emitters has been a limiting factor in achieving efficient management of the use of applied water; therefore, studies aimed at increasing the efficiency of water use have become fundamental (FRIZZONE *et al.*, 2012; OLIVEIRA, 2014; ZAGO *et al.*, 2022).

The aim of this study was to evaluate the influence of fertigation with nitrogen sources in a localized drip irrigation system.

4 MATERIALS AND METHODS

The experiment was carried out in a greenhouse installed in the experimental area of IFGoiano – Campus Rio Verde. The greenhouse consisted of a transparent polyethylene plastic film cover (150 microns) and closed sides, with a shade screen 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 rain from October to May and drought from June to September. The average annual temperature varies from 20 to 35 °C, and the amount of rainfall varies from 1,500 to 1,800 mm annually.

The experimental 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 six operating times (100, 200, 300, 400, 500 and 600 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) and 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 flow rate, relative flow rate, Hart uniformity coefficient and standard HSPA efficiency, according to equations (1) to (4).

$$q = \frac{P}{1000\,t\,d}\,60 \qquad (1)$$

$$Q_r = \frac{Q_{x,y}}{Q_i} \qquad (2)$$

$$CUH = 100\left\{1 - \sqrt{\frac{2}{\pi}}\left(\frac{S}{\overline{X}}\right)\right\} \qquad (3)$$

$$UDH = 100\left(1 - 1{,}27\,\frac{S}{\overline{X}}\right) \qquad (4)$$

where:

q – dripper flow rate, L h $^{-1}$;
Q $_r$ – relative flow, %;
CUH - Hart's coefficient of uniformity, in %;
UDH - HSPA standard efficiency, in %;
Q $_{x,y}$ – flow rate of an emitter x on an irrigation day y, L h $^{-1}$;
Q $_i$ – flow rate of this emitter on the first day of irrigation, L h $^{-1}$;
P – weight of collected water, g;
t – collection time, min;
d – density of the water used in the test, g L $^{-1}$;
$\overline{X}$ - average flow rate of the drippers, in L h $^{-1}$;
S - standard deviation of flow data, in 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

Table 2 shows the values of the average flow rates of the emitters for the N sources during the operating times.

Table 2. Flow rates for nitrogen sources and operating times

Sources of N [1]	**Operating time (h)**											
	100		**200**		**300**		**400**		**500**		**600**	
NitCa	1.99	a	1.97	b	1.94	a	1.90	bc	1.86	c	1.83	c
NitAm	1.98	a	1.96	b	1.93	a	1.91	ab	1.90	a	1.85	bc
NitK	2.00	a	1.96	b	1.93	a	1.91	b	1.88	bc	1.85	b
SAm	1.99	a	1.97	b	1.93	a	1.89	c	1.88	abc	1.86	ab
Ureia	1.99	a	2.00	a	1.93	a	1.93	a	1.89	ab	1.88	a

[1] Calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea). Means with the same lowercase letter in the same column are not significantly different according to the Tukey test at 5% probability.

At operating times of 100 and 300 h, there was no significant difference in the average flow rate among the N sources of calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea), whereas at an operating time of 200 h, the highest average flow rate value was obtained in the presence of urea, which was higher than those of the other sources.

The average flow rate of emitters can be considered a good parameter for evaluating changes in the proper functioning of emitters, which may be due to partial and total clogging problems or other problems (MÉLO, 2007; CUNHA *et al.*, 2014; AVELINO NETO; SANDRI; SILVA, 2019).

At the final operating time (600 h), the highest flow value was observed in the urea N source, with an intermediate value in potassium nitrate (NitK) and the lowest flow value in calcium nitrate (NitCa) (Table 2). Low water distribution uniformity rates can cause irregular plant growth, productivity losses, and other problems related to soil degradation (CUNHA *et al.*, 2008; SILVA *et al.*, 2021b).

For the relative flow rate, as for the average flow rate, no differences were observed between the N sources at operating times of 100 and 300 h. At an operating time of 200 h, the highest relative flow rate was observed for the urea N source, with a value of approximately 96% (Table 3).

Table 3. Relative flow rate (RF) for nitrogen sources and operating times

N sources	**Operating time (h)**											
	100		**200**		**300**		**400**		**500**		**600**	
NitCa	96.25	the	94.61	b	93.51	the	91.59	bc	89.74	b	88.15	w
NitAm	95.54	the	94.30	b	93.08	the	92.15	ab	91.28	a	89.05	bc
NitK	96.28	a	94.54	b	92.94	a	91.86	bc	90.27	ab	89.25	b
SAm	95.86	a	94.79	b	93.08	a	90.82	c	90.61	ab	89.77	ab
Ureia	95.85	the	96.19	the	93.09	the	93.09	the	90.96	the	90.71	the

[1] Calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea). Means with the same lowercase letter in the same column are not significantly different according to the Tukey test at 5% probability.

The lowest relative flow rate was observed under fertigation with ammonium sulfate (SAm) at an operating time of 400 h; at an operating time of 500 h, differences in the relative flow rate were observed between the N sources, indicating a maximum difference of 1.5%, which was observed between the N sources of calcium nitrate (NitCa) and ammonium nitrate (NitAm).

Generally, variations in the average flow and relative flow values can be observed after each weekly reading, and from one week to the next, the average flow and relative flow may present low and high values, respectively (TEIXEIRA *et al.*, 2014; TAMBO; THEBALDI; LIMA, 2020).

At an operating time of 600 h, the highest relative flow values in decreasing order were as follows: urea, ammonium sulfate (SAm), potassium nitrate (NitK), ammonium nitrate (NitAm) and calcium nitrate (NitCa) (Table 3). Evaluating the conditions of pressure, flow, relative flow and applied water layers is always necessary for ensuring good uniformity of water application (SILVA; SILVA, 2005; SILVA *et al.*, 2021a).

Water uniformity during the 100 h operating time ranged from 86--89%, with an emphasis on fertigation with urea, which presented the highest Hart uniformity coefficient (CUH); for CUH, ammonium sulfate (SAm) and ammonium nitrate (NitAm) did not significantly differ (Table 4).

Table 4. Hart coefficient of uniformity (CUH) for nitrogen sources and operating time

Sources of N [1]	Operating time (h)											
	100		200		300		400		500		600	
NitCa	87.34	bc	85,02	bc	83,66	bc	81,71	c	80,60	c	77,82	c
NitAm	88,11	b	85,78	ab	84,23	b	82,92	b	81,64	ab	80,08	a
NitK	86,53	c	84,74	c	83,02	c	80,67	d	79,23	d	76,92	c
SAm	87,51	b	85,40	bc	84,18	b	82,64	bc	80,94	bc	78,83	b
Ureia	89,11	a	86,69	a	85,44	a	84,28	a	82,11	a	80,89	a

[1] Calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea). Means with the same lowercase letter in the same column are not significantly different according to the Tukey test at 5% probability.

Inadequate uniformity of water distribution in irrigation systems results in excess water in part of the cultivation area and shortages, reducing the availability of water for crops and increasing production costs (NASCIMENTO; FEITOSA; SOARES, 2017).

At operating times of 200 and 300 ha, fertigation with urea resulted in the best CUH values; in contrast, the application of potassium nitrate (NitK) via irrigation water resulted in the lowest CUH values. The analysis of uniformity coefficients allows more restricted measurements, avoiding excessive or a lack of water for the crop (FRIZZONE; DOURADO NETO, 2003; MELO *et al.*, 2019).

At operating times of 400 and 500 ha, urea fertigation also presented the highest CUH values, whereas calcium nitrate (NitCa) and potassium nitrate (NitK) had the lowest uniformity values, close to 80%. Improvements in these uniformity values can be achieved by adopting management practices, such as more careful periodic cleaning of the filtration system, enabling greater pressure at the emission points, reducing dripper clogging and cleaning of the lateral lines (BONOMO, 1999; AVELINO NETO; SANDRI; SILVA, 2019; MELO *et al.*, 2019).

The highest CUH values during the 600 h operating time, in decreasing order, were as follows: urea and ammonium nitrate (NitAm), which did not significantly differ from each other; ammonium sulfate (SAm), calcium nitrate (NitCa) and potassium nitrate (NitK), the latter two of which were also the same (Table 4). Silva Júnior *et al.* (2017) emphasized that one of the recommended criteria for sizing localized irrigation systems is based on the desired emission uniformity in the operational unit, assuming that the uniform application of water also generates an adequate application of nutrients and uniform production.

At the 100 ha operating time, the standard efficiency of HSPA (UDH) was 97.6% and 96.4% for fertigation with urea and potassium nitrate (NitK), respectively, indicating a difference of 1.2% (Table 5).

Table 5. Standard HSPA efficiency (UDH) for nitrogen sources and operating time

Sources of N [1]	**Operating time (h)**											
	100		**200**		**300**		**400**		**500**		**600**	
NitCa	96.80	bc	95.52	b	94.67	bc	93.32	c	92.49	c	90,18	c
NitAm	97,18	ab	95.97	ab	95.04	b	94,18	b	93.27	ab	92.08	a
NitK	96.38	c	95.35	b	94.24	c	92.54	d	91.38	d	89.37	d
SAm	96.89	bc	95.75	b	95.01	b	93.99	b	92.75	bc	91.05	b
Ureia	97.63	a	96.46	a	95.77	a	95.05	a	93.62	a	92.70	a

[1] Calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea). Means with the same lowercase letter in the same column are not significantly different according to the Tukey test at 5% probability.

The UDH was the same for the N sources ammonium sulfate (SAm), potassium nitrate (NitK), ammonium nitrate (NitAm) and calcium nitrate (NitCa) at an operating time of 200 h. The lowest UDH at operating times of 300 and 400 h occurred when potassium nitrate (NitK) was applied to the irrigation water, with values of 94 and 92.5%, respectively; ammonium nitrate (NitAm) and ammonium sulfate (SAm) exhibited the same uniformity at this operating time.

The decrease in the uniformity of the water distribution over time between the first and fourth stages may indicate a tendency for drippers to become clogged (RIBEIRO; PATERNIANI, 2013; ZAGO *et al.*, 2022).

At the final operating times (500 and 600 h), the application of urea was the N source that least influenced uniformity, followed by ammonium nitrate (NitAm), ammonium sulfate (SAm), calcium nitrate (NitCa) and potassium nitrate (NitK) (Table 5).

The uniformity of water application is a fundamental tool for evaluating the performance and maintenance of localized irrigation systems, both in the sizing phase and in monitoring performance after implementation, providing better use of water and inputs, consequently increasing crop productivity and the economic return for the farmer (AVELINO NETO; SANDRI; SILVA, 2019).

The average flow rate conformed to a linear model, with R2 above 95%, indicating that at most 4.78% of the variation in the average flow rate was not explained by the variation in operating time (Figure 1).

Figure 1. Flow rate as a function of operating time for calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea).

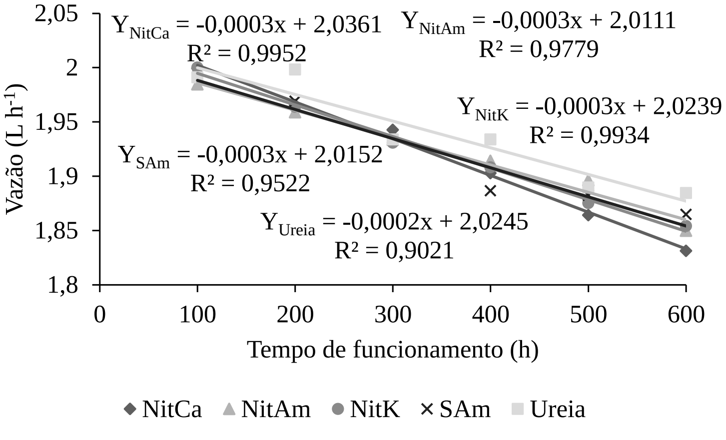

Figure 1 shows the behavior of the average flow rate for each N source as a function of the operating time. Compared with the operating times of 100 and 600 h, reductions in the average flow rates of approximately 8.4, 6.8, 7.3, 6.3 and 5.7% were observed when the N sources calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea) were used in fertigation, respectively. Other studies also reported the same behavior in most dripper models, where the flow rate decreased, as it presented problems with clogging (SOUZA; CORDEIRO; COSTA, 2006; ALVES *et al.*, 2020).

Several factors can interfere with the performance of the irrigation system, the main ones being the clogging of the emitters, the oscillation of pressure in the network and hydraulic failures in sizing and operation (CARMO *et al.*, 2016).

The relative flow rate as a function of operating time conformed to a linear model for calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea), with $^{\text{R2 values}}$ above 90% (Figure 2).

Figure 2. Relative flow rate (QR) as a function of operating time for calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea).

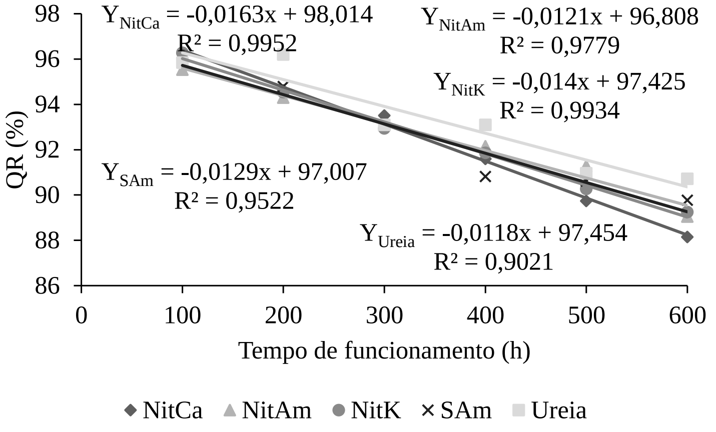

Figure 2 shows the behavior of the relative flow rate for each N source as a function of the operating time. Taking into account the operating times of 100 and 600 h, reductions in the relative flow rates of approximately 8.1, 6.5, 7, 6.1 and 5.1% were observed when the N sources calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea) were used in fertigation, respectively.

Vieira *et al.* (2020) reported that a localized irrigation system under intense use presented a CUC value of approximately 88%, which occurred because of the greater variations in flow in the last emitters evaluated, indicating that its performance is compromised by the absence of cleaning practices in the system.

The flow rate relative to each 100-h increase in operating time decreased by 1.63, 1.21, 1.4, 1.29, and 1.18% when the N sources calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm), and urea (urea), respectively, were applied via irrigation water (Figure 2). High uniformity coefficients and adequate flow rates are recommended to obtain a good spatial distribution of water and, consequently, better uniformity in crops (BERNARDO; SOARES; MANTOVANI, 2008; SILVA *et al.*, 2021a).

The CUH as a function of operating time was fitted with a linear model for calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea), with $^{R2\ values}$ greater than 98.8% (Figure 3).

Figure 3. Hart coefficient of uniformity (CUH) as a function of operating time for calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea).

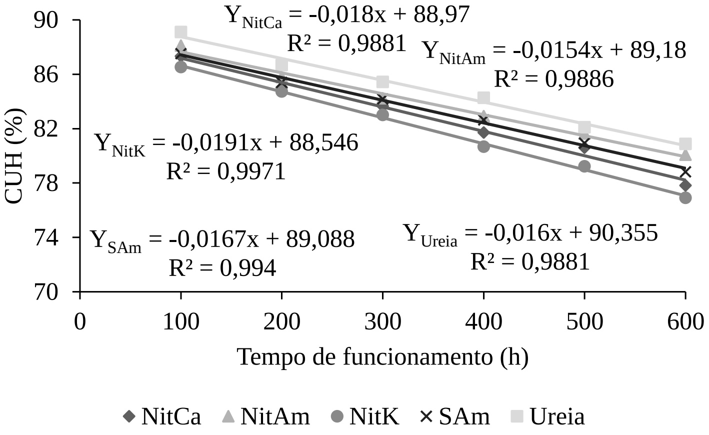

Figure 3 shows the Hart uniformity coefficient for each N source as a function of operating time. At operating times of 100 and 600 h, reductions in the CUH of approximately 9.5, 8, 9.6, 8.7 and 8.2% were observed when the N sources calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea) were used in fertigation, respectively.

For the correct assessment of distribution uniformity, it is important to use more than one coefficient, one of which may be the CUH, as it presents a greater distinction of results (CUNHA *et al.*, 2013; ALVES *et al.*, 2020).

The CUH for each 100-h increase in operating time decreased by 1.8, 1.54, 1.91, 1.67, and 1.6% when the N sources calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm), and urea (urea), respectively, were applied via irrigation water (Figure 3). Reduced uniformity values increase production costs because of increased water and energy consumption, greater nutrient loss, and water deficit in a significant proportion of the irrigated area (PAULINO *et al.*, 2009; SILVA *et al.*, 2021b).

The UDH fit a linear model, with R2 above 97.6%, indicating that at most 2.4% of the variations in the UDH are not explained by the variation in operating time (Figure 4).

Figure 4. Standard HSPA efficiency (UDH) as a function of operating time for calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea).

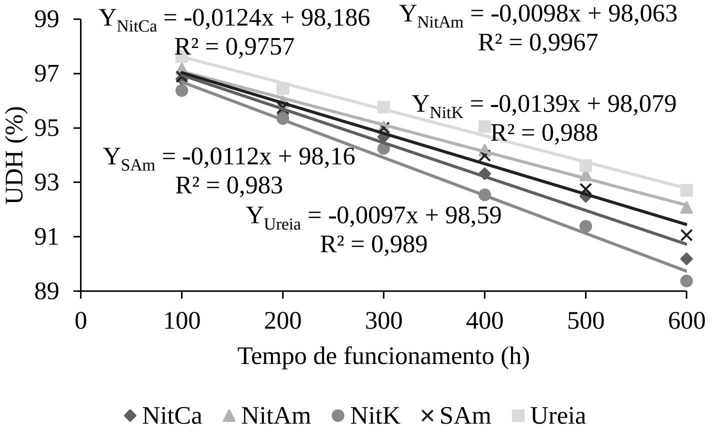

Figure 4 shows the behavior of application uniformity for each N source as a function of operating time. Compared with operating times of 100 and 600 h, reductions in the UDH of approximately 6.6, 5.1, 7, 5.8 and 4.9% were observed when the N sources calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm) and urea (urea) were used in fertigation, respectively.

Uniformity coefficient values lower than 90% in localized irrigation systems can only be accepted if rainfall has a significant value during cultivation or if the reduction in system costs due to the reduction in uniformity compensates for the decrease in revenue due to the reduction in crop production (DANTAS NETO *et al.*, 2013; SILVA *et al.*, 2021a).

The UDH for each 100-h increase in operating time decreased by 1.24, 0.98, 1.39, 1.12, and 0.97% when the N sources calcium nitrate (NitCa), ammonium nitrate (NitAm), potassium nitrate (NitK), ammonium sulfate (SAm), and urea (urea), respectively, were applied via irrigation water (Figure 4). Typically, lower water application uniformity values result in higher energy and water consumption, in addition to large nutrient losses due to surface runoff, deep percolation, and simultaneous water deficit (MARTINS *et al.*, 2011; SILVA *et al.*, 2021b).

6 CONCLUSIONS

The relative flow rate at all operating times (100, 200, 300, 400, 500 and 600 h) was greater than 90% only when urea was used for fertigation.

The average flow rate and relative flow rate are more significantly reduced when calcium nitrate and ammonium nitrate are used as N sources.

The performance of drippers is affected mainly by the application of potassium nitrate.

The highest Hart uniformity coefficient and HSPA standard efficiency are obtained when fertigation is performed with urea and ammonium nitrate N sources.

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