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Original Article

Emitter clogging and distribution uniformity in nitrogen fertigation[1]

Fertirrigação com nitrogênio no entupimento e na uniformidade de distribuição de emissores

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HIGHLIGHTS:
Fertigation with nitrogen sources changes the water application uniformity in drip irrigation system.
Nitrogen application via fertigation causes partial clogging of emitters.
Fertigation and operation time affect the performance of irrigation system.

ABSTRACT: Despite highly efficient, the main limitation of using drip irrigation for fertigation with nitrogen (N) fertilizers is the sensitivity of emitters to clogging by contaminants. The objective in this study was to assess the effect of different sources of N fertilizer and different operation times on water distribution uniformity and emitter clogging using a localized surface drip irrigation system. A randomized block experimental design with three replicates was used, in a 5 × 6 factorial arrangement consisting of five N sources (potassium nitrate, ammonium sulfate, calcium nitrate, ammonium nitrate, and urea) and six operation times (100, 200, 300, 400, 500, and 600 hours). The same nitrogen (N) rate applied in all treatments was equivalent to 100 kg ha^{-1}. The drip tubing used had 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. The variables evaluated were: statistical uniformity coefficient, absolute uniformity coefficient, and degree of clogging. The best absolute and statistical uniformity coefficients were found when using urea and ammonium nitrate for fertigation, mainly at the longest operation times, which presented the best water application uniformity (>91.72%).

Key words: urea, potassium nitrate, ammonium sulfate, calcium nitrate

RESUMO: Apesar da elevada eficiência, a principal limitação dos sistemas de irrigação localizada para uso em fertirrigação com fertilizantes nitrogenados é a sensibilidade de obstrução dos emissores por contaminantes. O objetivo deste trabalho foi avaliar o efeito de fontes de adubos nitrogenados em diferentes tempos de funcionamentos na uniformidade de distribuição de água e no entupimento de emissores em um sistema de irrigação localizada por gotejamento superficial. O delineamento experimental utilizado foi em blocos ao acaso, no 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 aplicada uma dose de nitrogênio igual para todos os tratamentos, equivalente a uma recomendação de 100 kg ha^{-1} de N. 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. As variáveis avaliadas foram o coeficiente de uniformidade estatístico, coeficiente de uniformidade absoluto e o grau de entupimento. Os melhores coeficiente de uniformidade absoluto e estatístico foram encontrados na fertirrigação com ureia e nitrato de amônio, principalmente nos tempos de funcionamento finais, onde foram verificados os melhores valores de uniformidade de aplicação de água (>91,72%).

Palavras-chave: ureia, nitrato de potássio, sulfato de amônio, nitrato de cálcio

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Introduction

Considering current conditions, the future of irrigation will involve increases in crop yield and profitability through improvements in application uniformity and efficiency in the use of water, energy, and inputs, using sustainable management practices that respect the environment (Mantovani et al., 2013; Reis et al., 2021). Water distribution uniformity is essential for assessing the performance and maintenance of localized irrigation systems and improving the utilization of water and inputs (Avelino Neto, 2019).

Despite highly efficient, the main limitation of using drip irrigation for fertigation with nitrogen (N) fertilizers is the sensitivity of emitters to clogging, which occurs due to the presence of inorganic particles in the irrigation water (Silva et al., 2013; Alves et al., 2022). Additionally, hydraulic networks and drippers used for surface irrigation are prone to clogging due to the suction of soil particles into the pipes and formation of precipitates; this clogging affects water distribution uniformity, resulting in some areas with excess irrigation and others areas with irrigation deficit (Frizzone et al. 2012; Reis et al., 2021).

Dripper clogging harms the overall functioning of irrigation systems, affecting operations and demanding more frequent maintenance (cleaning filters, valves, and fertigation tubes); moreover, clogging often causes significant changes in water application uniformity when using localized irrigation systems (Liu & Huang, 2009; Batista et al., 2013). Therefore, using sand or disc filters to retain suspended particles to avoid physical clogging is essential to assess the operational conditions of irrigation systems and define performance parameters, including flow rate, water distribution uniformity, degree of clogging, water application efficiency, and irrigation time (Andrade et al., 2021). In this context, the objective in this study was to assess the effect of different sources of N fertilizer and different operation times on water distribution uniformity and emitter clogging using a localized surface drip irrigation system.

Material and Methods

The experiment was conducted in a greenhouse at the experimental area of the Instituto Federal Goiano, in Rio Verde, GO, Brazil (17° 48' 28" S, 50° 53' 57" W, and average altitude of 720 m). The greenhouse was covered with a 150-micron transparent polyethylene plastic film and closed on the sides with a 30% shade screen. The climate of the region was classified as Aw, tropical, according to the classification of Köppen & Geiger (1928), with a rainfall season from October to May and a dry season from June to September. The mean annual temperature in the region varies from 20 to 35 °C and the mean annual rainfall depth varies from 1,500 to 1,800 mm.

A randomized block experimental design with three replicates was used, in a 5 × 6 factorial arrangement consisting of five N sources (potassium nitrate, ammonium sulfate, calcium nitrate, ammonium nitrate, and urea) and six operation times (100, 200, 300, 400, 500, and 600 hours). The same nitrogen (N) dose was applied to all treatments: equivalent to 100 kg ha^{-1}.

The drip tubing PC model used had a nominal flow of 2 L h^{-1}, nominal diameter of 16 mm, internal diameter of 13 mm, operating pressure of 350 kPa, and spacing between emitters of 0.7 m. Each line of drip tubing had a length of 7 m. A pressure gauge was installed at the inlet of the drip lines, allowing the pressure to be checked with each flow measurement and adjusted to the pre-established pressure when necessary. A Bourdon pressure gauge with a reading range of 0 to 4 kgf cm^{-2} was used. The water used was from a dam (pH of 7.4), the water temperature in the supply tank was monitored during the test period; the treatments were applied with a water temperature of 25 ± 1 °C.

The fertilizer injection time was set to 2 hours, thus ensuring an optimal application of the N sources based on minimum dilution. Fertilizers were injected into the irrigation system using a Venturi injector, taking the dissolved fertilizer from a 50-L tank through suction. The characteristics of potassium nitrate, ammonium sulfate, calcium nitrate, ammonium nitrate, and urea used for fertigation are shown in Table 1.

The flow reading procedure consisted of pressurizing the system, stabilizing the pressure at 150 ± 5 kPa at the beginning of the line, positioning collectors under the respective drippers with a 3-s lag, and removing the collectors in the same sequence and with the same time lag after 5 minutes of collection. The gravimetric method was used to determine the collected volume from each emitter. Monitoring the dripper flow enabled the determination of the mean dripper flow. Flow data were tabulated, and calculations of water application uniformity and degree of clogging were performed using Equations 1 to 3:

$$SUC = 100\left(1 - \frac{S}{\bar{X}}\right) \tag{1}$$

$$AUC = 50\left(\frac{X_{25\%}}{\bar{X}} + \frac{\bar{X}}{X_{12.5\%}}\right) \tag{2}$$

$$DC = \left(1 - \frac{q_{used}}{q_{new}}\right)100 \tag{3}$$

where:

SUC - statistical uniformity coefficient (%);

AUC - absolute uniformity coefficient (%);

DC - degree of clogging (%);

S - standard deviation of flow rate (L h^{-1});

$X_{25\%}$ - mean of 25% of the total drippers with the lowest flow rates (L h^{-1});

Table 1. Nutrient concentration in the nitrogen sources used for fertigation

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

Adapted from Vitti et al. (1994)

$X_{12.5\%}$ - mean of 12.5% of the total drippers with the highest flow rates (L h^{-1});

X_i - flow rate of each dripper (L h^{-1});

X - mean flow rate of drippers (L h^{-1});

q_{new} - flow rate of the new dripper (L h^{-1}); and,

q_{used} - flow rate of the used dripper (L h^{-1}).

The obtained data were subjected to analysis of variance ($p \leq 0.05$). The means of operation times were subjected to regression analysis, whereas the means of N sources were compared by the Tukey's test ($p \leq 0.05$), using the statistical software Sisvar® (Ferreira, 2019).

Results and Discussion

The analysis of variance showed that the statistical uniformity coefficient (SUC), absolute uniformity coefficient (AUC), and degree of clogging (DC) of the drip irrigation system were significantly affected by the interaction between nitrogen sources and operation times (NS × OT) (Table 2). Alves et al. (2022) also found significant effects of nitrogen sources on water application uniformity and degree of clogging over time. Clogging can be partial, decreasing application uniformity, or total when it completely interrupts system operation, causing serious problems to crops (Cararo et al., 2006).

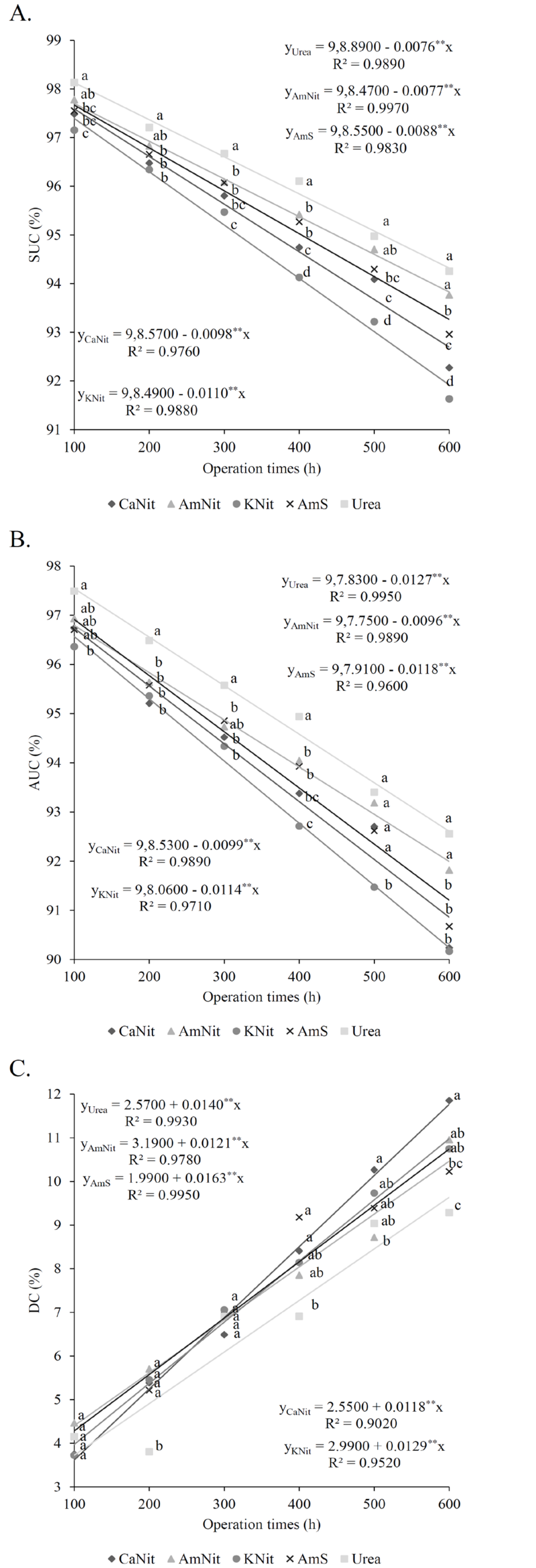
The statistical uniformity coefficient (SUC) at the 100-hour operation time was higher than 98% only when using urea as N source, whereas at the 200-hour operation time, calcium nitrate, potassium nitrate, and ammonium sulfate presented no significant differences (Figure 1A). The water application uniformity of drip irrigation systems used for urea fertigation presents, in general, a statistical uniformity coefficient above 94%, denoting a good irrigation performance and an adequate system operation, which results in reduced costs and improves fertilizer distribution and water use efficiency (Souza et al., 2019).

Urea presented a difference of 1.20% in SUC at the 300-hour operation time compared to potassium nitrate. The highest SUC at the 400-hour operation time was found when using urea as N source, followed by ammonium nitrate, ammonium sulfate, potassium nitrate, calcium nitrate, and potassium nitrate. Cunha et al. (2014a) found that the Christiansen uniformity coefficient generally presented higher sensitivity, identifying 62.5% of flow disturbances, followed by SUC, which identified 56.25% of flow changes.

Table 2. Analysis of variance for statistical uniformity coefficient (SUC), absolute uniformity coefficient (AUC), and degree of clogging (DC) of the drip irrigation system

Source of variation	DF	Mean square		
		SUC	AUC	DC
NS	4	6.40**	7.23**	2.75**
OT	5	42.76**	64.83**	95.03**
NS × OT	20	0.275**	0.352**	1.04**
Block	2	0.579**	0.377ns	0.274ns
Residue	58	0.052	0.125	0.343
CV (%)	-	2.24	2.38	7.96

NS - Nitrogen source; OT - Irrigation system operation time; DF - Degree of freedom; and CV - Coefficient of variation. ** significant at $p \leq 0.01$ and ns not significant by the F test



** - Significant at $p \leq 0.01$ by the F test. Lowercase letters differentiate the N sources by the Tukey test ($p \leq 0.05$). CaNit - Calcium nitrate; AmNit - Ammonium nitrate; KNit - Potassium nitrate; AmS - Ammonium sulfate

Figure 1. Statistical uniformity coefficient (SUC- A), absolute uniformity coefficient (AUC- B) and degree of clogging (DC-C) of the drip irrigation system as function of operation times and nitrogen sources

Fertigation with urea and ammonium nitrate provided the best SUC, mainly at the longest operation times, showing the highest uniformity (>93.70%); in general, lower uniformity was found when using potassium nitrate for fertigation. The operation times showed significant differences in SUC for the calcium nitrate, ammonium nitrate, potassium nitrate, and ammonium sulfate, with the highest and lowest application uniformity (differences above 4%) found for the initial and final operation times, respectively. The fertilizer rate applied through the irrigation water (fertigation) and the operation times may have affected the water distribution uniformity and water and nutrient use efficiency, impacting yield and productivity of crops (Contreras et al., 2020).

The absolute uniformity coefficient (AUC) at the operation times of 100, 200, and 300 hours presented practically no significant differences, with similar uniformity among N sources; the best AUC values were found when using urea as N source (Figure 1B). The increasing use of nitrogen fertilizers can lead to environmental problems because it is a dangerous pollutant and can contaminate water, plants, animals, and humans; furthermore, different sources of N can cause emitter clogging by chemical precipitation due to incompatibility between fertilizers, quality of irrigation water, insufficient dissolution of fertilizers, and low quality (purity and solubility) of fertilizers used in fertigation (Lima et al., 2023).

The use of urea at the 400-hour operation time resulted in an AUC 2.2% higher than potassium nitrate, whereas the use of ammonium nitrate and ammonium sulfate at this operation time presented no significant difference in AUC. High uniformity in localized drip irrigation systems can significantly increase the efficiency in the use of nitrogen fertilizers, promoting more sustainable and profitable agricultural productions (Yue et al., 2023).

The fertigation with calcium nitrate, ammonium nitrate, potassium nitrate, ammonium sulfate, and urea resulted in the same AUC at the 500-hour operation time; the lowest uniformity at this operation time was found for potassium nitrate. Similar results were found for the 600-hour operation time; however, calcium nitrate and ammonium sulfate presented the same application uniformity at this operation time. Cunha et al. (2014a) found that AUC was more sensitive when using surface drip irrigation, identifying more than 60% of flow disturbances.

Considering the 500- and 600-hour operation times, the highest AUC were found when using urea and ammonium nitrate for fertigation, with AUC higher than 91.80%. No significant difference in AUC was found for calcium nitrate and ammonium sulfate at the 200- and 300-hour operation times, as well as for ammonium nitrate and urea at the 300- and 400-hour operation times. Figure 1C shows the means of degree of clogging (DC) found for N sources, according to the operation times. Alves et al. (2020) found that changes in relative flow, application uniformity, and degree of clogging increased as the operation time of the irrigation system is increased, and the variations were more frequent when there were inorganic particles in the irrigation water.

The DC found for N sources showed no significant differences at the 100- and 300-hour operation times, presenting means of 4.00 and 6.90%, respectively. The lowest DC at the 200-hour operation time was found for fertigation with urea, whereas the other N sources presented no significant difference from each other at this operation time. This highlights the good performance of the irrigation system, which was probably due to the low change in water quality, as significant variations in water physical, chemical, and biological parameters may result in greater flow disturbances, significantly impacting application uniformity. There is a direct correlation between NO_3-N losses and inefficiency of fertigation and irrigation managements, mainly connected to low application uniformity. Therefore, the application of water and nitrogen fertilizers should be conducted in high-uniformity irrigation systems (Ashrafi et al., 2020).

The highest DC values tended to be found for calcium nitrate, whereas intermediate values were found for ammonium nitrate, potassium nitrate, and ammonium sulfate; the lowest DC values were found for fertigation with urea. In general, the best DC means at the 100-hour operation time were found for calcium nitrate, ammonium nitrate, potassium nitrate, ammonium sulfate, and urea, with means below 4.50%. Low uniformity in water distribution associated with dripper clogging, mainly due to chemical precipitates, is one of the main problems in localized irrigation systems, as it can significantly affect water use efficiency and crop yields (Silva et al., 2019; Contreras et al., 2021).

Figure 1 shows the application uniformity and degree of clogging as a function of operation times of the drip irrigation system under application of nitrogen sources. The SUC data found fitted to a linear model, with an R^2 above 97%, indicating that a maximum of 2.43% of SUC variations are not explained by the variations in operation time (Figure 1A). Figure 1A shows SUC results for each N source as a function of operation times. Monitoring uniformity in drip irrigation systems is important because of problems that may arise while applying fertilizers, as a partial obstruction of emitters causes a gradual reduction in application uniformity over time (Lopes et al., 2021).

The comparison between the 100- and 600-hour operation times showed decreases in SUC of approximately 5.2, 4.0, 5.5, 4.6, and 3.9% when using calcium nitrate, ammonium nitrate, potassium nitrate, ammonium sulfate, and urea, respectively. Water distribution uniformity and application efficiency are the main parameters used for evaluating irrigation systems, as they express the irrigation quality and are decisive for the operation of these systems (Oliveira & Villas Bôas, 2008).

Decreases in SUC for every 100-hour increase in operation time were 0.98, 0.77, 1.10, 0.88, and 0.76% when calcium nitrate, ammonium nitrate, potassium nitrate, ammonium sulfate, and urea were applied as N sources in the irrigation water, respectively. Andrade et al. (2021) evaluated the performance of a drip irrigation system and found water distribution uniformity coefficient, statistical coefficient of emitter flow variation (CVq), and SUC of 90.37, 12.47, and 99.88%, respectively, denoting an adequate and properly functioning system.

Figure 1B shows the AUC for each N source as a function of operation times. The comparison between the 100- and 600-hour operation times showed decreases in AUC of approximately 6.5, 5.1, 6.2, 6.0, and 4.9% when using calcium nitrate, ammonium nitrate, potassium nitrate, ammonium sulfate, and urea, respectively. Fertilizer application uniformity can be affected by variations in the solution concentration in the mixing tank, as the mixture may not be homogeneous. Additionally, clogging is the main issue that can emerge in fertigation, significantly impacting application uniformity (Burt et al., 1995; Cunha et al., 2014b).

Decreases in AUC for every 100-hour increase in operation time were 1.18, 0.96, 1.27, 1.14, and 0.99% when calcium nitrate, ammonium nitrate, potassium nitrate, ammonium sulfate, and urea were applied as N sources in the irrigation water, respectively. Ventura et al. (2017) also found decreases in water application uniformity, but it remained acceptable (>90%) even after two crop cycles.

Figure 1C shows the degree of clogging of each N source as a function of operation times. The DC data as a function of operation times fitted to a linear model for calcium nitrate, ammonium nitrate, potassium nitrate, ammonium sulfate, and urea, with an R^2 above 90% (Figure 1C). The comparison between the 100- and 600-hour operation times showed increases in DC of approximately 8.1, 6.5, 7.0, 6.1, and 5.1% when using calcium nitrate, ammonium nitrate, potassium nitrate, ammonium sulfate, and urea, respectively. Initially, clogging caused by application of fertilizer via irrigation water leads to reduction in flow rate and pressure peaks; later, distribution uniformity significantly decreases and degree of clogging increases (9.81%) due to increased fertilizer concentration in the pipes, mainly caused by fertilizer sedimentation, favoring the occurrence of a greater number of clogged emitters (Suszek et al., 2019).

Increases in DC for every 100-hour increase in operation time were 1.63, 1.21, 1.40, 1.29, and 1.18% when calcium nitrate, ammonium nitrate, potassium nitrate, ammonium sulfate, and urea were applied as N sources in the irrigation water, respectively. The presence of chemical agents in the irrigation water is a significant factor contributing to increases in clogging, as it favors partial or total clogging of emitters, consequently causing variations and changes in the operation and performance of localized irrigation systems (Sales & Sánchez-Román, 2019; Vale et al., 2020).

Conclusions

1. Decreases in water distribution uniformity are higher when drippers are subjected to application of potassium nitrate and calcium nitrate.

2. The best absolute and statistical uniformity coefficients are found when using urea and ammonium nitrate for fertigation, mainly at the longest operation times, for which the higher water application uniformity (>91.72%) are found.

3. The application of calcium nitrate causes more emitter clogging, whereas the application of urea results in less emitter clogging.

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Literature Cited

Alves, D. K. M.; Teixeira, M. B.; Cunha, F. N.; Cabral Filho, F. R. Avaliação de gotejadores com uso de água residuária de piscicultura e suinocultura em diferentes diluições. Irriga, v.27, p.282-295, 2022. http://dx.doi.org/10.15809/irriga.2022v27n2p282-295

Alves, D. K. M.; Teixeira, M. B.; Cunha, F. N.; Cabral Filho, F. R.; Soares, J. A. B.; Gomes, L. F. Grau de entupimento em um sistema de irrigação localizada submetido a diferentes tempos de funcionamento. Research, Society and Development, v.9, e210985622, 2020. http://dx.doi.org/10.33448/rsd-v9i8.5622

Andrade, A. R. S. de; Silva, E. G. da; Silva, E. T. da; Pereira, R. G.; Silva, J. F. da; Costa, C. M.; Zamora, V. R. O.; Cruzb, A. F. da S.; Ferreira, M. E. da S.; Silva, M. G. dos S.; Noronha, D. A. de. Avaliação do desempenho de sistema de irrigação por gotejamento em cultivo de maracujá. Research, Society and Development, v.10, e21710414034, 2021. http://dx.doi.org/10.33448/rsd-v10i4.14034

Ashrafi, M. R.; Raj, M.; Shamim, S.; Lal, K.; Kumar, G. Effect of fertigation on crop productivity and Nutrient use efficiency. Journal of Pharmacognosy and Phytochemistry, v.9, p.2937-2942, 2020.

Avelino Neto, S.; Sandri, D.; Silva, F. V. de O. Avaliação de um sistema de irrigação por gotejamento em pomar de Lima-Ácida Tahiti. Revista Mirante, v.12, p.215-231, 2019.

Batista, R. O.; Oliveira, R. A.; Santos, D. B. dos; Oliveira, A. de F. M.; Azevedo, C. A. V. de; Medeiros, S. de S. Obstrução e uniformidade de aplicação em sistemas de irrigação por gotejamento aplicando-se efluente da suinocultura. Revista Brasileira de Engenharia Agrícola e Ambiental, v.17, p.698-705, 2013. https://doi.org/10.1590/S1415-43662013000700002

Burt, C.; O'Connor, K.; Ruehr, T. Fertigation. California: The Irrigation Training Research Center. Polytechnic State University, p.1-320, 1995.

Cararo, D. C.; Botrel, T. A.; Hills, D. J.; Leverenz, H. L. Analysis of clogging in drip emitters during wastewater irrigation. Applied Engineering in Agriculture, v.22, p.251-257, 2006. https://doi.org/10.13031/2013.20286

Contreras, J. I.; Baeza, R.; Alonso, F.; Cánovas, G.; Gavilán, P.; Lozano, D. Effect of distribution uniformity and fertigation volume on the bio-productivity of the Greenhouse Zucchini crop. Water, v.12, p.1-15, 2020. https://doi.org/10.3390/w12082183

Contreras, J. I.; Roldán-Cañas, J.; Moreno-Pérez, M. F.; Gavilán, P.; Lozano, D.; Baeza, R. Distribution uniformity in intensive horticultural systems of Almería and influence of the production system and water quality. Water, v.13, p.233-248, 2021. https://doi.org/10.3390/w13020233

Cunha, F. N.; Silva, N. F. da; Teixeira, M. B.; Carvalho, J. J. de; Moura, L. M. F.; Santos, C. C. dos. Coeficientes de uniformidade em sistema de irrigação por gotejamento. Revista Brasileira de Agricultura Irrigada, v.8, p.444-454, 2014a. https://doi.org/10.7127/rbai.v8n600254

Cunha, F. N.; Silva, N. F. da; Teixeira, M. B.; Ribeiro, P. H.; Moura, L. M. de F.; Santos, C. C. dos. Repetibilidade de um sistema de irrigação por gotejamento sob entupimento. Revista Brasileira de Agricultura Irrigada, v.8, p.343-353, 2014b. https://doi.org/10.7127/rbai.v8n400246

Ferreira, D. F. Sisvar: a computer analysis system to fixed effects split plot type designs. Brazilian Journal of Biometrics, v.37, p.529-535, 2019. https://doi.org/10.28951/rbb.v37i4.450

Frizzone, J. A.; Freitas, P. S. L. de; Rezende, R.; Faria, M. A. de. Microirrigação: Gotejamento e microaspersão. 1.ed. Maringá: Eduem, 2012. 356p.

Köppen, W.; Geiger, R. Klimate der Erde. Gotha: Verlag Justus Perthes, 1928.

Lima, J. C. L.; Andrade, T. P.; Cerqueira, V. A.; Coelho, E. F.; Barros, D. L.; Carvalho, L. A. C. Nitrato e condutividade elétrica da solução do solo em fertirrigação para diferentes fontes e métodos de irrigação na cultura da bananeira. Cuadernos De Educación Y Desarrollo, v.15, p.9153-9167, 2023. https://doi.org/10.55905/cuadv15n9-064

Liu, H.; Huang, G. Laboratory experiment on drip emitter clogging with fresh water and treated sewage effluent. Agricultural Water Management, v.96, p.745-756, 2009. https://doi.org/10.1016/j.agwat.2008.10.014

Lopes, A. R.; Vilas Boas, M. A.; Pazuch, F. A.; Dalla Corte, L.; Gomes, B. M.; Prates, R. T. C. Uniformity of drip irrigation system with liquid peat on different slopes. Irriga, v. 1, p.357-366, 2021. https://doi.org/10.15809/irriga.2021v1n2p357-366

Mantovani, E. C.; Bernardo, S.; Palaretti, L. F. Irrigação: Princípios e métodos. 3.ed. Viçosa: UFV, 2013. 355p.

Oliveira, M. V. A. M. de; Villas Bôas R. L. Uniformidade de distribuição do potássio e do nitrogênio em sistema de irrigação por gotejamento. Engenharia Agrícola, v.28, p.95-103, 2008. https://doi.org/10.1590/S0100-69162008000100010

Reis, K. M. dos; Palaretti, L. F.; Barreto, A. C.; Zanini, J. R. Irrigação por gotejamento subsuperficial e fertirrigação da cultura brócolis. Irriga, v.26, p.383-397, 2021. http://dx.doi.org/10.15809/irriga.2021v26n2p383-397

Sales, M. A. de L.; Sánchez-Román, R. M. Uniformidade de um sistema de irrigação por gotejamento sob diferentes concentrações de água residuária tratada por radiação solar. Brazilian Journal of Biosystems Engineering, v.13, p.301-311, 2019. http://dx.doi.org/10.18011/bioeng2019v13n4p301-311

Silva, K. B. da; Silva Júnior, B. da; Batista, M. J.; Oliveira, R.; Santos, D. B. dos; Barbosa Filho, S. Desempenho de gotejadores operando com efluente da castanha de caju sob distintas pressões de serviço. Revista Ceres, v.60, p.339-346, 2013. https://doi.org/10.1590/S0034-737X2013000300006

Silva, W. R. da; Salomão, L. C.; Pereira, D. R. M.; Oliveira, H. F. E. de; Pereira, A. I. de A.; Cantuario, F. S. Irrigation levels and use of hydro retainer polymer in greenhouse lettuce production. Revista Brasileira de Engenharia Agrícola e Ambiental, v.23, p.406-412, 2019. http://dx.doi.org/10.1590/1807-1929/agriambi.v23n6p406-412

Souza, Ê. G. F.; Cruz, E. A. da; França, R. F. de; Silva, J. M. da; Barros Júnior, A. P.; Bezerra Neto, F. Economic nitrogen rate for fertigation of green corn crop in the Brazilian semiarid. Pesquisa Agropecuária Brasileira, v.54, e00556, 2019. https://doi.org/10.1590/S1678-3921.pab2019.v54.00556

Suszek, F. L.; Vilas Boas, M. A.; Sampaio, S. C.; Juchen, C. R.; Lima, V. L. A. Desobstrução de emissores com ácido fosfórico em fertirrigação com cloreto de potássio vermelho. Revista em Agronegócio e Meio Ambiente, v.12, p.9-24, 2019. https://doi.org/10.17765/2176-9168.2019v12n1p9-24

Vale, H. S. M.; Costa, D. O.; Batista, R. O.; Oliveira, F. de A. de; Medeiros, J. F. de; Coelho, D. da C. L. Distribution uniformity in drip units applying dilutions of treated water produced by oil exploration. Revista Brasileira de Engenharia Agrícola e Ambiental, v.24, p.394-401, 2020. http://dx.doi.org/10.1590/1807-1929/agriambi.v24n6p394-401

Ventura, K. M.; Bispo, R. de C.; Santos, R. D. da S.; Souza, M. H. C. de; Sánchez-Román, R. M. Análise da uniformidade de aplicação em diferentes sistemas de cultivo com irrigação localizada. Irriga, Botucatu, edição especial, Irriga, p.57-63, 2017. http://dx.doi.org/10.15809/irriga.2017v1n1p57-63

Vitti, G. C.; Boaretto, A. E.; Penteado, S. R. Fertilizantes e fertirrigação. In: Vitti, G. C.; Boaretto, A. E. (Ed.). Fertilizantes fluidos. Piracicaba, 1994. p.262-281.

Yue, W.; Chen, S.; Gao, L.; Li, N.; Liu, L. Effects of water and nitrogen coupling on yield, quality, water and nitrogen use efficiencies of greenhouse muskmelon. Water, v.15, p.1-13, 2023. https://doi.org/10.3390/w15142603