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Performance of drip irrigation system with bokashi fertilizer

Desempenho de um sistema de irrigação por gotejamento com fertilizante bokashi

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Highlights

The application of 5 g L^{-1} of bokashi performs well in drip irrigation.
A concentration of 15 g L^{-1} is unsuitable for drip irrigation.
The Shewhart control chart proved to be less sensitive in detecting non-uniformities.

Abstract

Drip irrigation systems have gained popularity as efficient solutions for enhancing water and fertilization use in agriculture. Despite their high efficiency, drip systems face the serious issue of dripper clogging. The problem is exacerbated by fertilizers that are not yet widely used in fertigation, such as bokashi. This study aimed to evaluate the performance of a drip irrigation system using bokashi. A drip irrigation system was installed under field conditions, and 25 trials were conducted for each bokashi concentration (5 g L^{-1}, 10 g L^{-1}, and 15 g L^{-1}) and irrigation (control). Uniformity was determined by uniformity distribution (UD) and monitored using Shewhart control charts. The spatial interpolation of the dripper flow rates was performed using the inverse distance method. Concentrations of 10 and 15 g L^{-1} resulted in high sediment levels, leading to clogging and reduced uniformity of 70.08 and 59.97%, respectively. Despite some physicochemical parameters indicating a high risk of clogging, the 5 g L^{-1} concentration achieved good uniformity, with a UD of 88.47%. Greater flow variations were observed along the lateral lines with increases and decreases for 10 and 15 g L^{-1}. Owing to its low sensitivity, the Shewhart control chart did

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not show out-of-control points for 5 and 10 g L^{-1} concentrations and only a few final points for 15 g L^{-1}, despite the high process variability.
Key words: Drip fertigation. Organic fertilizer. Uniformity.

Resumo

Em busca de soluções que aumentem a eficiência da água e fertilização na agricultura o uso de sistemas de irrigação por gotejamento vem se destacando. Apesar da alta eficiência, os sistemas por gotejamento possuem o problema do entupimento dos gotejadores o que compromete seu desempenho. Este problema é maior quando se utilizam fertilizantes que ainda não são difundidos na fertirrigação, como o bokashi. Este estudo teve o objetivo de verificar o desempenho de um sistema de irrigação por gotejamento com a utilização de bokashi. O sistema de irrigação por gotejamento foi instalado em condições de campo, realizando 25 ensaios para cada concentração de bokashi (5 g L^{-1}, 10 g L^{-1} e 15 g L^{-1}) e irrigação (controle). A uniformidade foi determinada pelo Coeficiente de Uniformidade de Distribuição (CUD) e monitorada pelo gráfico de controle de Shewhart. A interpolação espacial das vazões dos gotejadores foi realizada pelo método do Inverso da Distância. Concentrações de 10 e 15 g L^{-1} apresentaram elevados teores de sedimentos, que ocasionaram entupimentos e diminuíram a uniformidade, com 70.08% e 59.97%, respectivamente. A concentração de 5 g L^{-1} apesar de alguns parâmetros fisico-químicos com alto risco de entupimento, obteve uma boa uniformidade, com CUD de 88.47%. Maiores variações de vazão foram observadas ao longo das linhas laterais, com aumentos e diminuições para 10 e 15 g L^{-1}. Devido à sua menor sensibilidade, o gráfico de controle de Shewhart não apresentou pontos fora do controle para as concentrações de 5 e 10 g L^{-1}, e apenas alguns pontos finais para 15 g L^{-1}, apesar da alta variabilidade do processo.
Palavras-chave: Fertilizante orgânico. Fertirrigação por gotejamento. Uniformidade.

Introduction

The adoption of highly efficient irrigation systems is essential to promote a more rational use of water resources (Nascimento et al., 2009). Given the growing scarcity of water, drip irrigation has emerged as one of the main alternatives to irrigated agriculture owing to its superior efficiency (Petit et al., 2023).

In addition to its high efficiency, drip irrigation also enables the application of fertilizers through the irrigation system. This process, known as fertigation, involves the use of soluble fertilizers delivered via irrigation water. It is a widely adopted technique in modern irrigated agriculture and can employ fertilizers in both solid and liquid forms, including organic sources (Lopes et al., 2021b).

The use of organic fertilizers in irrigation provides several advantages. These fertilizers are generally less expensive than chemical ones, contribute to improving soil structure (Hemmat & Tacit, 2001) and fertility (Wang et al., 2019), and can even serve as substitutes for mineral fertilizers (Cardozo et al., 2016).

Bokashi is an organic fertilizer produced from diverse organic residues and is characterized by its high nutrient content.

This serves as an alternative method for managing organic waste through lactic acid fermentation under anaerobic conditions (Boechat et al., 2013). This term originates from a traditional Japanese technique with the same name (Olle, 2021). The use of bokashi has been proven effective as it increases soil organic matter, enhances soil physical properties, mitigates salinity, and reduces dependence on chemical fertilizers (Xiaohou et al., 2008). Numerous studies have highlighted its positive effects on plant growth, including those conducted on pink pepper (Wilkomm et al., 2024), papaya (Hafle et al., 2009), and arugula (Hata et al., 2024).

Although drip irrigation systems enable high fertilizer application efficiency, they also face the significant drawback of clogging. This issue arises from several factors, including the composition and concentration of the applied solution, the characteristics of the emitters, and the hydraulic behavior of the system itself (L. Liu et al., 2017; Tang et al., 2018; Yang et al., 2023).

Although drip irrigation systems are already widely adopted, and bokashi is commonly used in agriculture, studies evaluating the performance of irrigation systems that employ bokashi are lacking. Uniformity is the primary parameter considered when assessing the performance of an irrigation system. This is typically quantified through distribution uniformity coefficients, which indicate the variability in water application across irrigated areas. Higher uniformity coefficient values correspond to a more even water distribution, and consequently, lower irrigation costs (Andrade et al., 2017).

The uniformity of a fertigation system is affected by several factors, including the flow rate, pressure, system components, and the solubility and concentration of the fertilizer. According to M. V. A. M. Oliveira and Villas Bôas (2008), the composition of the irrigation solution plays a crucial role in determining distribution uniformity, and aspects such as solubility, application time, and concentration must be carefully considered. Similarly, Fan et al. (2017) emphasized that variations in fertilizer concentration can significantly influence system uniformity.

Although bokashi is widely used in agriculture, its application through fertigation remains unexplored, and there are currently no established recommendations on suitable dosages or their effects on system performance and emitter clogging in drip irrigation systems. In this context, the present study aimed to assess the impact of different bokashi concentrations on the performance of drip irrigation systems using Shewhart control charts as an analytical tool.

Material and Methods

The experiment was conducted at the Center for Agricultural Sciences of the State University of Londrina, located in Londrina, Paraná, at geographic coordinates 23°19′ S and 51°12′ W. The irrigation system was operated under gravity with a hydraulic head of 30 kPa. It comprised flat drip tubes (NETAFIM, model Streamline X 16060) with a diameter of 16.2 mm, an inlet filter with a 12 mm² area, an emitter equation proportionality coefficient (k) of 0.568, and a discharge exponent (x) of 0.45. Drippers were spaced 0.30 m apart along four lateral lines connected to a main line, totaling 33 drippers per line and 132 drippers overall. To minimize clogging, a 120-mesh screen filter was installed near the reservoir.

The bokashi fertilizer tested was a solid organic product composed of castor bean cake (40%), rice bran (25%), wheat bran (25%), bone meal (5%), and basal powder (5%). The physicochemical characteristics are summarized in Table 1. The bokashi solutions were prepared manually and allowed to rest for 9 h before testing. Three concentrations were used: 5 g L^{-1}, 10 g L^{-1}, and 15 g L^{-1}, with plain water serving as a control treatment.

Table 1
Physical-chemical characteristics of the bokashi used in the experiment

Composition	Concentration
Umidity (%)	9.51
Organic carbon (%)	34.19
Compostable organic matter (%)	58.94
Total organic matter (%)	76.62
Total mineral residue (%)	13.87
N (%)	3.19
P (%)	3.94
K (%)	1.65
Ca (%)	1.09
Mg (%)	0.67
S (%)	0.49
Fe (%)	0.2
Mn (mg kg^{-1})	133.21
Zn (mg kg^{-1})	160.77
Cu (mg kg^{-1})	23.89
B (mg kg^{-1})	15.08
pH	5.57
CEC (mmolc kg^{-1})	600
C/N	10.7

Physicochemical analyses of both the water and bokashi solutions were carried out at the initial stage of the experiment, following the American Public Health Association [APHA] (2005) guidelines. Measurements were performed at the Soil Laboratory of the State University of Londrina, including pH, suspended solids (SS), total iron (Fe), magnesium (Mg^{2+}), calcium (Ca^{2+}), potassium (K^{+}), copper (Cu^{2+}), and phosphate (PO_4^{3-})

concentrations (Pavan et al., 1992). These results were evaluated for their potential to cause emitter clogging (Nakayama & Bucks, 1986).

The emitter flow rates were determined according to the method proposed by Keller and Karmeli (1974), which involved measuring four emitters per lateral line: the first dripper, the drippers at 1/3 (11th dripper) and 2/3 (22nd dripper) along the line, and the last dripper (33rd) of each lateral line (Figure 1). For each treatment: water, bokashi 5 g L^{-1}, bokashi 10 g L^{-1}, and bokashi 15 g L^{-1}, a total of 25 tests were performed, as recommended for quality control by Montgomery (2016). The flow rates were measured using the gravimetric method to enhance accuracy. The volume of water collected over a defined time period was used to calculate the dripper flow rates according to Associação Brasileira de Normas Técnicas [ABNT] (2006) using Equation 1:

$$Q = \frac{V}{1000 \times t} \times 60 \qquad (1)$$

Where:

Q = Dripper flow rate, L h^{-1};

V = Volume of the collected solution, mL;

t = Collection time, min.

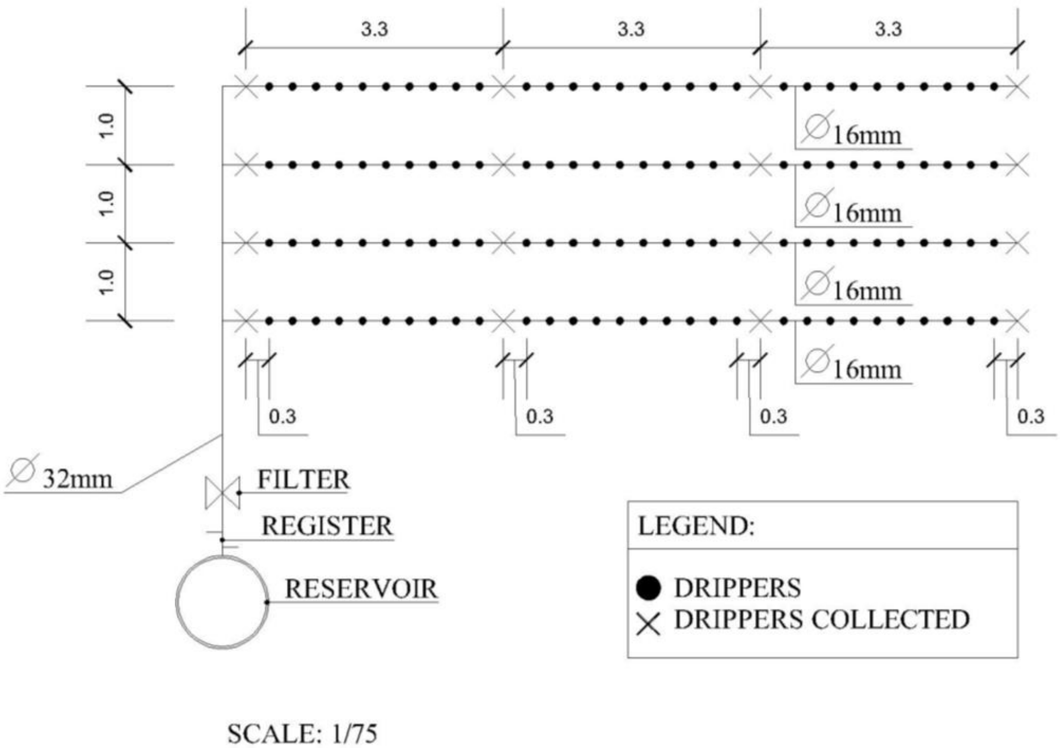

Figure 1. Experimental set-up and data collection methodology.

The Uniformity distribution (UD) was calculated based on the collected flow rates, as described in Equation 2:

$$UD = 100 \frac{q_{25\%}}{\bar{q}} \quad (2)$$

Where:

UD = Uniformity Distribution, %;

$q_{25\%}$ = Average flow rate of the lowest 25% of collected flow values, L h^{-1};

q = Average of all flow rates, L h^{-1}.

The UD results were classified as listed in Table 2.

Table 2
Classification of the distribution uniformity (UD)

UD (%)	Classification
90% or greater	Excellent
80% to 90%	Good
70% to 80%	Regular
60% to 70%	Bad
Less than 60%	Inaceptable

Source: Merriam & Keller (1978)

Shewhart control charts were used for quality control. To construct the Shewhart control charts, it is necessary to calculate the upper control limit (UCL) and lower control limit (LCL), which are obtained using Equations 3 and 4, respectively.

$$UCL = \bar{\bar{x}} + 3\frac{\overline{MR}}{d_2} \quad (3)$$

$$LCL = \bar{\bar{x}} - 3\frac{\overline{MR}}{d_2} \quad (4)$$

Where:

x = Average;

(MR) = Mobile range of observations;

d_2 = A constant equal to 1.128 when the number of observations is n = 2, considering individual measurements according to the tabulated values described by Montgomery (2016).

Interpolation of the drip flow data was performed using the Inverse of Distance Weighting (IDW) statistical model, as described in Equation 5:

$$z = \frac{\sum_{i=1}^{n} \frac{1}{d_i} zi}{\sum_{i=1}^{n} \frac{1}{d_i}} \quad (5)$$

Where:

z = estimate value for point z;

n = number of observations;

z_i = observed values;

d_i = distances between observed and estimated values (z_i e z).

Data were submitted to ANOVA, using F-test at 5% probability. Means were compared using Tukey's test at a 5% significance level. All statistical, graphical, and control charts were created using MINITAB 18 software.

Results and Discussion

Table 3 presents the physicochemical properties of the water and bokashi solutions used in the drip irrigation experiments. The parameters SS, PO_4^{3-}, and K^+ indicate a high risk of dripper clogging, independent of the bokashi concentration applied. Elevated sediment levels are known to contribute significantly to emitter obstruction (Shen et al., 2022; Muhammad et al., 2021). According to Hermes et al. (2018), higher SS concentrations are associated with reduced irrigation uniformity. In contrast, Fe^{2+} and Cu^{2+} concentrations posed a low clogging risk across all tested bokashi concentrations. Analysis of Ca^{2+} indicated a moderate clogging risk for all bokashi treatments, whereas pH values corresponded to a moderate clogging risk for the 10 g L^{-1} and 15 g L^{-1} bokashi solutions.

Table 3
Physicochemical parameters of the analyzed treatments

Fertigation solutions	K^+ (g L^{-1})	PO_4^{3-} (g L^{-1})	Fe^{2+} (g L^{-1})	Cu^{2+} (g L^{-1})	Mg^{2+} (g L^{-1})	Ca^{2+} (g L^{-1})	pH	SS (g L^{-1})
Water	0.065*	0.065*	0*	0*	0.0027*	0.024*	6.2*	0*
Bokashi 5g L^{-1}	7.8***	1.92***	0*	0.0008*	0.23*	0.361**	6.76*	0.324***
Bokashi 10g L^{-1}	8.5***	2.18***	0.111*	0.002*	0.247*	0.472**	7.1**	0.684***
Bokashi 15 g L^{-1}	13.5***	2.77***	0.142*	0.002*	0.429**	0.75**	7.3**	0.964***

* = Low risk of clogging, ** = Moderate risk of clogging, *** = Severe risk of clogging.
Source: Nakayama and Bucks (1986).

A comparison of the results indicates that the 15 g L^{-1} bokashi treatment presents the highest risk of dripper clogging. This risk is exacerbated by elevated concentrations of Ca^{2+} and Mg^{2+} in fertigation solutions, especially when combined with a pH above 7, which promotes scaling (Shi et al., 2022). Additionally, high levels of PO_4^{3-} can react with Ca^{2+} and Mg^{2+} to form insoluble precipitates such as $CaHPO_4$ or $MgHPO_4$, contributing further to the obstruction of drip irrigation emitters (Mikkelsen, 1989).

The 5 and 10 g L^{-1} bokashi concentrations differed only in pH, according to the classification used. For the 10 and 15 g L^{-1} treatments, pH values exceeded 7, a condition that promotes the formation of precipitates. These precipitates tend to accumulate along lateral lines, thereby increasing the risk of emitter clogging (Lamm et al., 2006). Nakayama and Bucks (1986) reported that pH values above 7.2 enhance the precipitation of elements such as calcium and magnesium within filters, pipes, and emitters, thereby contributing to the obstruction of drip irrigation systems.

Characterizing the spatial distribution of water application is crucial for optimizing water use in irrigated areas (Ferreira et al., 2016). Figure 2 presents the contour maps of the emitter flow rates. Spatial analysis revealed similar flow patterns for water and the 5 g L^{-1} bokashi treatment, with the highest rates observed at the beginning of the lateral lines (>0.70 L h^{-1} and 0.67 L h^{-1}, respectively), followed by a gradual decrease along the length of the lateral lines (Figures 2A and 2B).

For the 10 and 15 g L^{-1} bokashi treatments, similar flow patterns were also observed, characterized by an initial increase in some lateral lines followed by a decline toward the end of the lines, with extremely low flow rates (<0.35 L h^{-1} and <0.24 L h^{-1}, respectively) (Figures 2C and 2D). Clogging can cause both increases and decreases in emitter flow, which directly reduces the uniformity of the irrigation system.

For all bokashi concentrations, the flow rates at the ends of the lateral lines were consistently lower than those recorded at the beginning. This variation can be attributed to several factors including energy losses from friction along the pipelines, material quality, water temperature effects on flow, dripper design, partial or complete emitter obstruction, and pressure drops (Dias et al., 2005; Busato et al., 2012). In a study evaluating the spatial variability of flow rates in two drip irrigation systems, Alves et al. (2015) observed that the flow declined owing to pressure reductions along the lateral lines.

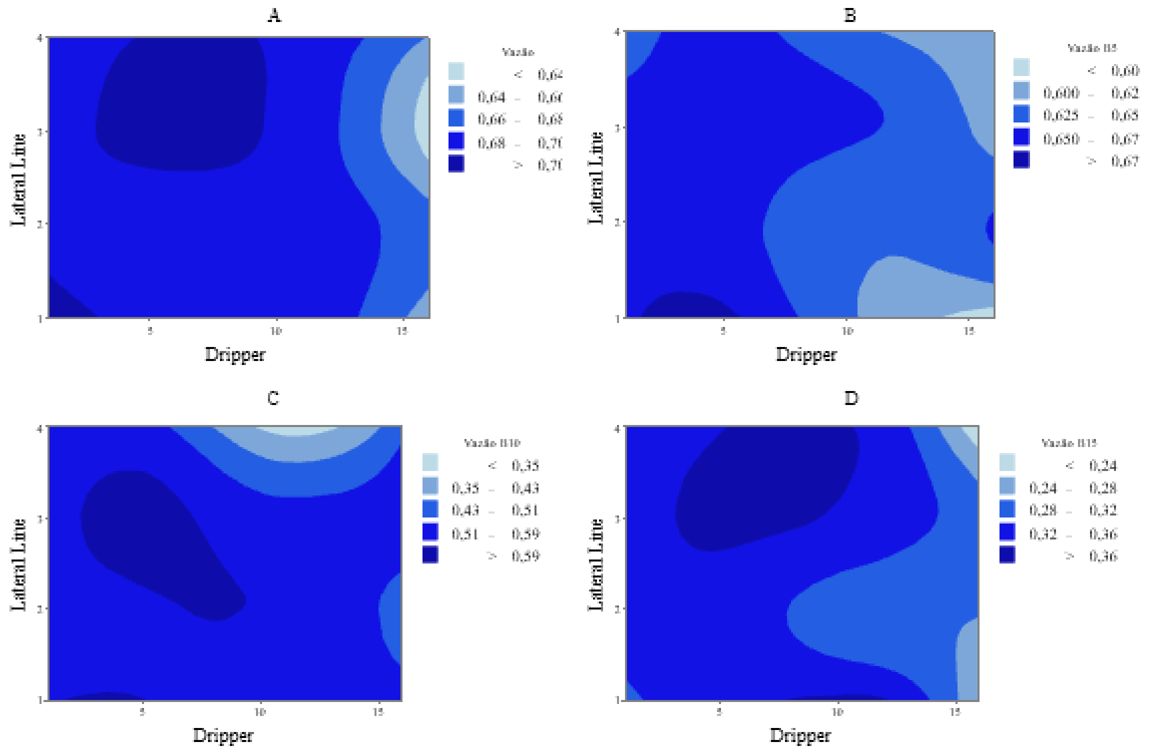

Figure 2. Countour plots for the flow rates with water (A), bokashi 5 g L^{-1} (B), bokashi 10 g L^{-1} (C) and bokashi 15 g L^{-1} (D).

Table 4 indicates that the uniformity of drip irrigation with water (91.23%) and with 5 g L^{-1} bokashi (88.47%) did not differ significantly, reflecting excellent uniformity for water and good uniformity for the 5 g L^{-1} bokashi treatment (Merriam & Keller, 1978). Similar to water, the 5 g L^{-1} bokashi concentration exhibited low variability in uniformity across the tests, suggesting fewer clogging incidents compared to the 10 and 15 g L^{-1} treatments. Kepp et al. (2023) reported that lower urea concentrations result in reduced variability in irrigation uniformity.

Table 4
Descriptive statistics of the uniformity of a drip fertigation system with different concentrations of bokashi

Fertigation solutions	UD (%)	SD	Var.	CV (%)	Min.	Max.
Water	91.23a	3.68	13.54	4.03	85.86	98.32
Bokashi 5g L^{-1}	88.47a	5.04	25.39	5.70	74.26	95.50
Bokashi 10g L^{-1}	70.08b	10.78	116.25	15.39	45.61	88.39
Bokashi 15 g L^{-1}	59.97c	23.86	569.43	40.39	11.72	94.51

*Means followed by the same letter in the column do not differ from each other, according to the Tukey's test at a 5% probability. SD = Standard Deviation; Var = Variance; CV = Coefficient of Variation; Min = Minimum; Max = Maximum.

The 10 g L^{-1} bokashi treatment achieved a uniformity of 70.08%, which is considered acceptable, whereas the 15 g L^{-1} concentration was deemed unacceptable, with a uniformity of 59.97% (Merriam & Keller, 1978). This decrease in uniformity is attributed to emitter clogging resulting from the high concentrations of the physicochemical compounds shown in Table 3. Uneven water distribution in irrigation systems not only lowers crop productivity and the economic returns from irrigated fields (Álvarez et al., 2004) but also increases environmental impacts through the inefficient use of water, energy, and fertilizers (Faria et al., 2009).

The low uniformity values observed for the 10 g L^{-1} and 15 g L^{-1} bokashi treatments can be explained by the physicochemical properties of the solutions, which promote emitter clogging and, consequently, reduce uniformity. Factors contributing to this decline include blockages along lateral lines (Bralts et al., 1982; V. Oliveira et al., 2019) and higher fertilizer concentrations (Tang et al., 2018; C. Liu et al., 2021). Consistent with Wang et al. (2023), the fertilizer concentration plays a key role in dripper clogging, which in turn affects uniformity. Additionally, fertilizer can enhance emitter susceptibility to clogging (H. J. Liu & Hang, 2009), and emitters operating under extreme hydraulic or environmental conditions are more prone to obstruction, leading to further reductions in irrigation uniformity (Ribeiro et al., 2012).

In irrigated agriculture, assessing the factors that influence irrigation quality, particularly those related to the uniformity of water distribution, is essential (Levien & Figueiredo, 2013). Control charts are valuable tools for identifying process deviations, and their systematic application is crucial for detecting or minimizing variability in performance (Frigo et al., 2013). This approach is particularly useful when variability arises from factors such as service pressure, flow rate, or head loss. Observations of the sample that fell outside the control limits indicate the need for further investigation and corrective measures. Figure 3 shows the Shewhart control charts for the uniformity (UD) for different bokashi concentrations and control.

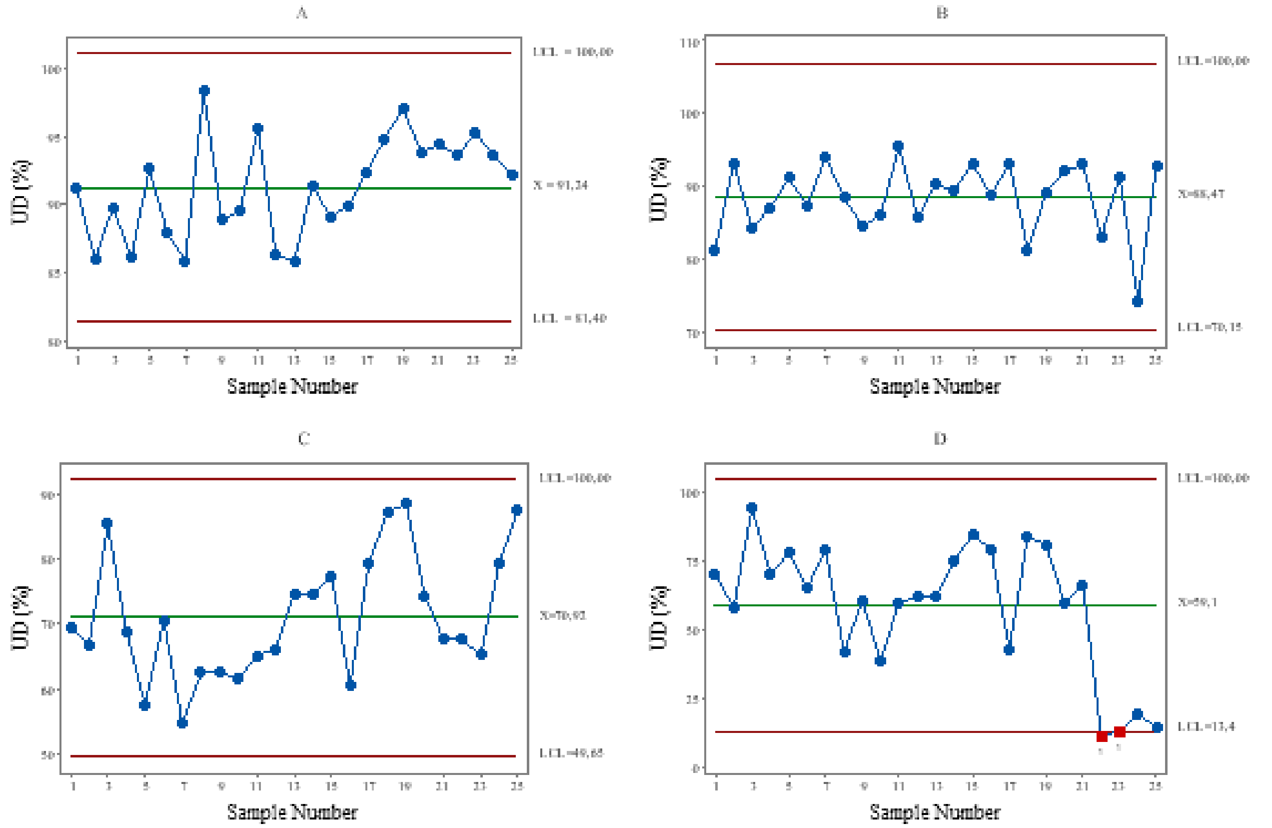

Figure 3. Shewhart control charts for the UD with water (A), bokashi 5 g L^{-1} (B), bokashi 10 g L^{-1} (C) and bokashi 15 g L^{-1} (D).

The 5 g L^{-1} and 10 g L^{-1} bokashi treatments, as well as water, exhibited stability when monitored using the Shewhart control chart, with no points falling outside the control limits (LCL and UCL) (Figures 3A and 3B). This highlights the limited sensitivity of the Shewhart chart; for the 10 g L^{-1} treatment, the maximum UD was 88.39% while the minimum reached 45.61% (Figure 3C), demonstrating its low responsiveness to variability. According to Cossich et al. (2024), although the Shewhart chart may not capture all sources of variability, it remains an effective tool for monitoring the uniformity of drip irrigation systems. However, alternative control charts such as the exponentially weighted moving average (EWMA) and CUSUM have been shown to be more sensitive. They can enhance the detection of variations in irrigation uniformity.

At the 15 g L^{-1} bokashi concentration, uniformity experienced a sharp decline during the trials, dropping from 70.76% at the beginning to 14.83% at the end (Figure 3D) due to sediment accumulation in the drippers. This reduction brought uniformity below the LCL, indicating that the 15 g L^{-1} concentration adversely affects the performance of the drip irrigation system and places the process out of statistical control. Similarly, Cosmo et al. (2021) reported a lack of statistical control when applying organic fertilizer at a concentration of 18 g L^{-1} through fertigation.

Although the Shewhart control chart is recognized for its reliability, its application in fertigation has produced mixed results, with some studies reporting processes remaining under statistical control (Zocoler et al., 2015) and others showing deviations (Acuña Chinchilla et al., 2018). Variability and out-of-control points in fertigation can be attributed to multiple factors, including the lateral line slope, pressure fluctuations, fertilizer solubility and concentration, fertilizer origin, environmental conditions, and system maintenance (Lopes et al., 2021a).

Variability in uniformity was observed across all bokashi concentrations during the trials, likely owing to the composition of the fertilizer and the low operating pressure of the system, which functioned under gravity at 30 kPa. Despite these fluctuations, low-pressure irrigation in small gravity-fed areas remains feasible (Nascimento et al., 2009). This approach eliminates the need for commercial drippers that require higher pressures, thereby reducing the environmental impact and lowering the overall cost of irrigation systems (Sokol et al., 2019).

Conclusions

Physicochemical parameters were influenced by increased bokashi concentration and were determinants of UD.

The use of bokashi is viable for drip fertigation, if it is used at an appropriate concentration. A concentration of 5 g L^{-1} showed good performance, approaching the performance of water application, whereas a concentration of 15 g L^{-1} was not feasible for use in drip irrigation systems.

Clogging caused greater flow rate variations at concentrations of 10 and 15 g L^{-1}, with increases and decreases in the flow rates along the lateral lines.

Owing to its low sensitivity, the Shewhart control chart fails to show several trends and process variabilities.

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