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Statistical process control in self compensating emitters using water at different saline concentrations

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The statistical process control applied in the irrigation systems allows the visualization of process to reduce wastage of inputs, such as water and energy quality, which contributes to assessing its proper functioning, and feasibility of implementation and operation. That is why it is necessary to evaluate the self-compensating emitters using saline water at different concentrations. This experiment was applied in the greenhouse, agricultural engineering academic unit, Federal University of Campina Grande. The treatments consisted of five salinity levels of irrigation water (ECwi) (0.6, 1.5, 2.5, 3.5 and 4.5 dS m^{-1} at 25°C), set in pressure of 160 kPa during 15 irrigation trials for new emitters, with 350 h of operation. The use of statistical process control tool has shown promise in identifying emitters' problems due to the use of lower quality water for irrigation. The inferior quality of water does not influence the flow and Christiansen uniformity coefficient of self-compensating emitters, but after 350 h of operation, there is need management operations and maintenance of the system to be made. The uniformity coefficient Christiansen (CUC) for new and used emitters above 90% was rated as excellent in all treatments saline. The Shewhart control charts allowed diagnosing of about 350 h of operation which is necessary for the maintenance of the irrigation system when operating with saline water.

Key words: Quality engineering, Shewhart charts, electrical conductivity.

INTRODUCTION

Statistical process control is a tool in scientific experiments, used to assess product quality and can submit changes so as to generate information to improve it (Montgomery, 2009). This information helps to verify that the process is within an acceptable standard of quality (Werkema, 1995).

Irrigation systems are perfectly adapted to the application of statistical quality control, since with the fixed elimination of waste water in the operation and maintenance there are cost reduction and increased efficiency of the systems (Justi et al., 2010).

One of the main tools of statistical control are the Shewhart charts that allow monitoring of the average and the variability of the evaluated data quality characteristics

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inherent in any product or process (Saldanha et al., 2013;Ide et al., 2009; Roldan et al., 2013). It is also important to point out that, regardless of the process, it will hardly be the null variability.

In Brazil, there are few places that have enough structure to make a detailed assessment of irrigation systems in order to be able to carry out the improvement of such equipment, and it is necessary for the construction of test benches designed for laboratory testing in order to compare with the field conditions (Valnir Júnior et al., 2011).

The deployments of increasing frequent environmental laws and stringent rules on the classification of water bodies and environmental guidelines were made to frame CONAMA RESOLUTION nº 357, on 17 March 2005. Technological development for systems that make use of low-quality water is increasingly necessary, considering the rationing of this well increasingly scarce on the planet (Orssatto et al., 2014). Faced with the problem of scarcity of water resources, saline water irrigation system applied to crops was used as an alternative; aimed to save water resources of good quality (Busato and Soares, 2010).

Therefore, the use of the control tools in identifying problems caused by emitters on the basis of low-quality water usage in irrigation is of utmost importance, since the methodology used for the evaluation of uniformity based on coefficients of uniformity can be subjected to errors. In this way, the Shewhart control charts rise as an alternative to identifying random variations, common causes, systematic variations, and the special causes of continuous adjustment process allowed.

The aim of this study is to evaluate self-compensating emitters submitted to the use of different saline water concentrations through the application of statistical process control tools.

MATERIALS AND METHODS

The experiment was conducted in a greenhouse owned by an academic unit of agricultural engineering, Federal University of Campina Grande - PB, 7° 12 ' 88 "South latitude, 35° 54 ' 40" West longitude and an average elevation of 532 m.

The pressurization system used in the experiment consisted of a motorcycle 0.5 HP centrifugal pump. The operation of pump operation, with start time 6.00 h and end each cycle of application at 11.00 h, was performed manually following the start times, duration of application and flow test. To prevent the entry of suspended particles in the system with size greater than the diameter of the exit of the emitters, a 1 "screen filter with a capacity of 5 m^3 h^{-1} was used. The five sidelines were composed of masonry structure with 8 m long, 1 m wide and 0.11 m tall, with three experimental modules, five reservoirs and Bourdon type gauge 1, connected to the input of the emitters. The drip hose used in the experiment is self-compensating, with emitters spacing of 0.30 m and a recommended operating pressure in the range of 60 to 420 kPa.

The treatments were composed of five levels of irrigation water salinity (ECw) (0.6, 1.5, 2.5, 3.5 and 4.5 dS m^{-1} at 25°C) and three repetitions, to 160 pressure (kPa) provided to the system. The waters of different concentrations saline were prepared methodology as proposed by Richards (1954).

The flow rates of the emitters were sampled comparable to the method proposed by Deniculi et al. (1980). 15 evaluations in each collection to new emitters and 350 h of operation at each level of salinity of the water were carried out. The flow data determined the coefficient of the uniformity of Christiansen CUC (Equation 1):

$$CUC = 1 - \left(1 - \frac{\sum_{i}^{n}|Q_i - \bar{Q}|}{n * \bar{Q}}\right) \quad (1)$$

In that, Qi = flow collected on each emitter (L h^{-1}); $\bar{Q}$ = average flow rates collected from all the emitters (L h^{-1}); n = number of emitters. The application of the tools provided by the statistical process control emphasized the need to determine the normality of the data by the Kolmogorov-Smirnov test, with the modification of Lilliefors, then the stages of statistical process control was applied through the Shewhart control charts of individual samples, with the aid of Minitab 16 software.

The "X - R" graphic was used in monitoring the mean value (X) and its variability. The model uses the arithmetic mean of the values resulting from the measurements of sample form as a process of position measurement, securing three standard deviations, increased average standards and setting the Upper Control Limit (UCL). According to Equation 2, three fallen deviations from the average as Equation 3 sets the Lower Control Limit (LCL) of the process; thus, the center line represents the mean value of quality according to the state under control (Lima et al., 2006).

$$UCL = X + 3\sigma \quad (2)$$

$$LCL = X - 3\sigma \quad (3)$$

In that, UCL = upper bound of control; X = is the control chart axis and corresponds to the average value of flows; σ = is the estimator of the population standard deviation; LCL = lower bound of control.

RESULTS AND DISCUSSION

Normality tests

The results of applying the Kolmogorov-Smirnov test for normality with the modification of Lilliefors (Lilliefors, 1967), to flow and the Christiansen Uniformity coefficient (CUC) of new issuers, are in Table 1 with uniformity coefficient of Christiansen (CUC) of new emitters. It was found that only the flow parameter from issuers to S2 treatment (1.5 dS m^{-1}) did not obtained a normal distribution; this fact occurred because the level of significance observed is lower than 10%. Possibly, this could have occurred because of differences between the data, but as the samples were always collected in pairs, the difference may be due to the clogging of the holes, providing flow with uneven distribution.

Saldanha et al. (2013) opine that the process has a normal distribution of their frequencies that can carry out a proper assessment of process capability. If these prerequisites are not met, it is not possible to make any inference about the process capability.

The normality of the data by the Kolmogorov-Smirnov with modifying Lilliefors (Lilliefors, 1967) to the flow and the coefficient of uniformity of Christiansen (CUC) to

Table 1. Descriptive statistics of parameters evaluated according to the Kolmogorov-Smirnov test with the Lilliefors modification (1967) for flow and Christiansen uniformity coefficient in the new emitter.

Parameter	Maximum value	Minimum value	Average	Standard deviation	CV	Normality			
						Value	V Crit	P- Valor	Normal
S1 (0.6 dSm^{-1})									
FLOW	2.45	2.21	2.39	0.064	0.69	0.12	0.22	0.15	Yes
CUC	99.98	98.53	99.41	0.46	0.47	0.10	0.22	0.15	Yes
S2(1.5 dSm^{-1})									
FLOW	3.64	2.21	2.45	0.33	13.76	0.42	0.22	0.01	No
CUC	99.89	97.00	98.92	0.87	0.88	0.13	0.22	0.15	Yes
S3(2.5 dSm^{-1})									
FLOW	2.45	2.21	2.37	0.07	3.28	0.15	0.22	0.15	Yes
CUC	99.94	97.47	99.20	0.67	0.68	0.13	0.22	0.15	Yes
S4(3.5 dSm^{-1})									
FLOW	2.45	2.21	2.38	0.06	2.53	0.12	0.22	0.15	Yes
CUC	99.97	99.06	99.56	0.32	0.32	0.12	0.22	0.15	Yes
S5(4.5 dSm^{-1})									
FLOW	2.45	2.21	2.38	0.06	2.66	0.19	0.22	0.10	Yes
CUC	99.98	98.75	99.49	0.41	0.42	0.12	0.22	0.15	Yes

p-valor, The observed significance level. Vcrit:, critical value.

Table 2. Descriptive statistics of parameters evaluated according to the Kolmogorov-Smirnov test with the Lilliefors modification (1967) for flow and Christiansen uniformity coefficient in drippers with 350 h of operation.

Parameter	Maximum value	Minimum value	Average	Standard deviation	CV	Normality			
						Value	V Crit	P- Valor	Normal
S1 (0.6 dSm^{-1})									
FLOW	2.57	2.09	2.32	0.15	6.65	0.13	0.22	0.15	Yes
CUC	99.88	96.58	98.57	0.92	0.93	0.15	0.22	0.15	Yes
S2(1.5 dSm^{-1})									
FLOW	2.60	2.21	2.41	0.12	4.98	0.13	0.22	0.15	Yes
CUC	99.93	90.00	97.71	2.35	2.38	0.19	0.22	0.10	Yes
S3(2.5 dSm^{-1})									
FLOW	2.63	2.27	2.47	0.10	4.30	0.09	0.22	0.15	Yes
CUC	99.88	97.75	98.77	0.74	0.75	0.11	0.22	0.15	Yes
S4(3.5 dSm^{-1})									
FLOW	2.61	2.15	2.49	0.13	5.45	0.22	0.22	0.05	No
CUC	99.94	94.34	98.61	1.34	1.36	0.17	0.22	0.15	Yes
S5(4.5 dSm^{-1})									
FLOW	2.75	2.27	2.49	0.15	6.03	0.19	0.22	0.10	Yes
CUC	99.69	97.00	98.53	0.84	0.85	0.08	0.22	0.15	Yes

p-valor, The observed significance level. Vcrit:, critical value.

emitters with 350 h of operation are shown in Table 2. Note that the flow to the emitters in S4 (3.5 dSm^{-1}) did not show a normal distribution, since the observed level of significance was 0.05. This can be explained by sediment

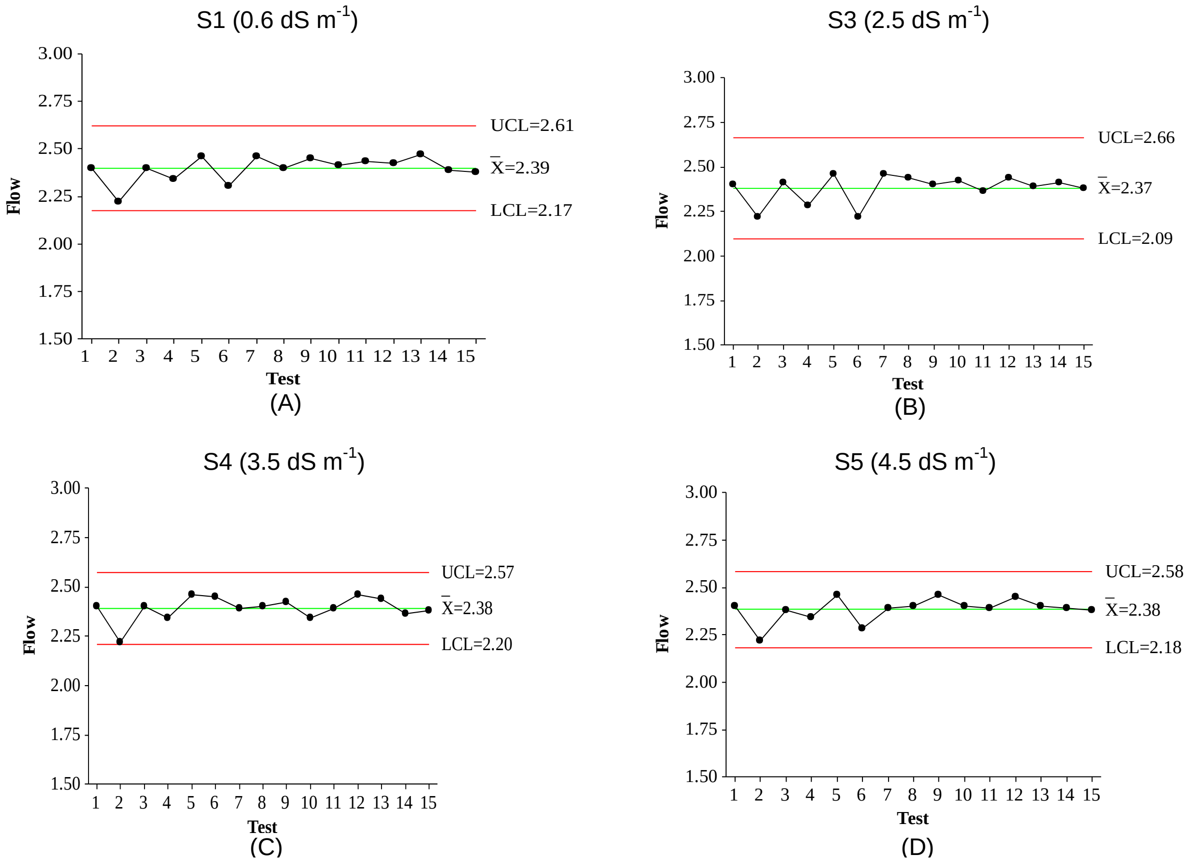

Figure 1. Control charts of individual flow measurements for the S1 treatment (A), S3 (B), S4 (C) and S5 (D) in the new emitters.

buildup forming a white crust through the water reflected in the hole observed in differences flows. Vasconcelos et al. (2013) found similar results for the electrical conductivity of water, using the same Lilliefors modification test.

Application of statistical process control

The Shewhart control chart for individual measurements over 15 tests for evaluation of the emitters is given in Figure 1. It was observed that the testing for the flow of the new emitters in the S1 treatment (0.6 dS m^{-1}); S3 (2.5 dS m^{-1}) and S5 (4.5 dS m^{-1}) are within the control limits, that is they did not show variation, >3σ or <3σ which were the limits for the process, and the UCL control upper limit of approximately (2.66 L h^{-1}) and lower control limit LCL (2.09 L h^{-1}). The process was under control and the distributed flow near the observed mean line (2,3 h L^{-1}) was indicated. Thus, there was no particular factor that promotes a process that behaves differently than usual or could result in a displacement of the expected quality level (Figure 1A, B and D).

The S4 treatment (3.5 dS m^{-1}) test 2 was close to the lower control limit, that is, out of statistical control (Figure 1C). According Werkema (1995), this fact is indicative of the lack of control of a process due to special causes that account for 15% of the problems in the process. The removal of these special causes may be done by trained operatives and maintenance personnel through local actions such pressure variation correction, cleaning emitter obstructed, the energy oscillation control and others that do not involve significant investment, that is, there is a point at which maintenance needs for the irrigation system may be used efficiently.

If special causes responsible for process variation are eliminated, and even present in a normal distribution, then it can be considered that the process is in statistical control, which means it is a stable process. Even so, the process still produces defective items and it is essential to evaluate the process capability to meet the specifications laid down in accordance with customer requirements (Gonçalez and Werner, 2009).

A similar result was gotten by Juchen et al. (2013) while studying drip irrigation for the production of fertigated lettuce with agro-industrial wastewaters. The limits control specification (ECL) were among 6,069 L h^{-1} m^{-1} for the lower limit (LCL) and 8,058 L h^{-1} m^{-1} to the upper limit (UCL); four treatments applied work were observed and the flows were distributed close to the

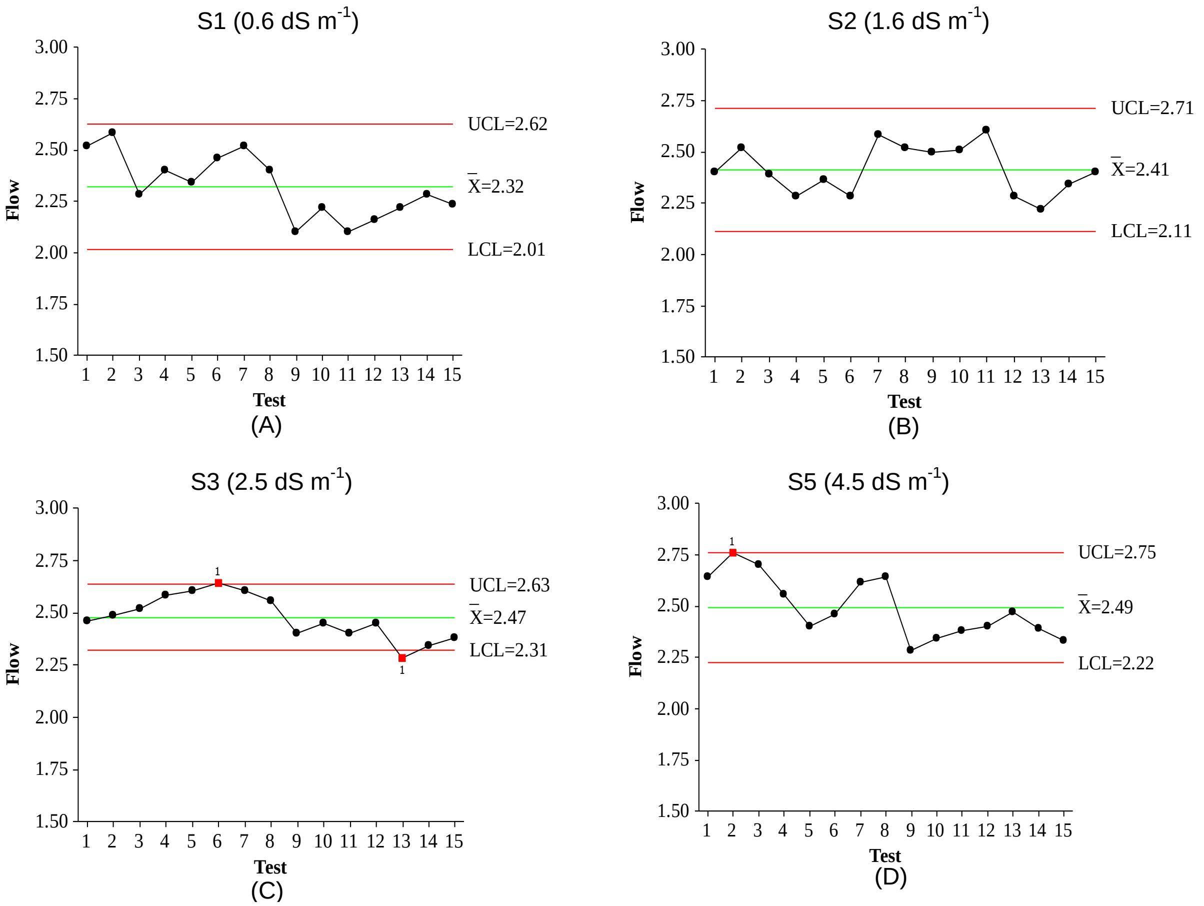

Figure 2. Control charts of individual flow measurements for the S1 treatment (A), S2 (B), S3 (C) and S5 (D) applied to emitter with 350 h of operation.

average of 7,063 L h^{-1}m^{-1}. As for the S2 (1.5 dS m^{-1}) points of the tests, they were not normally distributed and, therefore, could not get a control chart with the same.

The data collected for the preparation of Shewhart charts with 350 operating hours over 15 trials are shown in Figure 2. It is noted that the S1 treatment (0.6 dS m^{-1}) and S2 (1.5 dS m^{-1}) flow of data remains within the control limits (Figure 2A and B), but for the S1treatment (0.6 dS m^{-1}) test 4 to 8, the data represented an average line sequence above and as for the S2 treatment (1.5 dS m^{-1}) test 7 to 11, the data are in the following midline above; therefore, such processes were considered out of quality statistical control (Figure 2A and B).

A similar result was that of Giron et al. (2014) who studied the application of statistical process control in a company poultry sector. Such observations may be the result of one or a few related causes that produces large variations in the process and occur as a result of behavior deviations from "normal" process, and lack of timely evaluation agreement with the criteria recommended by Werkema (1995), which may happen due to changes in temperature conditions inside the greenhouse or even destabilization of the pressure supplied to the system.

In S3 treatment (2.5 dS m^{-1}), it is observed that test 6 is above the upper control limit and the test 13 below the control lower limit outside. Therefore, for the process to S5 treatment (4.5 dS m^{-1}), test 2 is above the upper control limit, similar to the S3 treatment (2.5 dS m^{-1}) which process remains out of control (Figure 2C and D). These variations of controlled irrigation may be the result of variations in the irrigation system as an oscillation in the emitter operating pressure during operation (Montgomery, 2009). Also according to the author, points that are under the lower control limit (LCL) recommended denouncement of the existence of some problems in the process and, in the case of evaluation of irrigation, they can be explained by factors such as pressure variation system, clogging, water temperature, and many other factors.

Figure 3 displays the results for individual measures with the distribution of 15 tests for the Christiansen uniformity of coefficient (CUC). There is, for the S1 treatments (0.6 dS m^{-1}); S2 (1.5 dS m^{-1}); S4 (3.5 dS m^{-1}) and S5 (4.5 dS m^{-1}). The CUC results were satisfactory

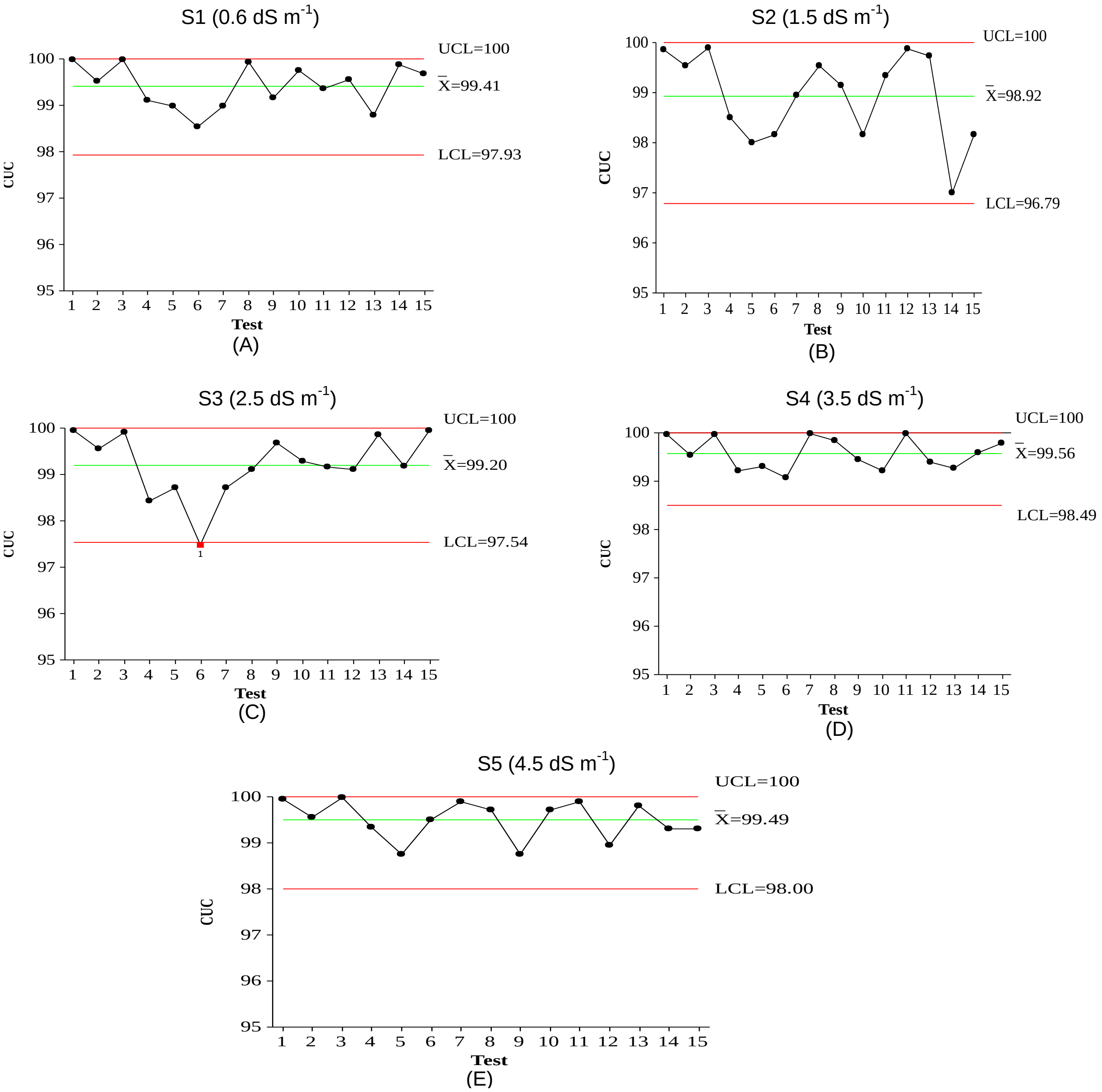

Figure 3. Control charts for individual averages and Christiansen uniformity coefficient (CUC) as a function of salinity of irrigation water S1(A), S2 (B), S3 (C), S4(D) and S5 (E) in new emitters.

although some trials were very close to the UCL and the data distribution was random to the median line lying within the control limits. However, only the S1 and S5 are under control treatments. S2 treatment (1.5 dS m^{-1}) is from test 4 to 9; sequence points such as the S4 (3.5 dS m^{-1}) have a non-random point sequence 11 to 15 (Figure 3 A, B, D and E).

Juchen et al. (2013) also noted in their study, the existence of a type of points sequence below the central line configuration between samples 22 to 27, suggesting therefore that there may be a special problem cause for the process and promotes a different behavior as usual or may result in a displacement of the expected quality level.

For S3 treatment (2.5 dS m^{-1}) it is found that the test 6 is below the lower control limit (LCL = 97.54%) and this is considered an extreme variation for having a point outside the limit, that is, the process is out of quality control, but no value was greater than the upper control limit (UCL = 100%) (Figure 3C). Similar results were found by Hermes et al. (2013) in his work on quality control in drip irrigation with a wastewater cassava

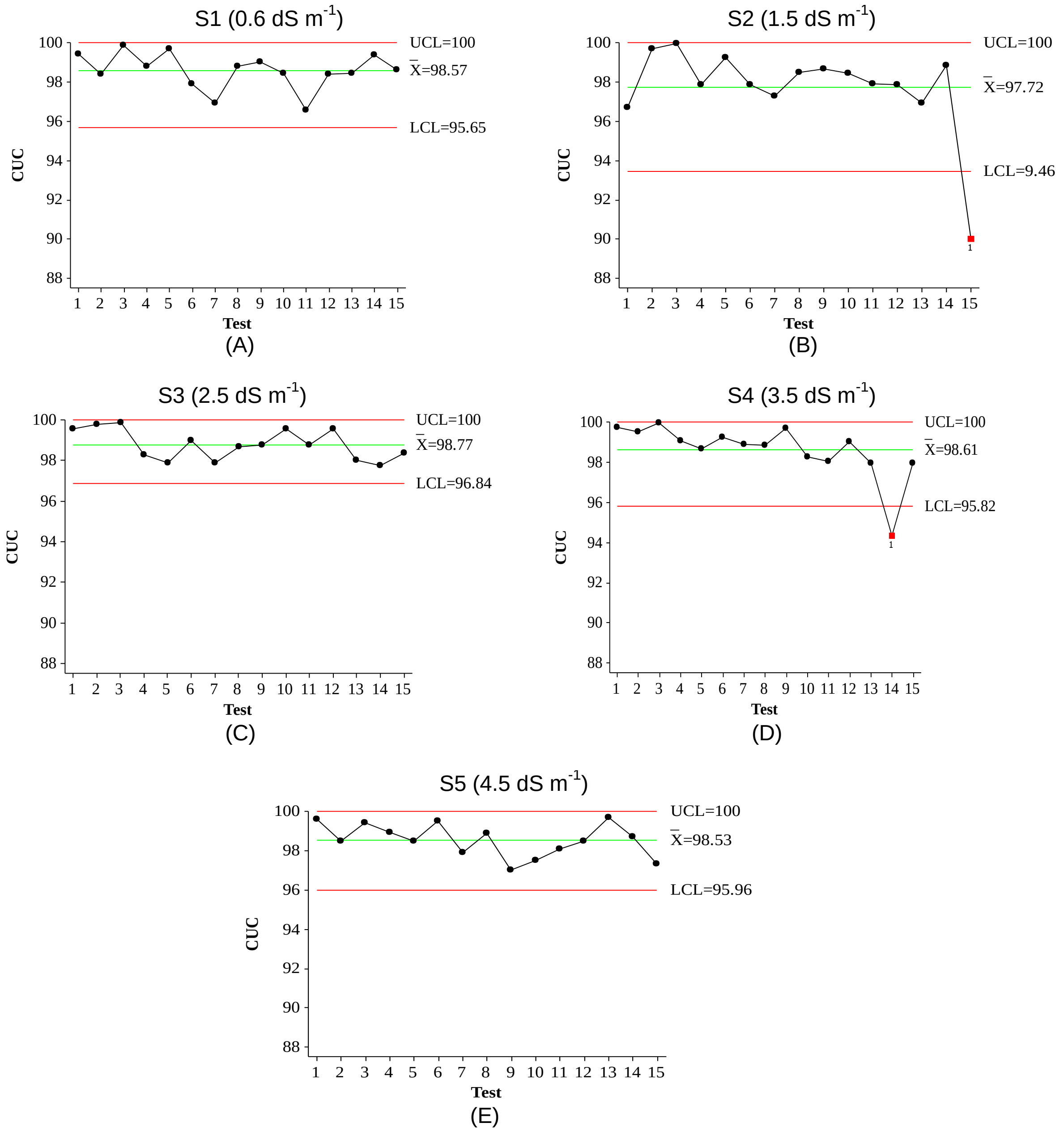

Figure 4. Control charts for individual averages and Christiansen uniformity coefficient (CUC) as a function of salinity of irrigation water S1(A), S2 (B), S3 (C), S4(D)and S5 (E) with 350 h operation.

processing system.

Another observation was indications of lack of control in the S2 treatments process (1.5 dS m^{-1}); S3 (2.5 dS m^{-1}) and S4 (3.5 dS m^{-1}) with the existence of consecutive sequences values both above and below the middle line, besides the very occurrence points outside the control limits (Figure 3B, C and D). It is emphasized, however, that all assays over 90% were rated as excellent Justi et al. (2010) applied control chart $\bar{X}$ for Christiansen uniformity coefficient in a sprinkler irrigation system and observed the existence of a point outside the upper control limit, and the graph had behaved so similar to that described in this study. Frigo et al. (2013) states that the values above the upper control limit should be considered acceptable because the higher the values, the better the irrigation of evaluated coefficients.

The control chart for the CUC in 15 tests, with five irrigation water salinity levels with 350 operating hours is seen in Figure 4. Note that S1; S3 and S5 were approximately between 95% for the lower limit (LCL) and 100% for the upper limit (UCL) and by observing 3 treatments, it is seen that the CUC is distributed close to the average of 98% while the S1 treatment and S3 were under control. However, in the S5 treatment the existence of a sequence values setting type, such as the increase of the Christiansen uniformity coefficient, 9 to 13 was observed (Figure 4A, C, and E).

Juchen et al. (2013) also found the same effect studying quality control in drip irrigation for the production of lettuce fertigated with agro industrial wastewaters.

For Gonçalves and Antoniassi (2010), the estimation uncertainty is a term that refers to statistical control maintenance as a survey conducted by a testing laboratory that can only return to the specific or random causes, while significant changes in the object usually analyzed occur in uncertainty.

In S2 treatments (1.5 dS m^{-1}) and S4 (3.5 dS m^{-1}) the existence of a sequence of values of the type which also have points outside the lower limit setting control (LCL = 98 46 and 95.82%, respectively) (Figure 4B and D) was observed. When observing some point outside the control limits, when the point is below the lower control limit, it indicates that this should be given special attention and be investigated (Souza et al., 2009). Also, according to the authors one process is out of control when one or more points are outside the limits; under the random configuration or when there are special settings with points inside or outside the control limits.

In this context, the use of statistical methods does not guarantee the solution of all the problems of a process, but it is a rational, logical and organized way to determine where the problems are and to find ways to solve them. These methods can help in getting systems to ensure continuous improvement of quality and productivity at the same time (Lima et al., 2006).

Conclusions

1. The use of statistical process control tool has shown promises in identifying emitters' problems due to the use of lower quality water for irrigation.
2. The inferior quality of water does not influence the flow and Christiansen uniformity coefficient of self-compensating emitters, but after 350 h of operation, management operations and maintenance of the system should be made.
3. The uniformity coefficient Christiansen (CUC) for new and used emitters above 90% rated were excellent in all treatments S1 saline (0.6 dS m^{-1}), S2 (1.5 dS m^{-1}), S3 (2.5 dS m^{-1}), S4 (3.5 dS m^{-1}) and S5 (4.5 dS m^{-1}).
4. The Shewhart control charts allowed diagnosing of about 350 h of operation which is necessary for the maintenance of the irrigation system when operating with saline water.

Conflict of Interests

The authors have not declared any conflict of interests.

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