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STATISTICAL QUALITY CONTROL AND ELECTRICAL CONDUCTIVITY FOR EVALUATION OF THE UNIFORMITY OF DIFFERENT DRIP FERTIGATION SOLUTIONS

BRUNO MARCOS NUNES COSMO[1]; MAURICIO GUY DE ANDRADE[2]; TATIANI MAYARA GALERIANI[3]; ELIANE HERMES[4]; MÁRCIO ANTÔNIO VILAS BOAS[5]; GLAUBER JOSÉ DE CASTRO GAVA[6]

[1] Departamento de Engenharia Rural, Faculdade de Ciências Agronômicas, Universidade Estadual Paulista "Júlio de Mesquita Filho", Avenida Universitária, nº 3780, Altos do Paraíso, 18610-034, Botucatu, SP, Brazil. E-mail: brunomcosmo@gmail.com
[2] Departamento de Engenharias e Exatas, Universidade Federal do Paraná – Setor Palotina, Rua Pioneiro, nº 2153, Jardim Dallas, 85950-000, Palotina, PR, Brazil. E-mail: mauricio.andrade@ufpr.br
[3] Departamento de Produção e Melhoramento Vegetal, Faculdade de Ciências Agronômicas, Universidade Estadual Paulista "Júlio de Mesquita Filho", Avenida Universitária, nº 3780, Altos do Paraíso, 18610-034, Botucatu, SP, Brazil. E-mail: tatianigaleriani@gmail.com
[4] Departamento de Engenharias e Exatas, Universidade Federal do Paraná – Setor Palotina, Rua Pioneiro, nº 2153, Jardim Dallas, 85950-000, Palotina, PR, Brazil. E-mail: eliane.hermes@ufpr.br
[5] Centro de Ciências Exatas e da Terra, Universidade Estadual do Oeste do Paraná, Rua Universitária, nº 2069, Jardim Universitário, 85814-110, Cascavel, PR, Brazil. E-mail: márcio.vilasboas@unioeste.br
[6] Unidade de Pesquisa e Desenvolvimento de Jaú "Hélio de Moraes", Instituto Agronômico de Campinas (IAC), Rodovia Deputado Leônidas Pacheco Ferreira (SP 304, Jaú - Bariri), Km 304, Pouso Alegre de Baixo, C.P. 66, 17201-970, Jaú, SP, Brazil. E-mail: ggava@iac.sp.gov.br

1 ABSTRACT

Population growth has led to an intensified search for ways to increase the efficiency of agricultural production, including improvements of irrigation systems. This work aimed to evaluate the uniformity of different drip fertigation techniques, as well as their monitoring using electrical conductivity measurements and statistical quality control charts. For this, an experiment was performed according to a fully randomized design, with six treatments: T1) water (control); T2) Forth Frutas fertilizer; T3) Fortgreen fertilizer; T4) water (control); T5) Bio Bokashi liquid fertilizer; and T6) swine production wastewater. Each treatment consisted of 25 assays (replications). For the assays, 16 collection points were selected for measurements of volume, pH, and electrical conductivity. The data were analyzed using the Christiansen uniformity coefficient, the distribution uniformity coefficient, and the coefficient of variation of the total flow, employing Tukey's test (5% level), with statistical quality control charts. The results revealed uniformity above 90% for irrigation and fertigation, while statistically better control was obtained for irrigation. It could be concluded that irrigation and fertigation were similar in terms of uniformity, demonstrating the feasibility of using different fertigation solutions, while the control charts enabled efficient monitoring of the uniformity of the systems.

Keywords: control charts, operation monitoring, agricultural reuse.

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COSMO, B. M. N.; ANDRADE, M. G.; GALERIANI, T. M.; HERMES, E.; VILAS BOAS, M. A. V.; GAVA, G. J. C.

CONTROLE ESTATÍSTICO DE QUALIDADE E CONDUTIVIDADE ELÉTRICA NA AVALIAÇÃO DA VIABILIDADE DO GOTEJAMENTO COM DIFERENTES SOLUÇÕES DE FERTIRRIGAÇÃO

2 RESUMO

O crescimento populacional estimula a busca por meios de aumentar a eficiência agrícola, incluindo os sistemas de irrigação. Desta forma, o objetivo do estudo foi avaliar a uniformidade de diferentes soluções de fertirrigação via gotejamento, bem como o uso da condutividade elétrica e de gráficos de controle estatístico de qualidade para seu monitoramento. Para tal conduziu-se um experimento em delineamento inteiramente casualizado, na Universidade Federal do Paraná, Palotina-PR, composto por seis tratamentos: T1) Água (controle); T2) Forth Frutas; T3) Fortgreen; T4) Água (controle); T5) Bio Bokashi Líquido; e T6) Água Residuária da Suinocultura, com 25 ensaios (repetições) cada. Durante os ensaios selecionou-se 16 pontos de coleta, mensurando-se volume, pH e condutividade elétrica. Os dados foram avaliados por meio dos coeficientes de uniformidade de Christiansen, uniformidade de distribuição e variação da vazão total, teste de Tukey a 5% e por meio de gráficos de controle estatístico. Os resultados demonstram que irrigação e fertirrigação apresentaram uniformidade acima de 90%, porém, a irrigação apresentou melhor controle estatístico. Conclui-se que a irrigação e a fertirrigação foram similares em uniformidade, demonstrando a viabilidade no uso de diferentes soluções de fertirrigação, enquanto os gráficos de controle estatístico mostraram-se eficientes no monitoramento da uniformidade do sistema.

Palavras-Chave: gráficos de controle, operacionalidade, reúso agrícola.

3 INTRODUCTION

Global population growth has led to concerns regarding the capacity of the agricultural sector to produce both sufficient food and industrial raw materials (SAATH; FACHINELLO, 2018). Hence, there are intensified efforts to find ways to improve agricultural productivity, both quantitatively and qualitatively, while ensuring sustainability, by developing new techniques and improving existing ones (COSMO; GALERIANI, 2016).

One of the activities essential for agricultural development is irrigation, practiced since antiquity and associated with the development of human societies (FERREIRA, 2011). The practice continues to evolve, as evidenced by the emergence of localized systems, which provide greater uniformity and lower water consumption (JUCHEN; SUSZEK; VILAS BOAS, 2013; OLIVEIRA et al., 2016).

A promising development in irrigation is the possibility of combining other processes in the system, which led to the emergence of chemigation (BALDIN et al., 2013). There are various forms of chemigation, highlighting fertigation, which involves the combined application of water and fertilizers using an irrigation system (PAULINHO et al., 2011).

The composition of the fertigation solution depends on the crop and the production objectives, among other aspects (CORDEIRO et al., 2020). Irrespective of the composition of the solution, successful irrigation requires monitoring to ensure the uniformity of the system. This involves the determination of the spatial distribution of delivery of the irrigation solution, since low uniformity can lead to uneven crop development, resulting in lower profitability (KLEIN et al., 2013). The factors affecting uniformity include the characteristics of the sprinkler and configuration of the system (RODRIGUES et al., 2019), climatic factors (FRIGO et al., 2013), and the quality and composition of the irrigation solution (ALMEIDA, 2010).

Many techniques have been developed for the evaluation of irrigation solutions. However, in the case of fertigation, research is still needed to establish the best ways to assess the uniformity of fertilizers within the system, as well as to make this process simpler. In earlier work, Antunes et al. (2000) determined the concentrations of nitrogen (N) and potassium (K) in a drip system, to evaluate the uniformity of distribution of these elements. Oliveira and Villas Bôas (2008) also evaluated the variation of N and K in a drip system.

Rodrigues et al. (2020) measured the concentrations of K in a microsprinkler system, obtaining the Christiansen Uniformity Coefficient (CUC), the Distribution Uniformity Coefficient (DUC), and the coefficient of variation of the total flow (CVt) for this element. However, these methodologies are labor-intensive and time-consuming, hindering their application in the field. Differently, Cosmo et al. (2018) described the use of electrical conductivity for the evaluation of fertilizers, which was supported by Menezes and Matos (2018), who highlighted the suitability of this parameter for *in situ* monitoring with low time requirement.

In addition to the use of these methods and their adaptations to improve the assessment of fertigation, new techniques have emerged for determining the uniformity of irrigation with or without fertilizers, since the uniformity of the irrigation solution directly affects nutrient delivery. Among such techniques, the use of statistical quality control charts (SQCCs) can be highlighted as suitable for monitoring and improving the performance of production systems (JUSTI; SAIZAKI, 2016). In this approach, the quality of irrigation is evaluated by monitoring the variability of parameters such as uniformity and the factors affecting it (MERCANTE et al., 2014).

As specified by Justi and Saizaki (2016), the adoption of only one method of evaluating an irrigation system is often limited to a specific situation, providing, for example, an instantaneous uniformity coefficient. In contrast, the use of tools such as SQCCs allows a series of assessments during a desired period. Therefore, the traditional assessment methods should be complemented with new tools that have become available, as shown in the studies of Hermes et al. (2013), Mercante et al. (2014), Hermes et al. (2015), Justi and Saizaki (2016), Tamagi et al. (2016), Andrade et al. (2017), Chinchilla et al. (2018), and Szekut et al. (2018), which provide examples of the use of SQCCs in irrigation monitoring.

The present study evaluated the uniformity of different fertigation solutions applied using a drip system, as well as the use of electrical conductivity and statistical quality control charts for monitoring purposes.

4 MATERIAL AND METHODS

4.1 Experimental procedures

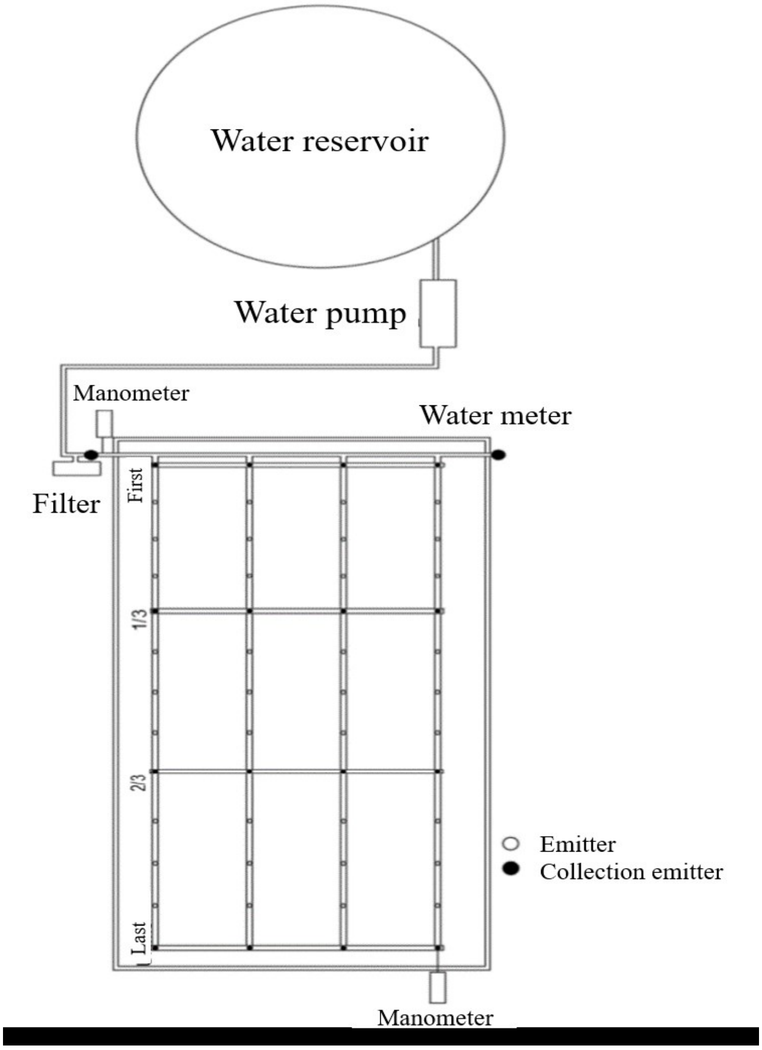
The trial was conducted in a plant house at the Federal University of Paraná

(24° 17' 36" S, 53° 50' 27" W, altitude of 327 m). The climate of the region is characterized as Cfa, according to the classification of Köppen and Geiger (1928). The experiments were performed between October 2017 and June 2018, employing a drip irrigation system installed on a wooden support, with dimensions of 6.00 x 1.60 m (9.60 m^2).

The irrigation system consisted of a drip tube (Model P1, Manari) with 16 mm internal diameter, 0.40 m distance between the emitters, and individual flow of approximately 1.48 L h^{-1}, at a working pressure of 85 kPa, as described by the manufacturer. A 736 W water pump was used, with the flow controlled using two water outlets, where one provided the feed to the system, while the other allowed return of the excess flow.

The drip system was composed of four lateral lines, each with 15 emitters, totaling 60 emitters. To minimize problems due to clogging, a 200-mesh filter was installed at the inlet of the system. Pressure measurements at the beginning and end of the system were obtained using digital manometers (ITMPD-15 Model 8215, Instrutemp) with an accuracy of ± 0.3% at 25 ºC. Figure 1 shows the configuration of the system.

Figure 1. Schematic top view of the drip system.



Data collection followed the methodology described by Keller and Karmeli (1975), using 16 collection points (the first emitter, the emitters at 1/3 and 2/3 of the total length, and the last emitter, for each line). A fully randomized experimental design was adopted, with 25 assays (replications) for each treatment and a collection time of 3 min for each assay.

The pump was started around 20 min before each assay, to stabilize the flow and pressure. To avoid problems with clogging, the inlet filter was cleaned before each treatment and/or set of consecutive tests. The assays followed the protocols of NBR ISO 9261 (ABNT, 2006). The treatments are described in Table 1.

Table 1. Description of the treatments.

Treatment	Content	N-P-K*	Concentration ($g\ L^{-1}$)
T1	Water (Control I)	------	------
T2	Mineral fertilizer 1 (Forth Frutas)	12-05-15	1.50
T3	Mineral fertilizer 2 (Fortgreen)	20-10-20	0.90
T4	Water (Control II)	------	------
T5	Bio Bokashi liquid (organic)	1.00-0.15-**	18.00
T6	Swine production wastewater (SPW)	0.16-0.02-**	112.50

* N-P-K: Nitrogen, phosphorus, and potassium, respectively; information provided by the manufacturer (T2, T3, and T5) and/or determined at the Soil Chemistry and Fertility Laboratory of the Federal University of Paraná (T5 and T6). ** Not determined.

The definition of the quantities of the fertilizers used was based on information reported by Trani, Tivelli and Carrijo (2011), who provided the fertigation N-P-K requirements for different crops. From interpolation of the data, a supply of N-P-K equivalent to 09-03-15 kg ha^{-1} met the minimum daily or weekly requirements of crops such as tomatoes and lettuce. Considering this formulation and providing the N requirement with a 5 mm depth of solution resulted in the concentrations shown in Table 1.

The treatments were characterized according to information provided by the manufacturer and determined in the laboratory. The mineral treatments T2 and T3 were recommended to be applied fortnightly, at concentrations from 5 to 20 g L^{-1}, while treatment T5 was recommended to be applied weekly or monthly at concentrations from 0.15 to 1.0% (v v^{-1}). The concentrations of P in organic samples were determined spectrophotometrically using molybdenum blue, as described by Silva (2009), while total N in treatment T6 was determined as described by Silva et al. (2006) and Silva (2009).

For determination of the uniformity coefficients, the volume collected was measured using 150 mL graduated beakers. In each assay, two collections were made at each point and the arithmetic mean was used in the evaluations. The electrical conductivity of the solutions was measured using a conductivity meter (Model mCA150, MS TECNOPON), with five replicates per treatment. These analyses were performed for collections 1, 7, 13, 19, and 25. The pH was determined following the same procedure, using a pH meter (Model mPA210, MS TECNOPON).

The evaluations were conducted between November 2017 and January 2018, for T1, T2 and T3. Then, the drip tubes were replaced by others with the same specifications, where T4, T5 and T6 were evaluated between April and June 2018.

4.2 Evaluation of uniformity

The uniformity indexes for the delivery of the irrigation solution were obtained using the Christiansen Uniformity Coefficient (CUC) (CHRISTIANSEN, 1942), the Distribution Uniformity Coefficient (DUC) (MERRIAM; KELLER, 1978), and the coefficient of variation of the total flow (CVt) (SOLOMON, 1979). These coefficients were obtained according to Equations 1, 2, and 3, respectively.

The distribution uniformity of fertilizer delivery along the drip line was evaluated using adaptations of the CUC and DUC (CUCa and DUCa), which were based on the electrical conductivity of the system (COSMO et al., 2018), employing variations of Equations 1 and 2. To improve the applicability of these indexes, new indexes were obtained, denoted CUC and DUC for nutrients (CUCn and DUCn), as described by Equations 4 and 5, respectively, in order to combine the information for the irrigated solution with the concentration obtained by conductivity measurements.

$$\mathrm{CUC} = \left(1 - \frac{\sum_{i=1}^{n} |qa - qi|}{nqa}\right) \times 100 \quad (1)$$

$$\mathrm{DUC} = \frac{\overline{q}_{25}}{\overline{qa}} \text{ x } 100 \quad (2)$$

$$\mathrm{CVt} = \frac{\sigma q}{\mathrm{qa}} \text{ x } 100 \quad (3)$$

$$\mathrm{CUCn} = \left(\frac{CUC \ x \ CUCa}{100}\right) \quad (4)$$

$$\mathrm{DUCn} = \left(\frac{DUC \ x \ DUCa}{100}\right) \quad (5)$$

Where: **CUC**: Christiansen Uniformity Coefficient (%): ***n***: number of emitters; ***q_a***: average flow for the emitters (L h^{-1}); ***q_i***: flow for each emitter (L h^{-1}); **DUC**: Distribution Uniformity Coefficient (%); **q_{25}**: average flow of the 25% smallest discharges from the emitters (L h^{-1}); **CVt**: Coefficient of variation of the total flow; **σq**: standard deviation of the flows sampled; **CUCa**: adapted CUC (%); **CUCn**: CUC for nutrients (%); **DUCa**: adapted DUC (%); **DUCn**: DUC for nutrients (%). Note: For determination of CUCa and DUCa, the flow was substituted by the electrical conductivity (dS m^{-1}).

The results obtained were evaluated using the parameters shown in Table 2. Comparisons of the treatments employed test F and Tukey's test (5% probability level), applied using SISVAR statistical software (FERREIRA, 2014). Data normality was determined using the Anderson-Darling method, performed using MINITAB v.16 software.

Table 2. Classifications of the Christiansen Uniformity Coefficient (CUC), Distribution Uniformity Coefficient (DUC), and coefficient of variation of the total flow (CVt) indexes.

Coefficients (%)			**Classification**
CUC*	**DUC****	**CVt*****	
> 90	> 90	≤ 0.03	Excellent
80 – 90	80 – 90	0.05 – 0.07	Good
70 – 80	70 – 80	0.07 – 0.11	Average
60 – 70	60 – 70	0.11 – 0.15	Poor
< 60	< 60	> 0.15	Unacceptable

Sources: Adapted from * Bernardo, Soares and Mantovani (2008), ** Bralts (1986), and *** Solomon (1979). Note: For CUCa, DUCa, CUCn, and DUCn, the interpretation of the results was performed using the same classification.

4.2.1 Statistical quality control charts

An alternative way to evaluate uniformity in the tests was the construction of Shewhart statistical quality control charts (SQCCs), which are commonly used in irrigation applications. For this purpose, the upper control limit (UCL) and lower control limit (LCL) were calculated using Equations 6 and 7, respectively.

$$UCL = \bar{x} + \frac{3MA}{d_2} \quad (6)$$

$$LCL = \bar{x} - \frac{3MA}{d_2} \quad (7)$$

Where: **UCL**: Upper control limit; **LCL**: Lower control limit; $\bar{\boldsymbol{x}}$: Mean; **d_2**: Predetermined value (tabulated in Montgomery (2009)), according the number of replications; **MA**: Moving amplitude of the observations (value of each parameter for each collector).

The SQCCs were constructed for the CUC and DUC indexes with normality above 5%. It is often assumed that SQCCs should not be used when the variable analyzed presents self-correlation. However, Montgomery (2009) reported that self-correlation is not a limiting factor for obtaining these charts, with only an absence of normality being a limiting factor. No SQCCs were produced for the CUCa, DUCa, CUCn, and DUCn coefficients due to the small number of repetitions.

The evaluation of control graphs involves adopting certain conditions, as described by Werkema (2006) and Montgomery (2009). For the process to be statistically under control, the chart should not present points that touch or exceed the upper or lower limits, which would be the main evidence of lack of control. Furthermore, there should be no trends or sequences, where the former is characterized by the appearance of seven or more points below or above the mean line, while the latter is indicated by the presence of seven or more consecutive points in ascending or descending directions.

5 RESULTS AND DISCUSSION

The values obtained for temperature, pressure, flow, pH, and electrical conductivity of the system for each treatment are shown in Table 3.

Table 3. Values obtained for temperature, pressure, flow, pH, and electrical conductivity.

Treat *	Temperature (°C)	Pressure (kPa)		Flow (L h^{-1})	pH	EC** (dS m^{-1})
		Initial	Final			
T1	26.5±4.5	84.7±1.5	82.9±2.0	1.30±0.02	8.33±0.07	0.18±0.00
T2	25.5±4.5	84.0±1.0	83.0±1.3	1.27±0.02	7.24±0.05	2.32±0.02
T3	27.0±5.0	84.2±0.9	83.2±0.8	1.29±0.01	7.23±0.12	1.37±0.03
T4	16.5±2.5	84.4±1.5	83.2±1.4	1.29±0.02	8.97±0.11	0.17±0.00
T5	14.0±4.0	83.7±1.6	82.0±1.7	1.23±0.02	5.66±0.11	1.19±0.03
T6	15.0±3.0	83.4±1.7	82.0±1.7	1.23±0.02	9.14±0.03	1.41±0.04

* Treatment; ** EC: Electrical conductivity.

As shown in Table 3, the temperature was higher for treatments 1-3 and lower for treatments 4-6. This variation was due to the time of year when the evaluations were carried out. Between the controls (T1 and T4), T4 normally presented lower fluctuations of pressure and flow, possibly due to the lower temperature, in agreement with Kunz, Ávila and Petry (2014), who found that dripping was sensitive to temperature changes.

The results corroborated the findings of Al-Amoud, Mattar and Ateia (2014) and Tan et al. (2017), who reported that oscillation of soil, water, and environmental temperatures could alter the uniformity in irrigation systems, especially localized installations. Further studies are needed to elucidate these effects, although it is likely that they are associated with dilation and contraction of drip tubes (ARAÚJO, 2019).

The mineral treatments showed oscillations of pressure and flow that were similar to those of the controls. In fertigation, both pressure and flow generally tend to decrease as the concentration of the irrigation solution increases. However, these reductions are not caused by obstructions in the system, since the system has been cleaned for each set of assays. This effect was described by Lima Neto (2006), where higher density of the irrigation solution led to a lower pressure range of the system. In a study using treated domestic sewage in fertigation, Batista, Souza and Ferreira (2010) observed a decrease of the flow in the system over time.

Lower pH was observed for treatments T2, T3, and T5, as expected due to the characteristics of many fertilizers used in fertigation, which act to decrease the pH of the mixture, as reported by Rezende et al. (2012). The electrical conductivity was influenced by the concentrations of the fertilizer salts in the different treatments, since it reflects the concentrations of the salts or solutes (ions) present in the solution (SILVA, 2014).

Notably the observed values of initial pressure are close between treatments, oscillating less than 5% between initial and final pressure in each treatment. This proximity between the observed values, as well as the reduction of flow and pressure observed in the treatments with higher density composition, reinforce the findings of the studies by Lima Neto (2006) and Batista, Souza and Ferreira (2010). This small oscillation and high uniformity observed in the system (Table 4), reduce the potential for interference from clogging.

Table 4 shows the results for the comparison of the means for CUC, DUC, CVt the adapted coefficients (CUCa and DUCa) and the coefficients for nutrients (CUCn and DUCn).

Table 4. Comparison of means for the Christiansen Uniformity Coefficient (CUC), the Distribution Uniformity Coefficient (DUC), the coefficient of variation of the total flow (CVt), the adapted coefficients (CUCa and DUCa), and the coefficients for nutrients (CUCn and DUCn).

Treat.	**Irrigation solution**					**Solution concentration**		**Quantity of nutrients**	
	CUC	TN (p)	DUC	TN (p)	CVt	CUCa	DUCa	CUCn	DUCn
T1	95.2bc	0.66	93.7a	0.44	0.06b	99.3b	98.8b	94.5a	92.6ab
T2	95.0c	0.93	93.4ab	0.02*	0.06b	99.5ab	99.2ab	94.6a	93.0a
T3	95.5a	0.38	93.9a	0.04*	0.05a	99.8a	99.7a	95.4a	93.7a
T4	95.4ab	0.22	93.8a	0.86	0.06b	99.7a	99.5ab	95.2a	93.4a
T5	95.5a	0.14	92.8b	<0.01**	0.07c	99.7a	99.5ab	95.1a	92.9a
T6	95.2bc	0.33	91.3c	0.33	0.08d	99.7a	99.4ab	94.5a	90.0b
F	9.5**		23.3**		41.9**	5.3**	2.9**	3.0**	4.8**
CV	0.4		1.1		10.2	0.2	0.4	0.5	1.4

TN (p): Test of normality by the Anderson-Darling method; CV: Coefficient of variation (%); * Results with less than 5% normality, according to the Anderson-Darling method; ** Significant results at 5% probability, according to the F test; Means followed by the same letter in the columns are statistically equivalent (Tukey's test, 5% probability).

As shown in Table 4, the CUC values indicated that treatments T3, T4, and T5 were superior to the others, although T4 did not differ from T1 and T6. The DUC values highlighted treatments T1 to T4, although T2 did not differ from T5. In the case of the CVt values, treatment T3 could be considered superior. It should be noted that higher values are more desirable for CUC and DUC, while lower values are desired for CVt. Despite the observed differences, all the treatments presented ratings of "excellent" for CUC and DUC, with ratings of "good" for CVt, with the exception of T6, for which the CVt rating was "average". It was notable that T3 was superior to T1, which was similar to the observations of Cosmo et al. (2018), who found that fertigation with mineral elements at low concentrations (below 1.00 g kg^{-1}) could improve uniformity.

Rodrigues et al. (2020), who evaluated different injection rates in fertigation using a microsprinkler, also found no differences between irrigation and fertigation for CUC, or for injections of up to 60 L h^{-1} for DUC. Similarly, in an investigation of subsurface drip fertigation, Cunha et al. (2014) found no differences between irrigation and fertigation for DUC, while differences were observed for CUC. Borssoi et al. (2012) reported similar DUC values for systems with and without fertigation, while Hermes et al. (2018) obtained similar DUC values using clean water and wastewater from cassava processing.

The indices indicated that T1 was generally inferior to the other treatments, but with no difference from T2 for CUCa and differing only from T3 for DUCa. For CUCn, the means comparison test revealed no differences among the treatments. For DUCn, T6 was inferior to the other treatments, but showed no difference to T1. DUCn is directly influenced by DUC, since it is the product of this with DUCa. However, all the treatments were again rated as "excellent", according to the adapted CUCa and DUCa classifications.

These indexes were based on traditional evaluation of the irrigation solution and evaluation of nutrients using electrical conductivity measurements. Although the procedure adopted did not allow quantification of individual nutrients, it enabled rapid in situ evaluation, as observed by Cosmo et al. (2018) and Menezes and Matos (2018). Other studies (ANTUNES et al., 2000; OLIVEIRA; VILLAS BÔAS, 2008; RODRIGUES et al., 2020) have performed similar evaluations using nutrient concentrations determined in the laboratory, which may be more accurate, but offers less flexibility.

Notably, the results obtained for CUCa and CUDa were very close to 100%, which could have been due to solubilization of the fertilizers. These results demonstrated that in this case, CUC and DUC were mainly responsible for the values of CUCn and DUCn, with the latter always being inferior to the former, as also found in the work of Rodrigues et al. (2020).

5.1 Statistical quality control charts

Although the CUC and DUC classified all the treatments as "excellent", control charts were constructed to determine whether the results were statistically under control. Figures 2 and 3 present the control charts for the evaluations, constructed only for the treatments and variables with normal distributions, according to the Anderson-Darling test. The points in red and the circled regions indicate occurrences of statistical lack of control for the treatment.

Figure 2. Statistical control charts for CUC.

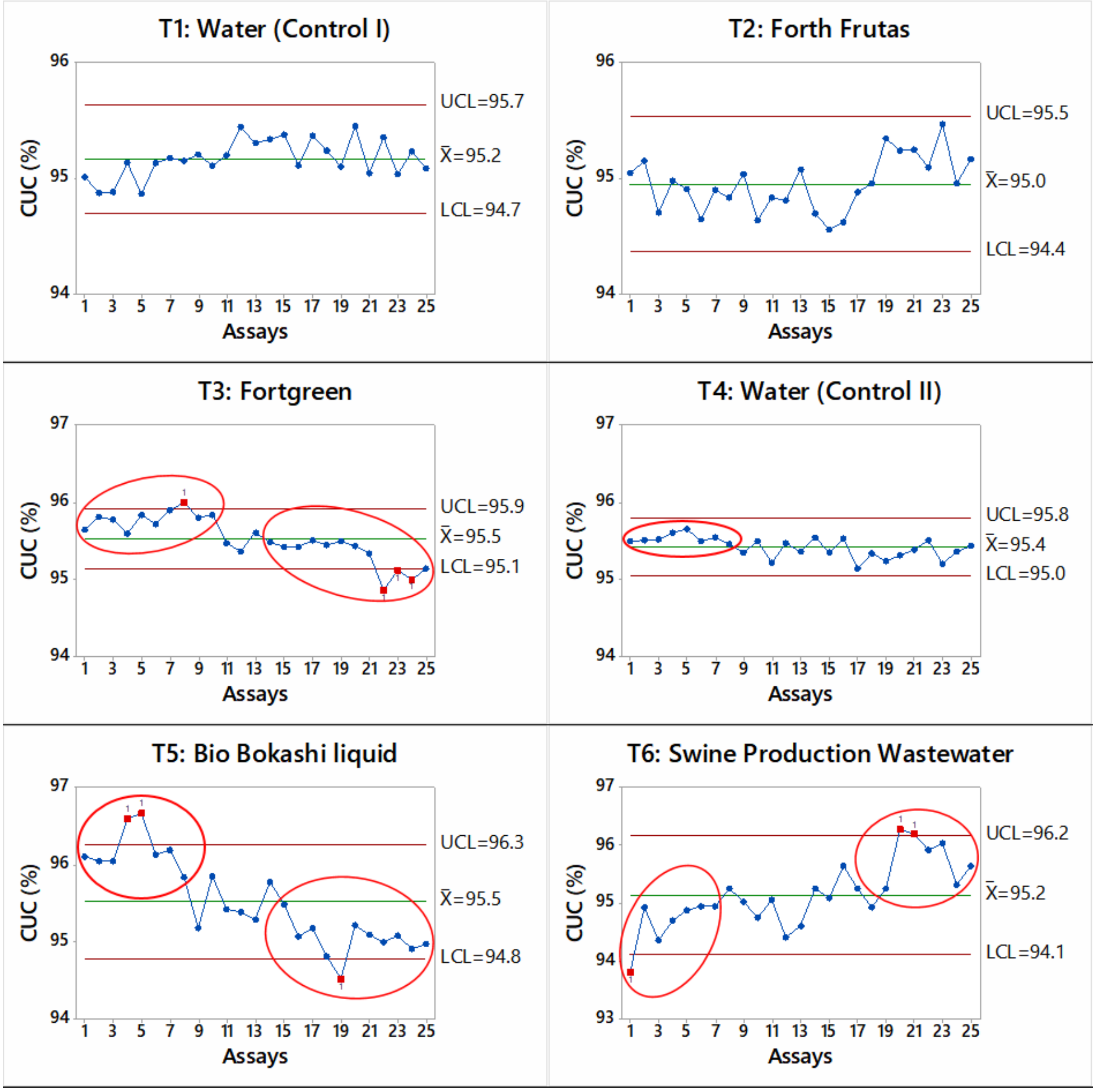
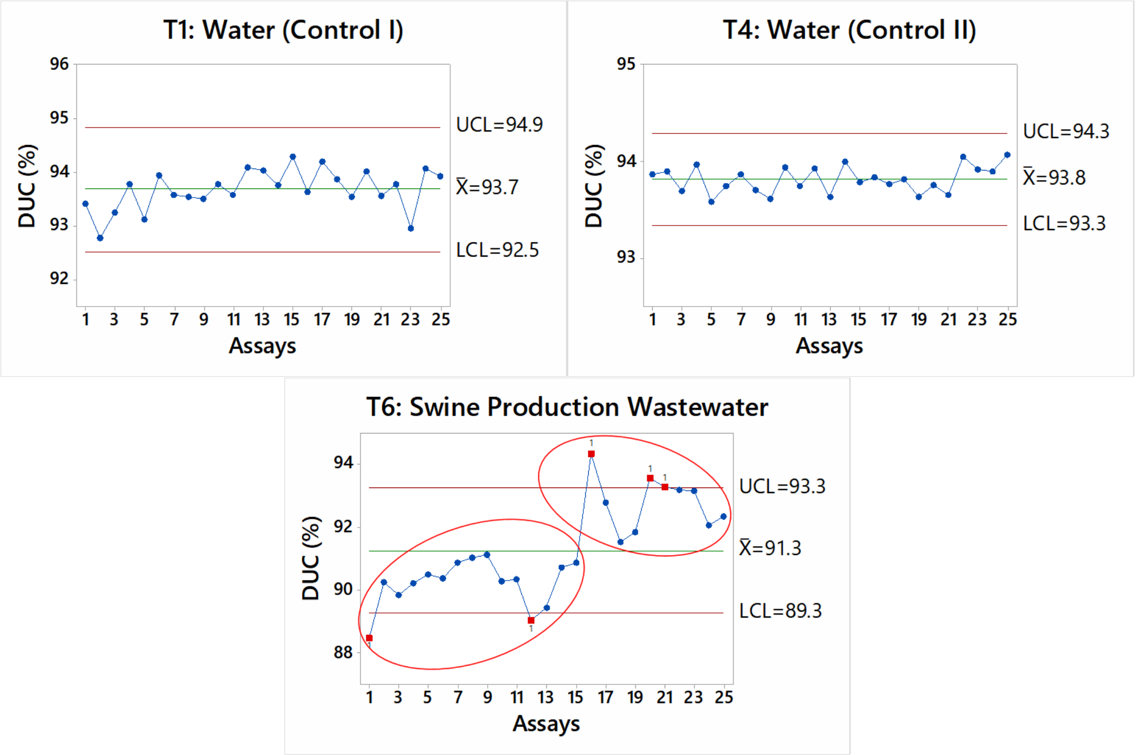


Figure 3. Statistical control charts for DUC.



It can be seen from Figures 2 and 3 show that for CUC, treatments T1 and T2 were statistically under control due to the absence of trends and sequences, with values within the limits. However, the other treatments (T3 to T6) were statistically out of control, as shown by values exceeding the limits and presence of trends. For DUC, T1 and T4 were under control, while T6 was out of control, due to exceedances of the limits and the presence of trends.

The statistical control charts and the means comparison test showed that in both cases, the only treatment under control was T1, which the Tukey test indicated to be inferior or intermediate. Although the CUC and DUC classifications for all the treatments exceeded 90%, the charts revealed an absence of control for the treatments with fertigation due to the increased variability of the processes and consequently decreased quality, compared to irrigation without fertilizers.

The results obtained were in agreement with the findings of Tessaro (2012), who also observed excellent CUC and DUC values, but no statistical control, for drip fertigation. Szekut et al. (2018) evaluated drip system flows for different slopes using clean water, water with fertilizers, cassava processing wastewater, and poultry slaughterhouse effluent. A lack of control was observed for the organic treatments, while the best control was obtained for water with fertilizers, followed by clean water. This differed from the present findings, where the best statistical control was observed using clean water.

Different results were reported by Hermes et al. (2013), who evaluated fertigation with cassava-processing wastewater (CPW) and irrigation with clean water, employing a drip system. Both systems showed a lack of control, although the irrigation presented superior uniformity, classified as "excellent", while the fertigation was classified as "good". In another study, Hermes et al. (2015) evaluated fertigation with CPW and clean water applied using a drip system and collected in different periods. The absence of control was observed only for one period of CPW collection, while DUC classified the treatments as “excellent,” again except one CPW collection period, which was classified as “good”.

Chinchilla et al. (2018) evaluated drip fertigation with treated domestic sewage and irrigation with clean water during 85 h of operation, using four types of drip emitters. When new, the emitters statistically remained under control, but all were outside the control parameters at the end of the processes employing the fertigation compositions. It was suggested that an evaluation conducted in the first seven hours could assist in the adoption of measures to minimize clogging and maintain the performance of the process. A possibility highlighted was monitoring the behavior of the system using the last emitters in the lines, since they presented lower average flow rates than the others, under all conditions.

Justi and Saizaki (2016) studied a sprinkler fertigation system and observed statistical absence of control for CUC and DUC. In other work, investigating sprinkler irrigation, Tamagi et al. (2016) applied the use of control graphs for monitoring, enabling the identification of points outside the control limits, attributed to the effects of wind.

In this work, a possible cause of variation was the temperature variation during the day, since the 25 assays of each treatment was performed in two periods, one with 15 assays and the other with 10 assays, during the periods 07:00-11:00 h and 14:00-17:00 h. This could provide an explanation for the more significant changes observed between tests 10 and 11 and/or 15 and 16, in agreement with the studies of Al-Amoud, Mattar and Ateia (2014) and Tan et al. (2017), who found that the temperatures of the environment and the water could affect the uniformity of the system.

The amplitudes between the lower and upper limits were low, generally between 1 and 2%, without exceeding 4%. This indicated that although the fertigation did not present statistical control, uniformity values were high and close to those of the controls. Hence, the charts should not be used in isolation, but rather as complementary tools. They could be used for the monitoring of system components and identification of problems such as clogging, enabling the timely implementation of corrective measures, as also mentioned by Chinchilla et al. (2018).

The results demonstrated the effectiveness of control charts for monitoring irrigation, considering the quality of the process and the standardization of system components such as the drip pipe. The identification of changes in the system can assist in establishing the most appropriate times for cleaning and maintenance, ensuring the best possible operating conditions. In the field, the use of charts with preestablished uniformity limits can provide alerts for suitable actions to be taken when values approach the established limits.

6 CONCLUSIONS

Under the conditions employed in this work, irrigation and fertigation (mineral or organic) showed similar uniformities in most cases, with index classifications of “excellent”, demonstrating the viability of using different fertigation compositions in the system. Evaluation using traditional methods complemented by the proposed indexes for nutrients, obtained from electrical conductivity measurements, is a viable approach that is easy to perform at the field level.

The use of statistical control charts is also an effective way to monitor the quality and stability of the system, only requiring studies to improve calibration procedures. Better understanding of potential interferences in irrigation/fertigation systems can assist in improving existing monitoring methods and developing new strategies for this purpose.

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