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

CONTROLE ESTATÍSTICO NO MONITORAMENTO DO ENTUPIMENTO DE UNIDADES GOTEJADORAS IRRIGADAS COM ÁGUA DE FECULARIA DILUÍDA

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1 RESUMO

A utilização de ferramentas de controle estatístico de qualidade na irrigação vem se disseminando por propiciar a detecção rápida e eficaz dos possíveis problemas ocasionados aos gotejadores, em especial, quando se utiliza águas residuárias na irrigação. Desse modo, essa pesquisa teve como objetivo utilizar cartas de controle estatístico de qualidade no acompanhamento do grau de entupimento de unidades gotejadoras irrigadas com água residuária de fecularia diluída. A pesquisa foi desenvolvida em uma área experimental pertencente ao Laboratório de Engenharia de Irrigação e Drenagem (LEID), da Universidade Federal de Campina Grande – UFCG, no Campus de Campina Grande, Paraíba, Brasil. Foram avaliadas quatro unidades gotejadoras diferentes a cada 20 horas, por 480 horas, totalizando 25 ensaios, com pressão de serviço de 100 kPa. Ao comparar as cartas de controle estatístico de Shewhart com as da média móvel exponencialmente ponderada (MMEP), observou-se que as cartas de MMEP foram mais sensíveis a variações de menor porte. Além disso, percebe-se que a água residuária de fecularia diluída aumentou problemas de entupimento nos modelos de fitas gotejadoras M1 e M3 ao decorrer de 480h de irrigação e que o uso da água residuária de fecularia bruta não é recomendado para a irrigação localizada, por apresentar altos de teores de dureza de cálcio e magnésio, sódio e cloretos.

Palavras-chave: Emissores, qualidade de água, obstrução, reutilização, biofertilizante.

Recebido em 26/07/2022 e aprovado para publicação em 20/11/2022
DOI: http://dx.doi.org/10.15809/irriga.2022v27n4p700-714

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STATISTICAL CONTROL IN MONITORING THE CLOGGING OF DRIPPER UNITS IRRIGATED WITH DILUTED FECULENCE WATER

2 ABSTRACT

The use of statistical quality control tools in irrigation has been disseminated because it provides a fast and efficient detection of possible problems in drippers, especially when wastewater is used in irrigation. Thus, this research aimed at using statistical quality control charts to monitor the degree of clogging of drip irrigation units irrigated with diluted fecula wastewater. The research was performed in an experimental area belonging to the Laboratory of Irrigation and Drainage Engineering (LEID), of the Universidade Federal de Campina Grande - UFCG, Campina Grande Campus, Paraíba, Brazil. Four different dripper units were evaluated every 20 hours, for 480 hours, totaling 25 trials, with service pressure of 100 kPa. When comparing the Shewhart statistical control charts with the exponentially weighted moving average (EPM) charts, it was observed that the EPM charts were more sensitive to minor variations. Furthermore, it was observed that the diluted fecula residue water increased clogging problems in the dripline models M1 and M3 during 480 hours of irrigation and that the use of raw fecaria residuary water is not recommended for localized irrigation, because it presented high levels of calcium and magnesium hardness, sodium and chlorides.

Keywords: Emitters, water quality, obstruction, reuse, biofertilizer.

3 INTRODUCTION

In the semiarid region of Brazil, water is considered an increasingly limiting factor in the development of irrigated agriculture, which, according to Bezerra *et al.* (2019), is due to the region's irregular rainfall and high evapotranspiration. Considering that the demand for water for irrigation is constantly increasing, it is necessary to seek and use more efficient irrigation systems and water with lower physical, chemical, and biological qualities to ensure that better-quality water resources are allocated to the most valuable purposes, such as the urban water supply.

Given the importance of properly disposing of low-quality water (wastewater), studies have advanced its use not only as an alternative to meet crop water needs but also as a biofertilizer, aiming to provide nutrients, not only to save water but also to reduce the use of chemical fertilizers (SOUSA *et al.*, 2021). Furthermore, from an environmental perspective, recycling this water is a way to properly dispose of waste that poses serious environmental risks and is often discharged "unprocessed" into waterways.

Among the most diverse wastewaters available for irrigation are water resulting from cassava processing, popularly known as "Manipueira," which comes from pressing cassava roots to obtain starch or flour. They have a milky appearance and are rich in nitrogen, phosphorus, and potassium, which are elements that favor crop development (HERMES *et al.*, 2018). Several researchers emphasize the potential of manipueira as a fertilizer for various crops, citing Araújo *et al.* (2019), who concluded that manipulizers can replace potassium fertilization via fertigation in the production of 'Potiguar' corn. Ramos *et al.*

(2020), when studying the effectiveness of organic fertilization with human urine and cassava applied via foundation and fertigation on the growth of hybrid corn AG1051, achieved the best results with organic fertilization applied via foundation, highlighting that it can be seen as a strategy to replace mineral fertilization, as long as it is not applied in excess.

With respect to irrigation technologies developed for rational water use, localized irrigation systems, especially drip irrigation, stand out as the most recommended. According to Melo *et al.* (2020), technicians and researchers are increasingly interested in drip systems because of their greater efficiency in terms of water use and fertilizer application, as they enable the rational use of water and, therefore, energy due to low-volume application. With respect to fertilizer application, Pereira *et al.* (2019) reported that, in both microsprinkling and drip irrigation, conventional fertilization can be replaced by fertigation, as this technique increases the efficiency of nutrient use by the plant because timely application close to the roots reduces the need for excessive fertilizer doses.

When wastewater is used, it is essential to carry out more precise and more frequent monitoring, aiming to avoid possible clogging problems and excessive wear of irrigation materials, as stated by Szekut *et al.* (2018). Drippers are highly susceptible to clogging, as they have small labyrinths and holes for water passage.

In this context, the use of the statistical quality control (CEQ) tool has stood out in the agricultural sector, since, according to Gouveia (2018), the effective implementation of process control makes it possible to take improvement or preventive actions at the right time, enabling the correction or optimization of the process, resulting in increased quality, increased productivity, increased costs and reduced cycle time. When discussing the advantages of applying CEQ for rural producers using wastewater in their irrigation systems, Gomes *et al.* (2020) emphasized that this tool provides guidance for performing preventive maintenance of their irrigation systems. The best-known control chart is the Shewhart chart for individual measurements; however, weighted moving averages (WMAs) are also widely used.

Thus, this research aimed to monitor the degree of clogging of drip units irrigated with urban supply water and diluted starch wastewater via statistical quality control charts.

4 MATERIALS AND METHODS

The experiment took place in an experimental area belonging to the Irrigation and Drainage Engineering Laboratory (LEID) of the Agricultural Engineering Academic Unit (UAEA) of the Federal University of Campina Grande (UFCG) in the city of Campina Grande - PB. Three drip units installed in experimental benches developed by Ferreira (2015) were evaluated. Four different drip tape models (Azud On Line, Azud Sprint, Rivulis D9000 and Tiquira) were used, coded as M1, M2, M3 and M4, respectively, commercialized in the local market, whose characteristics are described in Table 1.

Table 1. Technical specifications of drip tapes

Nomenclature	Manufacturer	Model	FROM THE	Q* (L h⁻¹)	k	x	PN (kPa)	DN (mm)	EE (m)
M1	Azud	Online	No	1.61	0.49	0.5	50-125	16	0.20
M2	Azud	Sprint	No	1.61	0.49	0.5	50-125	16	0.20
M3	Rivulis	D9000	No	1.41	-	-	100	16	0.20
M4	Petroisa	Tiquira	No	1.51	0.46	0.5	100	16	0.20

(DA) = self-compensation device, (Q) = nominal flow rate, (k) = flow coefficient, (x) = flow rate exponent that characterizes the flow regime, (PN) = nominal pressure, (DN) = nominal diameter and (EE) = spacing between emitters **Note:** * - Nominal flow rate of drip tapes at a working pressure of 100 kPa; ** Information obtained from manufacturers' catalogs.

The test benches used in the experiment had the capacity to install four lateral lines, positioned in parallel, with a spacing of 0.15 m, in which drip unit 1 operated only with irrigation water from the urban supply of the municipality of Campina Grande - PB, called AA, and drip units 2 and 3 were subjected to irrigation with irrigation water from the dilution of starch wastewater, called AR, obtained from a flour mill located in the rural area of the municipality of Puxinanã - PB.

The starch wastewater used in the research was analyzed at the Desalination Reference Laboratory - LABDES/UFCG and at the Quality Control Laboratory of SENAI - Campina Grande - PB, and the urban supply water was analyzed at the Irrigation and Salinity Laboratory (LIS), in accordance with the recommendations of the Standard Methods (APHA, 2005), to obtain the physical-chemical and microbiological characteristics shown in Table 2.

Table 2. Physicochemical characteristics of the urban water supply and starch wastewater used in the research

Parameters¹	Units	Urban water supply	Feculary wastewater
Electrical conductivity (EC)	dS m $^{-1}$ at 25°C	0.74	13.68
Potential of Hydrogen (pH)	-	6.58	3.60
Calcium Hardness	mg L $^{-1}$	35.20	380.0
Magnesium Hardness	mg L $^{-1}$	19.68	1,440.0
Sodium	mg L $^{-1}$	57.22	671.5
Potassium	mg L $^{-1}$	8.99	34.1
Carbonates	mg L $^{-1}$	0.00	0.00
Bicarbonates	mg L $^{-1}$	77.48	0.00
Chlorides	mg L $^{-1}$	132.64	6,035.0
Sulfates	mg L $^{-1}$	Presence	Presence
Sodium Adsorption Ratio (RAS)	mg L $^{-1}$	10.92	22.26
Class	-	C2S1	C4S1

On the basis of the classification proposed by Richards (1954) for irrigation water according to electrical conductivity (EC), the starch wastewater was diluted in the urban water supply at a proportion of 1:30, with one part of starch wastewater in thirty parts of the urban water supply, maintaining an EC of 0.65 dS m $^{-1}$, classified as C2.

To analyze the four drip tape models, considering the capacity of the test benches, the tape models studied were analyzed at different times. Thus, drip tape models M1 and M2 were initially analyzed when they were subjected to irrigation with urban supply water and diluted starch wastewater, and subsequently, drip tape models M3 and M4 were analyzed under the same conditions. The eight treatments were then analyzed, as shown in Table 3.

Table 3. Treatments used in drip units

Treatments	Dripper Unit	Model	Water type
AAM1	UG1	Azud Line	AA [1]
AAM2	UG1	Azud Sprint	AA [1]
AAM3	UG1	Rivulis D9000	AA [1]
AAM4	UG1	Tiquira	AA [1]
ARM1	UG2	Azud Line	AR [2]
ARM2	UG2	Azud Sprint	AR [2]
ARM3	UG3	Rivulis D9000	AR [2]
ARM4	UG3	Tiquira	AR [2]

[1] Irrigation water from the urban supply of the municipality of Campina Grande – PB;
[2] Irrigation water obtained from the dilution of starch wastewater diluted in urban water supply.

The irrigation units analyzed in the research consisted of a ½ HP (single-phase) 220 V electric pump with a maximum flow rate of 35 L/min, a 500-liter water reservoir (fiberglass water tank), a 120-mesh disc filter, two glycerin pressure gauges (one at the pump outlet and the other at the end of the main line), a check valve, a globe valve, PVC pipes, fittings, drip tapes, and drippers. In addition, the test benches had a water recirculation system consisting of movable wooden shelves, which were used only during the irrigation unit evaluations, to support the water collection containers. After removal, the dripped water was returned to the reservoir through fiberglass tiles, where it was then directed back to the reservoir (water tank).

To analyze the clogging of the dripper units, an initial test was performed (0 hours), after which they were operated for 10 hours/day, with 25 tests performed at 20-hour intervals, totaling 480 hours of operation. The tests followed the NBR ISO 9261 standard (ABNT, 2006), with a preestablished time of 5 minutes, allowing a 20-second time lag between one dripper and another, with four repetitions. The volumes of the four lateral lines were collected simultaneously in 300 ml plastic containers.

With respect to the collected water volume, the flow rates and degree of clogging of the drippers were calculated according to equations (1) and (2):

$$q = \frac{V}{1000.t} . 60 \qquad (1)$$

where:
q – dripper flow rate, L h $^{-1}$;
V – volume of water collected, mL;
t – water collection time, min.

$$GE = \left(1 - \frac{q_{usado}}{q_{novo}}\right) . 100 \qquad (2)$$

where:
GE – degree of clogging, %;
q flow rate of the dripper used, L h $^{-1}$;
q_{new} – flow rate of the new dripper, L h $^{-1}$.

The degree of clogging of each of the drip units studied was classified according to Morata *et al*. (2014), as shown in Table 4.

Table 4. Interpretation of the degree of clogging of the drip units

Classification	GE [1] (%)
No clogging	< 0
Bass	0 – 10
Medium	10 – 40
High	40 – 90
Very high	90 – 100

Source: [1] Morata *et al.* (2014)

To monitor the hydraulic performance of the four drip units operating with urban supply water and wastewater from cassava processing, two types of control charts were used:

a) Shewhart control charts: Individual samples are used to determine the upper (ULC), central (LC) and lower (LIC) control limits according to the following equations:

$$LSC = \bar{x} + 3\sigma \quad (3)$$

$$LC = \bar{x} \quad (4)$$

$$LIC = \bar{x} - 3\sigma \quad (5)$$

$$\sigma = MR.(d^2)^{-1} \quad (6)$$

where:

$\bar{x}$- Central line of the control chart and corresponds to the average value of the flows;
σ - Population standard deviation estimator;
d^2 - Tabled correction factor that depends on the sample size;
MR - average sampling amplitude.

b) MMEP control charts: Constructed with the variables mean value and number of sample i, or time. From equation (7),

$$z_i = \lambda x_i + (1-\lambda)_{zi} - 1 \quad (7)$$

where:

i - Number of samples;
z_i- Values plotted on the graph;
λ - Smoothing factor, a constant that varies between 0 and 1, with λ used as 0.20;
x_i- Individual or real values found in the process.

The calculations of the control limits of the MMEP control charts were performed via equations 8 to 10.

$$LSC = \bar{x} + L\sigma\sqrt{\frac{\lambda}{2-\lambda}[1-(1-\lambda)^{2i}]} \quad (8)$$

$$LC = \bar{x} \quad (9)$$

$$LIC = \bar{x} - L\sigma\sqrt{\frac{\lambda}{2-\lambda}[1-(1-\lambda)^{2i}]} \quad (10)$$

where:

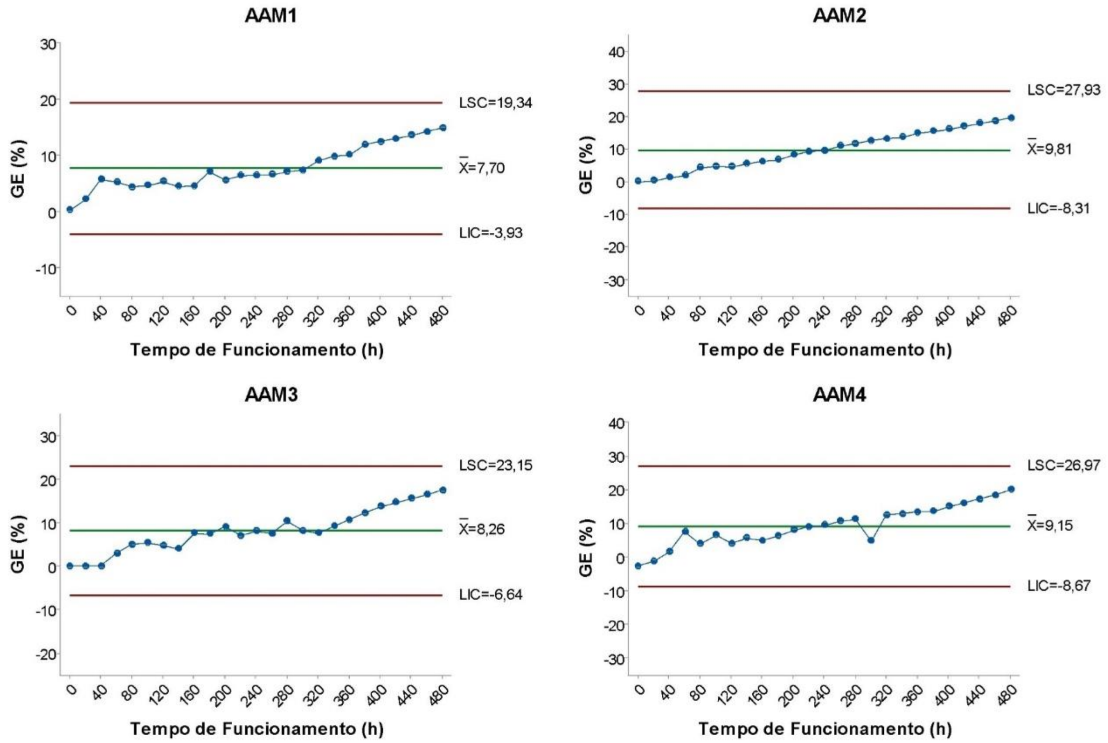
$\bar{x}$- Central line of the control chart and corresponds to the average value of the flows;
L - number of standard deviations of the control mean that you want to detect, with L equal to 2);
Σ - Standard deviation.

5 RESULTS AND DISCUSSION

Figure 1 presents the statistical control charts for the hydraulic parameter clogging degree (GE) for the different dripper units evaluated over the 480 hours of operation with an urban water supply

(Treatments AAM1, AAM2, AAM3, and AAM4). The Shewhart charts for the hydraulic parameter GE indicate that when there are signs of clogging in the drippers, the GE tends to increase. According to Reis *et al.* (2021), the degree of clogging parameter can present positive values, resulting from clogging problems that cause a reduction in flow, or negative values, resulting from an increase in flow due to clogging problems. An analysis of the control charts below reveals that there is no extrapolation of points in the upper and lower control limits in any of the treatments evaluated. However, there are sequences or trends of values in all the treatments studied, which, according to Montgomery (2013), would be indications of a lack of process control. According to Orssatto *et al.* (2014), when researching the application of Shewhart control charts in a wastewater treatment plant, these charts are a good alternative for visualizing process errors, especially for large changes.

Figure 1. Statistical quality control charts for the degree of clogging (GE) of the different drip units studied over 480 hours of operation with an urban water supply.

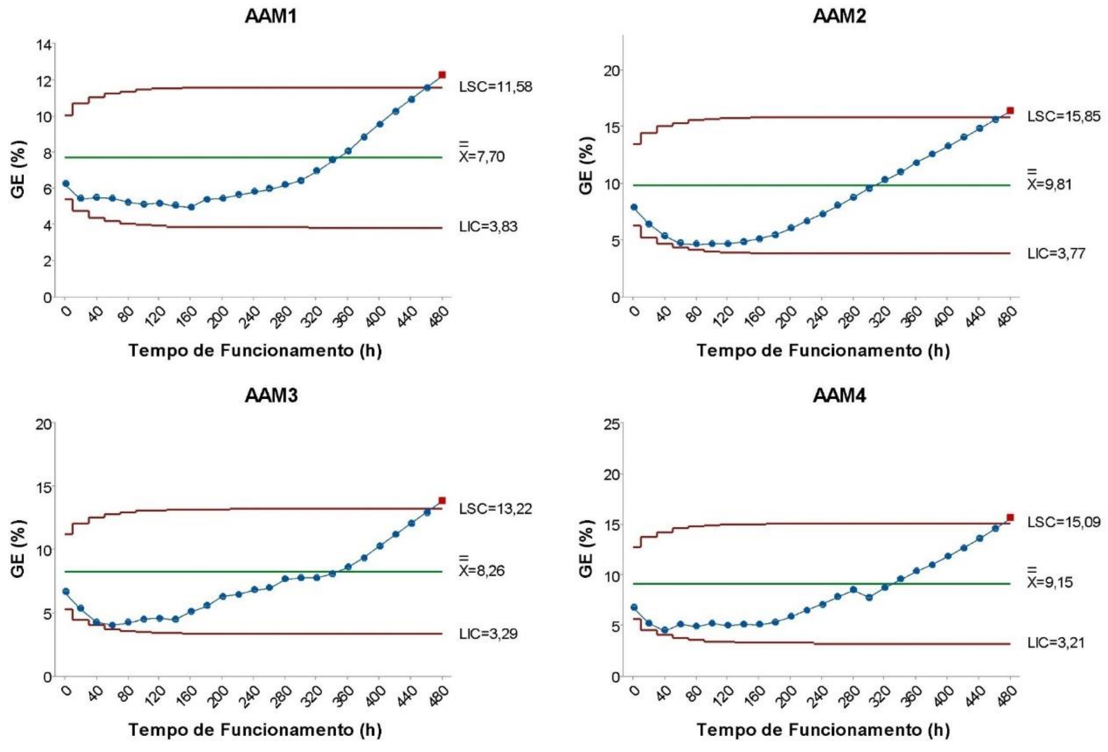


Source: Authors (2021)

The average degree of clogging (GE) for treatment AAM1 (Figure 1) over the study period was 7.70%, with an upper control limit of 19.34% and a lower control limit of -3.93%. In treatment AAM2 (M2 dripper unit irrigated with urban supply water), the average GE value was 9.81%, with an upper control limit of 27.93% and a lower control limit of -8.31%. In treatment AAM3 (M3 dripper unit irrigated with urban supply water), the average GE value was 8.26%, with an upper control limit of 23.15% and a lower control limit of -6.64%. In treatment AAM4 (M4 dripper unit irrigated with urban supply water), the average GE value was 9.15%, with an upper control limit of 26.97% and a lower control limit of -8.67%. The analysis of the hydraulic performance of drip units through the average degree of clogging (GE) over 480 hours of irrigation with an urban water supply revealed that these units can be classified as "medium" (GE between 10% and 40%), as they present GE values between -8.67% and 27.93%. The authors of Costa *et al.* (2019) reported that the susceptibility of drippers to clogging is related to the lower flow rate, the shorter labyrinth length, and the formation of biofouling, mainly in the filtration area and inside the labyrinth.

In Figure 2, the hydraulic parameter degree of clogging (GE) of the different drip units evaluated using urban supply water for irrigation (Treatments AAM1, AAM2, AAM3, and AAM4) is shown via exponentially weighted moving average (MMEP) statistical quality control charts. In the MMEP control charts, sequences of values can be identified that exceed the mean line toward the upper control limit, starting from the test carried out at 360 h (Test 19) in the AAM1 and AAM3 treatments and at 320 h (Test 17) in the AAM2 and AAM4 treatments. Furthermore, at 480 h (Test 25) of operation with urban supply water, all the studied treatments exceeded the upper control limits, which, according to Montgomery (2013), suggests a lack of control over these processes.

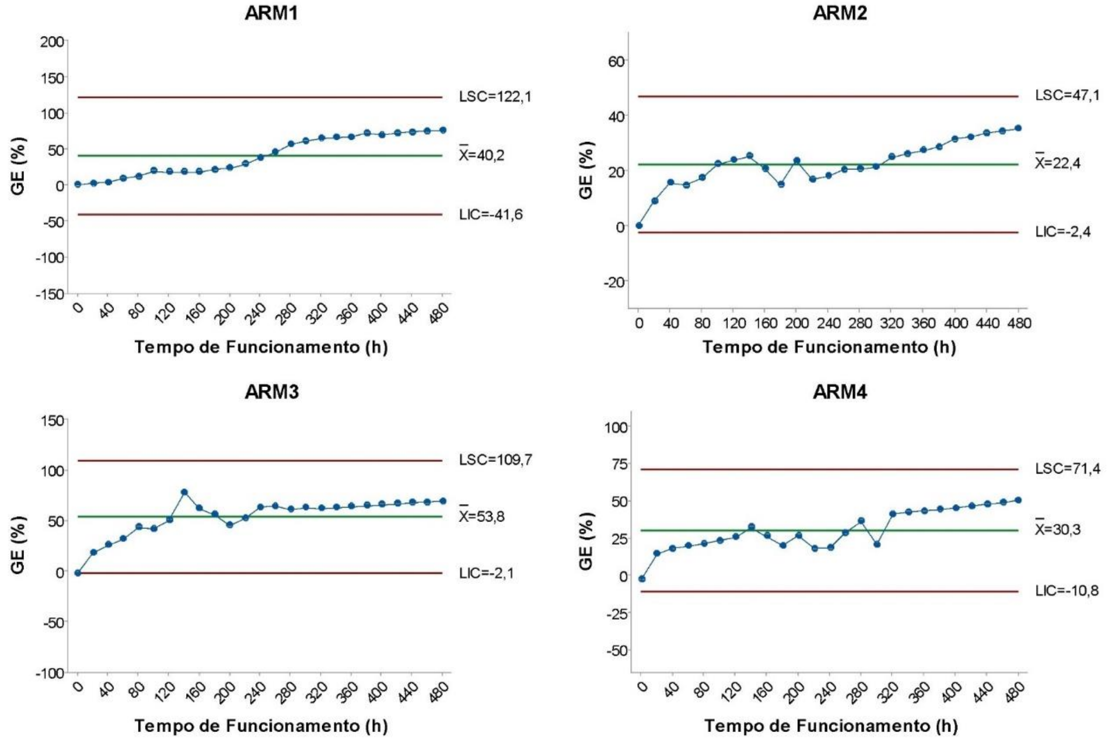
Figure 2. Statistical quality control charts of the MMEP for the degree of clogging (GE) of the different drip units studied over 480 hours of operation with an urban water supply.



Source: Authors (2021)

The statistical quality control charts for the individual values of the degree of clogging (GE) parameter are shown in Figure 3 for the drip units subjected to irrigation with diluted starch wastewater. No extrapolation of values above or below the stipulated control limits was observed. There is evidence of a lack of statistical control in the processes due to the presence of sequences or trends of values above the mean lines (MONTGOMERY, 2013) from the test carried out at 260 h (Test 14) in treatment ARM1, at 300 h (Test 16) in treatments ARM2 and ARM4, and at 220 h (Test 12) in treatment ARM3. Considering that, the values located above the mean lines should be highlighted, as they indicate significant changes in the degrees of clogging for all the treatments evaluated.

Figure 3. Statistical quality control charts for the degree of clogging (GE) of the different drip units studied over 480 hours of operation with diluted starch wastewater.

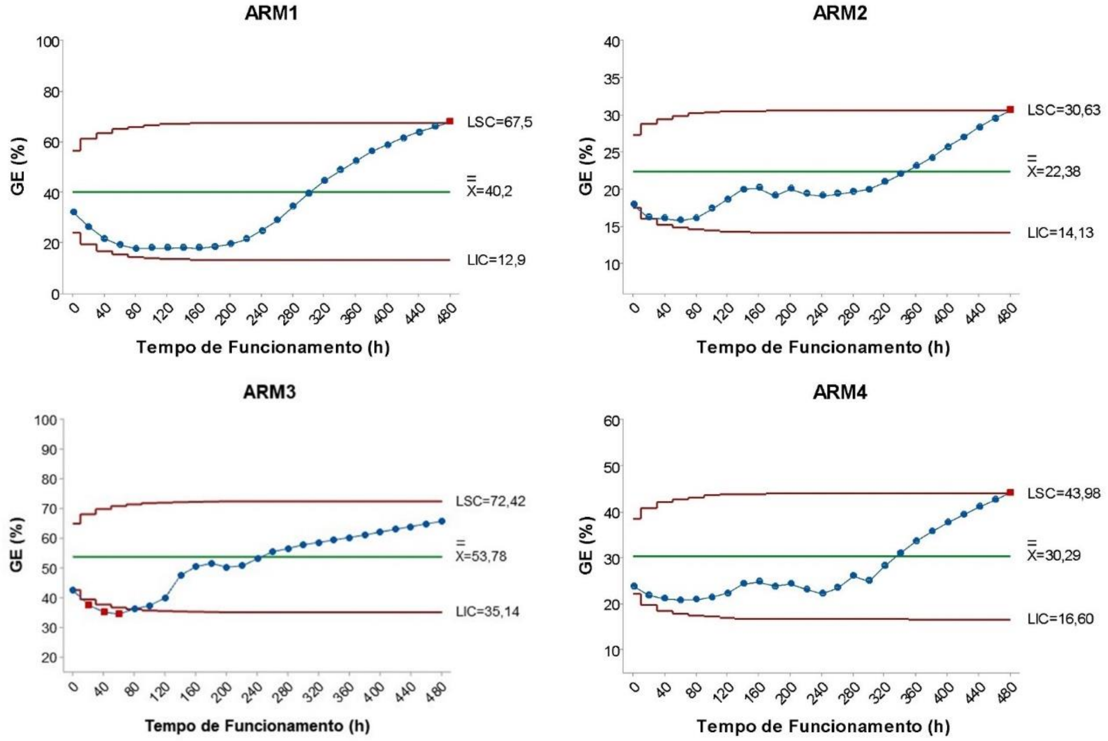


Source: Authors (2021)

As shown in Figure 3, the dripper unit in treatment ARM1 had an average estimated EG value over the experimental period of 40.20%, with an upper control limit of 122.1% and a lower control limit of -41.60%. In ARM2, the average estimated EG value over the experimental period was 22.40%, with an upper control limit of 47.1% and a lower control limit of -2.4%. In ARM3, the average EG value was 53.8%, with an upper control limit of 109.70% and a lower control limit of -2.1%. In the ARM4 treatment, the average EG value was 30.30%, with an upper control limit of 71.40% and a lower control limit of -10.80%. Using the classification proposed by Morata *et al.* (2014), which is based on the hydraulic parameter degree of clogging (GE), the drip units that make up treatments ARM1 and ARM3 are classified as “high clogging”, and those in treatments ARM2 and ARM4 are classified as “medium clogging”.

In Figure 4, the degree of clogging (GE) for the studied treatments (Treatments ARM1, ARM2, ARM3, and ARM4), when subjected to 480 hours of operation with diluted starch wastewater, can be evaluated from the statistical quality control charts of the exponentially weighted moving average (MMEP). There are sequences or data trends, a factor that, according to Montgomery (2013), reflects a problem in the analyzed processes. Conceição *et al.* (2018) stated that the MMEP chart is characterized by three lines (LSC, LC, and LIC) and is excellent for use with individual observations.

Figure 4. MMEP statistical quality control charts for the degree of clogging (GE) of the different drip units studied over 480 hours of operation with diluted starch wastewater.



Source: Authors (2021)

The analysis of the charts shown in Figure 4 reveals that the data above the mean line are detrimental to the processes, and in the MMEP control charts, the moment at which the GE values tend to exceed the mean line begins from the test carried out at 300 h (Test 16) in the ARM1 and ARM4 treatments and at 260 h (Test 14) in the ARM3 treatment. Cruz, Cunha Filho and Falcão (2014) emphasized that the MMEP charts have, among their positive points, the possibility of rapid detection of small deviations and information about the trend of the studied process, being robust to the normality hypothesis and highly sensitive to the small variations that occur.

Finally, relating the physical-chemical attributes of the irrigation water used in the research (Table 2) with the risk of dripper clogging, the electrical conductivity (EC) parameter for urban supply water (EC = 0.74 dS m^{-1}) falls within the low restriction level, and that for starch factory wastewater (EC = 13.68 dS m^{-1}) falls within the severe restriction level, as it exceeds the limit of 4.5 dS m^{-1} proposed by Capra and Scicolone (1998). In terms of pH, according to Nakayama and Bucks (1991), the two types of irrigation water used in this research presented a low risk of dripper clogging. With respect to the calcium and magnesium hardness values, in both cases, the limit of 150 mg/L, proposed by Nakayama and Bucks (1991), was exceeded, indicating a high risk of clogging. However, when starch wastewater is used, the risk of clogging the drippers is much greater, as observed in the physical–chemical analysis of the water.

Table 2 also shows high concentrations of sodium (671.5 mg L^{-1}) and chloride (6,035.0 mg L^{-1}) ions, which, according to the limits established by Ayers and Westcost (1999), are “moderate” and “severe” restriction of water for use in irrigation, respectively. The parameters analyzed indicate that the quality of the water used in irrigation, especially the starch wastewater, attenuated the clogging process of the different drip tape models over the preestablished operating time, confirming the findings of the Shewhart and MMEP statistical quality control charts.

According to Melo *et al.* (2008), several factors can cause partial or complete clogging of emitters and pipes, affecting water flow and distribution along the main line, branch lines, and lateral lines, particularly. Among these factors, chemical precipitation of ions present in irrigation water is particularly noteworthy. In addition to the quality of the water used in irrigation, the authors of Ribeiro, Coelho, and Teixeira (2010) considered, with respect to the characterization of the clogging process, that the internal architecture of the drippers evaluated was also a determining factor in the level of clogging of the drippers over the course of their operating time.

6 CONCLUSION

In the statistical quality control charts analyzed, the exponentially weighted moving average (EMMA) charts were more sensitive to smaller variations in the processes, since, in addition to the presence of sequences or trends present in the Shewhart charts, the extrapolation of the upper control limits was observed, indicating problems in most of the processes studied.

Over the course of 480 hours of irrigation, the M1 and M3 drip tape models were more susceptible to clogging problems when irrigated with diluted starch wastewater. The use of raw starch wastewater is not recommended for localized irrigation because of its high levels of calcium and magnesium hardness, sodium, and chloride.

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