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# DISCRIMINANT FUNCTIONS FOR AQUACULTURE WASTEWATER DILUTIONS IN WELL WATER APPLIED BY NON-SELF-COMPENSATING DRIPPERS

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**KEYWORDS**

multivariate statistics, agricultural reuse, emitters, clogging.

**ABSTRACT**

Emitter clogging is the main limitation of drip irrigation systems operating with wastewater. This paper aimed to employ discriminant analysis (DA) to generate classification functions that characterize aquaculture wastewater (AW) dilutions in well water (WA), delivered through non-self-compensating drippers. Five AW dilutions in WA were tested (D1: 100% AW; D2: 75% AW + 25% WA; D3: 50% AW + 50% WA; D4: 25% AW + 75% WA; and D5: 100% WA) to investigate the clogging susceptibility of three non-self-compensating dippers: TS (1.6 L $h^{-1}$), SL (1.6 L $h^{-1}$), and NJ (1.7 L $h^{-1}$) after 160 h of operation. Three hydraulic performance evaluations of the drippers were performed in this period. During the same interval, the quality attributes of the AW dilutions in WA were also quantified. The statistical analyses included correlation matrix and DA. The correlation matrix identified 188 variables with significant correlations. Discriminant functions were constructed for each dripper using DA. These functions revealed $Mg^{2+}$ as the most significant variable. The classification matrix of these functions achieved a 100% success rate.

## INTRODUCTION

Aquaculture is a significant socioeconomic activity that causes considerable environmental impacts, especially because of wastewater generation (Dauda et al., 2019). In this context, agricultural reuse of aquaculture wastewater (AW) could be an alternative to mitigate environmental impact (Groenveld et al., 2019).

Drip irrigation systems are the primary method for applying AW in agriculture, delivering water droplets directly to plant roots (Bansal et al., 2021; Dhayal et al., 2023). These systems, however, are limited by their susceptibility to emitter clogging (Zhang et al., 2021), which results from the obstruction caused by irrigation water quality attributes combined with the small size of drippers (Wang et al., 2020).

The concentration of these attributes is high in AW, which potentiates emitter clogging (Soliman et al., 2020). From this perspective, effluent dilution can reduce dripper obstruction by lowering the concentration of clogging agents, with benefits that range from potable water conservation to the compliance with existing norms and regulations (Vale et al., 2018).

Therefore, understanding emitter clogging mechanisms is the first step toward reducing dripper obstruction. Multivariate statistics could be a valuable tool because it allows for the simultaneous analysis of several variables, thus assisting in the characterization of sample objects and facilitating the interpretation of data sets (Popovic et al., 2021).

Among the various types of multivariate analyses, discriminant analysis (DA) identifies the variables that best differentiate between groups and describes the classification functions that represent the difference between groups (Gomes & Mendonça, 2017). As such, DA serves as a valuable tool for understanding emitter clogging mechanisms.

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Accordingly, this paper aimed to use DA to generate classification functions that characterize AW dilutions in well water (WA), delivered via non-self-compensating drippers.

## MATERIAL AND METHODS

### Description of the experimental area

The experiment was conducted from November to December 2021 at the outdoor experimental area of the Laboratory of Rural Constructions and Ambience of the Department of Engineering and Environmental Sciences of the Center for Engineering Sciences of the Federal Rural University of the Semi-Arid Region (UFERSA), Campus Leste, in Mossoró-RN, Brazil (5°12'13.14" S and 37°19'26.93" W).

AW was obtained from the Aquaculture Sector of UFERSA in Mossoró, where various experiments are conducted with aquatic species such as Nile tilapia (*Oreochromis niloticus*), Wami tilapia (*Oreochromis urolepis hornorum*), Tambaqui (*Colossoma macropomum*), Tambatinga (*Piaractus brachypomus*), and whiteleg shrimp (*Litopenaeus vannamei*) in both fresh and saline water ponds. The water used for dilution was collected from a well also located at the Campus Leste of UFERSA in Mossoró under the management of the Water and Sewerage Company of Rio Grande do Norte (CAERN).

### Experimental design and test benches

The experiment was conducted in a randomized complete block design with plots and three replications, as recommended by Batista et al. (2018). The plots consisted of five dilutions of AW in WA to investigate the clogging susceptibility of three types of emitters, considering variations in the measurements of physical, chemical, and microbiological clogging agents. The emitters were evaluated for their hydraulic performance over a period of 160 h, in line with the recommendations of Vale et al. (2020), who indicate that such timeframe is enough to understand the clogging dynamics, characterize the material deposited within the emitters, and assess their behavior.

AW dilutions in WA were prepared as follows: D1 – 100% AW; D2 – 75% AW + 25% WA; D3 – 50% AW + 50% WA; D4 – 25% AW + 75% WA; D5 – 100% WA.

Five experimental benches were set up for the experiment, each operating with a specific AW dilution in WA and three types of emitters. The distribution of the wastewater dilutions and emitters on the benches was completely randomized.

Each experimental bench measured 8 m² (1 m in width and 8 m in length) and was built on a wooden support frame to hold the corrugated fiber cement tiles, which were installed with a slope of 2.5% to allow for wastewater recirculation. A water tank with a capacity of 0.31 m³, connected to a drip irrigation system regulated by a central control unit, was set up downstream of each bench.

The drippers used to apply the five dilutions were split into three drip units, as recommended by Vale et al. (2020). Each drip unit had three lateral lines, 8 m in length, with 16 emitters, which were evaluated for hydraulic performance. The distribution of the lateral lines and the selection of emitters were completely randomized.

The non-self-compensating drippers used in the experiment and their respective technical specifications are as follows: TS dripper — nominal flow rate of 1.60 L $h^{-1}$; flow rate coefficient of 0.53; flow rate exponent of 0.48 characterizing the flow regime; filtering area of 34 mm²; labyrinth length of 23 mm; manufacturer variation coefficient of ±7; recommended pressure range of 60 to 300 kPa; and spacing between emitters of 0.30 m.; SL dripper — nominal flow rate of 1.60 L $h^{-1}$; flow rate coefficient of 0.57; flow rate exponent of 0.45 characterizing the flow regime; filtering area of 17 mm²; labyrinth length of 13 mm; manufacturer variation coefficient of ±7; recommended pressure range of 90 to 100 kPa; and spacing between emitters of 0.30 m; NJ dripper — nominal flow rate of 1.70 L $h^{-1}$; flow rate coefficient of 0.56; flow rate exponent of 0.46 characterizing the flow regime; filtering area of 6.0 mm²; labyrinth length of 44 mm; manufacturer variation coefficient of ±5; recommended pressure range of 70 to 300 kPa; and spacing between emitters of 0.20 m.

The drip units were operated at a pressure of 80 ± 10 kPa, which, according to Batista et al. (2018), is the pressure range that potentiates biofilm formation in the emitters of wastewater-based drip irrigation systems. The operating pressure was periodically adjusted using pressure gauges with 0 to 400 kPa and an accuracy of ± 1%.

### Evaluation of hydraulic performance of drip units

The irrigation system operated for an average of 8 h daily. Hydraulic performance of the emitters was evaluated according to NBR ISO 9261 recommendations at operational times of 0 h, 80 h, and 160 h. The evaluation results were applied to calculate the hydraulic performance coefficients (Table 1).

TABLE 1. Hydraulic performance coefficients, equations, and variables.

| Coefficient | Equation | Variables | No. of the equation | References |
|---|---|---|---|---|
| **Flow rate** | $Q = \frac{Vol}{1000t_{em}} . 60$ | Q – emitter flow rate, $L.h^{-1}$; Vol – wastewater volume collected, mL; $t_{em}$ – time of wastewater collection, minutes. | (1) | ABNT (2006) |
| **Relative flow rate** | $QR= \frac{q_a}{q_i}$ | QR – relative flow rate, L $h^{-1}$; $q_a$ - current flow rate, L $h^{-1}$; and $q_i$ - initial flow rate, L $h^{-1}$. | (2) | Capra & Scicolone (1998) |
| **Relative flow rate reduction** | $RQR = 100\left(\frac{q_i - q_a}{q_i}\right)$ | RQR – relative flow rate reduction, %; $q_i$ - initial flow rate, L $h^{-1}$; and $q_a$ - current flow rate, L $h^{-1}$. | (3) | Capra & Scicolone (1998) |
| **Distribution uniformity coefficient** | $DUC = 100\frac{q_{25\%}}{\bar{q}}$ | DUC- distribution uniformity coefficient, % $q_{25\%}$ - Mean value of the 25% lowest emitter flow rates, L $h^{-1}$; and q - mean flow rate of the emitters, L $h^{-1}$. | (4) | Keller & Karmeli (1975) |
| **Flow rate variation coefficient** | $CVQ=100\frac{\sqrt{\sum_{i=0}^{n}\frac{(q_i - \bar{q})^2}{n_e - 1}}}{\bar{q}}$ | CVQ - flow rate variation coefficient, %; $q_i$ – flow rate of each emitter, L $h^{-1}$; q – mean flow rate of the emitters, L $h^{-1}$; and $n_e$ – number of emitters evaluated. | (5) | ASABE (2008) |
| **Statistical uniformity coefficient** | $Us = 100(1\text{-}CVQ)$ | Us - statistical uniformity coefficient of wastewater application, %; and CVQ - flow rate variation coefficient, %. | (6) | Bralts et al. (1987) |

**Characterization of physicochemical and microbiological attributes of wastewater dilutions in well water**

Samples of the five dilutions were collected from the reservoirs of each bench at the beginning (0 h), middle (80 h), and end of the experiment (160 h). Some samples were analyzed at the Soil, Water, and Plant Laboratory of the Semi-Arid Region (LASAPSA) of UFERSA, where the following attributes were measured according to EMBRAPA recommendations and the standard methods for water and wastewater analysis: potential of hydrogen (pH), electrical conductivity (EC), calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), sodium ($Na^{+}$), carbonate ($CO_3^{2-}$), bicarbonate ($HCO_3^{-}$), total suspended solids (TSS), total solids (TS), and turbidity (Tur). Total dissolved solids (TDS) were calculated as the difference between TSS and TS. The concentrations of $Na^{+}$, $Ca^{2+}$, $Mg^{2+}$, $CO_3^{2-}$, and $HCO_3^{-}$ were used to calculate the Langelier saturation index (LSI), which indicates the tendency for calcium carbonate ($CaCO_3$) formation.

Some samples were used to quantify the total concentrations of manganese ($Mn^{+}$), iron ($Fe^{+}$), and sulfur ($S^{+}$). The samples were sent to the Laboratory of Organic Matter and Waste and Atomic Spectrophotometry of the Federal University of Viçosa (UFV) in Minas Gerais. The final sample aliquot was sent to the CACIM Laboratory, where total coliforms (TC) and thermotolerant coliforms (TTC) were quantified using the standard methods for water and wastewater analysis.

**Multivariate analysis**

These variables were determined as a function of the five dilutions of AW in WA (D1, D2, D3, D4, and D5) at operational times of 0 h, 80 h, and 160 h. The multivariate analyses included correlation matrix, canonical correlation analysis (CA), and DA. Statistical analyses were performed using Statistica 14.0.

**Correlation matrix**

The correlation matrix ($p \leq 0.05$) was used to investigate whether AW and its dilutions in WA and the hydraulic performance coefficients Q, QR, RQR, DUC, CVQ, and Us of the three non-self-compensating drippers exhibited sufficiently strong correlations to justify the use of CA and DA.

**Discriminant analysis**

The objective of DA is to generate classification functions. These functions work as models that determine where each dilution of AW in WA belongs, according to the analyzed water quality attributes and hydraulic performance coefficients. Two sets of variables were used: water quality attributes and hydraulic performance coefficients. In both cases, only variables with the strongest significant correlations in the correlation matrix ($p \leq 0.05$) were selected.

Subsequently, three classification functions were generated. The classification functions represent the AW dilutions in WA that can be used in the drip irrigation system with TS, SL, and NJ drippers, i.e., one classification function for each dripper.

## RESULTS AND DISCUSSION

The results of the analyses of AW and its dilutions in WA at the respective collection times are shown in Table 2. The results of the hydraulic performance coefficients for TS, SL, and NJ drippers operating with the D1, D2, D3, D4, and D5 dilutions in the evaluations and sample collections performed at 0 h, 80 h, and 160 h are shown in Table 3. The data presented in Tables 2 and 3 were used to construct the Pearson correlation matrix $p \leq 0.05$ (Table 4). The values indicated in red in the correlation matrix represent significant correlations between the studied variables.

TABLE 2. Quality attributes of aquaculture wastewater and its dilutions in well water (D1, D2, D3, D4, and D5) after 0 h, 80 h, and 160 h of operation

| **Dilutions and operational times** | **Water quality attributes** | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **pH** | **EC** | **$Ca^{2+}$** | **$Mg^{2+}$** | **$CO_3^{2-}$** | **$HCO_3^-$** | **TC** | **TTC** | **TSS** | **TDS** | **$Mn^+$** | **$Fe^+$** | **$S^+$** | **$Na^+$** | **LSI** | **Turbidity** | **Temperature** |
| **D1 – 0 h** | 7.93 | 5.88 | 20.40 | 33.80 | 0.14 | 1.78 | 180.00 | 16.00 | 44.00 | 6850.00 | 0.05 | 0.45 | 0.11 | 42.70 | -0.20 | 9.9 | 30 |
| **D2 – 0 h** | 8.04 | 5.01 | 13.50 | 25.80 | 0.20 | 1.76 | 70.00 | 12.00 | 26.00 | 5608.00 | 0.00 | 0.06 | 0.04 | 35.03 | 0.01 | 3.9 | 34 |
| **D3 – 0 h** | 8.06 | 3.60 | 11.90 | 17.80 | 0.25 | 1.94 | 120.00 | 20.00 | 4.00 | 3738.00 | 0.02 | 0.34 | 0.10 | 25.66 | 0.01 | 4.8 | 34 |
| **D4 – 0 h** | 7.92 | 2.26 | 5.30 | 13.10 | 0.12 | 1.51 | 110.00 | 15.00 | 14.00 | 2138.00 | 0.02 | 0.11 | 0.04 | 15.26 | -0.46 | 5.5 | 33 |
| **D5 – 0 h** | 7.05 | 0.52 | 0.60 | 0.28 | 0.05 | 1.66 | 20.00 | 0.00 | 2.00 | 452.00 | 0.00 | 0.00 | 0.01 | 7.98 | -2.12 | 0.23 | 35 |
| **D1 – 80 h** | 7.62 | 8.45 | 16.90 | 41.80 | 0.00 | 1.89 | 420.00 | 60.00 | 6.00 | 6644.40 | 0.02 | 0.06 | 0.08 | 70.42 | -1.46 | 4.2 | 28 |
| **D2 – 80 h** | 7.61 | 5.37 | 12.60 | 17.90 | 0.00 | 1.71 | 70.00 | 20.00 | 4.00 | 4300.00 | 0.02 | 0.09 | 0.08 | 45.44 | -0.14 | 2.6 | 29 |
| **D3 – 80 h** | 7.67 | 4.18 | 8.70 | 11.50 | 0.05 | 1.66 | 60.00 | 30.00 | 4.00 | 3246.00 | 0.00 | 0.01 | 0.11 | 35.55 | 0.13 | 1.5 | 28 |
| **D4 – 80 h** | 7.64 | 3.34 | 6.90 | 11.40 | 0.07 | 1.53 | 150.00 | 60.00 | 4.00 | 2470.00 | 0.00 | 0.08 | 0.08 | 29.62 | -0.24 | 1.36 | 27 |
| **D5 – 80 h** | 7.55 | 0.59 | 0.67 | 0.13 | 0.23 | 1.42 | 40.00 | 10.00 | 2.00 | 392.00 | 0.00 | 0.04 | 0.04 | 6.52 | -1.31 | 0.19 | 30 |
| **D1 – 160 h** | 7.65 | 10.33 | 18.00 | 54.70 | 0.00 | 2.40 | 460.00 | 90.00 | 68.00 | 7778.00 | 0.00 | 0.35 | 0.23 | 83.43 | -2.27 | 10.7 | 29 |
| **D2 – 160 h** | 8.20 | 5.49 | 10.00 | 23.10 | 0.09 | 1.72 | 70.00 | 20.00 | 6.00 | 3878.00 | 0.01 | 0.05 | 0.10 | 42.84 | 0.59 | 3.8 | 26 |
| **D3 – 160 h** | 8.28 | 4.26 | 6.80 | 21.20 | 0.15 | 1.51 | 60.00 | 10.00 | 6.00 | 2864.00 | 0.00 | 0.15 | 0.19 | 33.99 | 0.47 | 2.5 | 26 |
| **D4 – 160 h** | 8.47 | 3.70 | 6.00 | 15.70 | 0.20 | 1.45 | 50.00 | 10.00 | 4.00 | 2414.00 | 0.00 | 0.03 | 0.16 | 31.50 | 0.62 | 3 | 26 |
| **D5 – 160 h** | 8.50 | 0.67 | 0.52 | 0.31 | 0.33 | 1.40 | 70.00 | 20.00 | 2.00 | 308.00 | 0.00 | 0.03 | 0.17 | 8.60 | -0.28 | 0.5 | 27 |

**Note:** pH – potential of hydrogen; EC – electrical conductivity (dS $m^{-1}$); $Ca^{2+}$ - calcium (mmolc $L^{-1}$); $Mg^{2+}$ - magnesium (mmolc $L^{-1}$); $CO_3^{2-}$ carbonate (mmolc $L^{-1}$); $HCO_3^-$ - bicarbonate (mmolc $L^{-1}$); TC total coliforms (CFU 100 $mL^{-1}$); TTC –thermotolerant coliforms (CFU 100 $mL^{-1}$); TDS – total dissolved solids (mg $L^{-1}$); TSS – total suspended solids (mg $L^{-1}$); $Mn^+$ – manganese (mg $L^{-1}$); $Fe^+$ – iron (mg $L^{-1}$); $S^+$ – sulfur (mg $L^{-1}$); $Na^+$ - sodium (mmolc $L^{-1}$); LSI –Langelier saturation index; Tur – turbidity (UNT); T – temperature ºC; D1 - 100% aquaculture wastewater (AW), D2 - 75% AW and 25% well water (WA), D3 - 50% AW and 50% WA, D4 - 25% AW and 75% WA, and D5 - 100% WA.

TABLE 3. Hydraulic performance coefficients for TS, SL, and NJ drippers after 0 h, 80 h, and 160 h of operation.

| Dilutions and operational times | Hydraulic performance coefficients | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **QR TS** | **QR SL** | **QR NJ** | **DUC TS** | **DUC SL** | **DUC NJ** | **Q TS** | **Q SL** | **Q NJ** | **RQR TS** | **RQR SL** | **RQR NJ** | **CVQ TS** | **CVQ SL** | **CVQ NJ** | **Us TS** | **Us SL** | **Us NJ** |
| **D1 – 0 h** | 1.00 | 1.00 | 1.00 | 95.63 | 93.63 | 94.42 | 1.5 | 1.19 | 1.32 | 0.00 | 0.00 | 0.00 | 6.26 | 7.54 | 6.52 | 93.74 | 92.46 | 93.48 |
| **D2 – 0 h** | 1.00 | 1.00 | 1.00 | 92.20 | 95.85 | 96.40 | 1.48 | 1.22 | 1.34 | 0.00 | 0.00 | 0.00 | 8.86 | 5.66 | 6.72 | 91.14 | 94.34 | 93.28 |
| **D3 – 0 h** | 1.00 | 1.00 | 1.00 | 99.07 | 97.90 | 97.87 | 1.48 | 1.25 | 1.37 | 0.00 | 0.00 | 0.00 | 2.86 | 3.44 | 4.3 | 97.14 | 96.56 | 95.7 |
| **D4 – 0 h** | 1.00 | 1.00 | 1.00 | 97.13 | 96.54 | 96.98 | 1.47 | 1.23 | 1.35 | 0.00 | 0.00 | 0.00 | 5.71 | 6.13 | 5.88 | 94.29 | 93.87 | 94.12 |
| **D5 – 0 h** | 1.00 | 1.00 | 1.00 | 95.93 | 97.39 | 97.76 | 1.47 | 1.24 | 1.34 | 0.00 | 0.00 | 0.00 | 6.64 | 6.28 | 6.92 | 93.36 | 93.72 | 93.08 |
| **D1 – 80 h** | 0.96 | 0.73 | 0.90 | 91.11 | 92.58 | 91.49 | 1.43 | 1.09 | 1.35 | 4.10 | 8.54 | -2.38 | 8.08 | 6.95 | 8.71 | 91.92 | 93.05 | 91.29 |
| **D2 – 80 h** | 0.86 | 0.82 | 0.88 | 77.97 | 95.26 | 91.95 | 1.28 | 1.21 | 1.31 | 13.87 | 0.10 | 2.85 | 37.7 | 9.94 | 12.97 | 62.3 | 90.06 | 87.03 |
| **D3 – 80 h** | 1.00 | 0.81 | 0.89 | 95.46 | 90.11 | 84.59 | 1.48 | 1.2 | 1.31 | 0.00 | 4.06 | 4.56 | 5.88 | 16.49 | 19.35 | 94.12 | 83.51 | 80.65 |
| **D4 – 80 h** | 1.04 | 0.88 | 0.94 | 95.27 | 91.42 | 91.46 | 1.52 | 1.29 | 1.38 | -3.74 | -5.15 | -2.00 | 5.66 | 10.26 | 9.99 | 94.34 | 89.74 | 90.01 |
| **D5 – 80 h** | 0.95 | 0.80 | 0.89 | 92.78 | 92.74 | 92.78 | 1.4 | 1.18 | 1.31 | 4.78 | 4.96 | 2.39 | 6.63 | 6.53 | 9.39 | 93.37 | 93.47 | 90.61 |
| **D1 – 160 h** | 0.90 | 0.63 | 0.81 | 84.80 | 58.70 | 85.71 | 1.34 | 0.95 | 1.21 | 10.37 | 20.61 | 8.17 | 21.51 | 40.24 | 18.55 | 78.49 | 59.76 | 81.45 |
| **D2 – 160 h** | 0.77 | 1.02 | 1.12 | 74.92 | 90.72 | 89.73 | 1.14 | 1.21 | 1.34 | 23.1 | 0.24 | 0.59 | 59.27 | 13.19 | 14.97 | 40.73 | 86.81 | 85.03 |
| **D3 – 160 h** | 0.99 | 0.73 | 0.83 | 94.47 | 82.16 | 75.02 | 1.46 | 1.08 | 1.23 | 0.99 | 13.75 | 10.21 | 9.22 | 25.33 | 30.97 | 90.78 | 74.67 | 69.03 |
| **D4 – 160 h** | 1.00 | 0.79 | 0.91 | 95.44 | 93.24 | 94.90 | 1.46 | 1.16 | 1.33 | 0.48 | 5.76 | 1.57 | 8.44 | 9.64 | 8.59 | 91.56 | 90.36 | 91.41 |
| **D5 – 160 h** | 0.95 | 0.79 | 0.90 | 94.64 | 96.14 | 92.40 | 1.4 | 1.17 | 1.32 | 4.98 | 6.23 | 1.58 | 7.96 | 7.09 | 9.34 | 92.04 | 92.91 | 90.66 |

**Note:** QR –relative flow rate; DUC – distribution uniformity coefficient (%); Q – flow rate (L $h^{-1}$); RQR – flow rate reduction (%); CVQ – flow rate variation coefficient (%); Us – statistical uniformity coefficient (%); D1 - 100% aquaculture wastewater (AW), D2 - 75% AW and 25% well water (WA), D3 - 50% AW and 50% WA, D4 - 25% AW and 75% WA, and D5 - 100% WA.

TABLE 4. Correlation matrix ($p \leq 0.05$) between the quality attributes of aquaculture wastewater diluted in well water and the hydraulic performance coefficients for TS, SL, and NJ drippers after 0 h, 80 h, and 160 h of operation.

| | **pH** | **EC** | **$Ca^{2+}$** | **$Mg^{2+}$** | **$CO_3^{2}$** | **$HCO_3$** | **TC** | **TTC** | **TSS** | **TDS** | **$Mn^{+}$** | **$Fe^{+}$** | **$S^{+}$** | **$Na^{+}$** | **LSI** | **Tur** | **T** | **QR TS** | **QR SL** | **QR NJ** | **DUC TS** | **DUC SL** | **DUC NJ** | **Q TS** | **Q SL** | **Q NJ** | **RQR TS** | **RQR SL** | **RQR NJ** | **CVQ TS** | **CVQ SL** | **CVQ NJ** | **US TS** | **US SL** | **US NJ** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **pH** | 1.00 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **EC** | -0.03 | 1.00 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **$Ca^{2+}$** | -0.02 | **0.89** | 1.00 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **$Mg^{2+}$** | 0.02 | **0.97** | **0.89** | 1.00 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **$CO_3^{2}$** | **0.64** | **-0.59** | -0.43 | -0.48 | 1.00 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **$HCO_3$** | -0.28 | **0.81** | **0.76** | **0.82** | -0.48 | 1.00 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **TC** | -0.20 | **0.81** | **0.67** | **0.84** | -0.48 | **0.77** | 1.00 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **TTC** | -0.22 | **0.71** | 0.50 | **0.66** | **-0.52** | **0.66** | **0.87** | 1.00 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **TSS** | -0.06 | **0.66** | **0.67** | **0.76** | -0.24 | **0.73** | **0.63** | **0.52** | 1.00 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **TDS** | -0.03 | **0.94** | **0.98** | **0.95** | -0.47 | **0.80** | **0.74** | **0.57** | **0.73** | 1.00 | | | | | | | | | | | | | | | | | | | | | | | | | |
| **$Mn^{+}$** | -0.01 | 0.30 | **0.62** | 0.37 | -0.13 | 0.21 | 0.25 | -0.05 | 0.34 | 0.50 | 1.00 | | | | | | | | | | | | | | | | | | | | | | | | |
| **$Fe^{+}$** | 0.06 | 0.47 | **0.67** | **0.59** | 0.00 | **0.60** | 0.46 | 0.28 | **0.71** | **0.61** | **0.66** | 1.00 | | | | | | | | | | | | | | | | | | | | | | | |
| **$S^{+}$** | **0.51** | 0.46 | 0.25 | 0.45 | 0.06 | 0.31 | 0.38 | 0.43 | 0.42 | 0.31 | -0.07 | 0.38 | 1.00 | | | | | | | | | | | | | | | | | | | | | | |
| **$Na^{+}$** | -0.07 | **0.99** | **0.84** | **0.94** | **-0.63** | **0.79** | **0.83** | **0.75** | **0.62** | **0.90** | 0.24 | 0.40 | 0.48 | 1.00 | | | | | | | | | | | | | | | | | | | | | |
| **LSI** | **0.73** | -0.15 | -0.03 | -0.21 | 0.38 | -0.46 | **-0.54** | -0.43 | -0.37 | -0.11 | 0.06 | -0.10 | 0.13 | -0.20 | 1.00 | | | | | | | | | | | | | | | | | | | | |
| **Tur** | 0.08 | **0.73** | **0.81** | **0.84** | -0.25 | **0.73** | **0.66** | 0.45 | **0.88** | **0.82** | **0.61** | **0.84** | 0.39 | **0.67** | -0.16 | 1.00 | | | | | | | | | | | | | | | | | | | |
| **T** | -0.44 | -0.24 | 0.00 | -0.13 | 0.08 | 0.21 | -0.11 | -0.29 | 0.12 | -0.02 | 0.15 | 0.17 | **-0.62** | -0.30 | -0.38 | 0.10 | 1.00 | | | | | | | | | | | | | | | | | | |
| **QR TS** | -0.09 | -0.33 | -0.16 | -0.24 | 0.25 | -0.26 | -0.10 | -0.11 | -0.08 | -0.19 | 0.02 | 0.07 | -0.19 | -0.35 | -0.03 | -0.12 | 0.33 | 1.0 | | | | | | | | | | | | | | | | | |
| **QR SL** | -0.03 | -0.38 | -0.05 | -0.31 | 0.20 | -0.18 | -0.48 | **-0.55** | -0.17 | -0.15 | 0.30 | 0.05 | **-0.67** | -0.46 | 0.27 | -0.02 | **0.58** | 0.1 | 1.00 | | | | | | | | | | | | | | | | |
| **QR NJ** | 0.07 | -0.22 | 0.00 | -0.18 | 0.14 | -0.10 | -0.33 | -0.41 | -0.17 | -0.07 | 0.23 | -0.03 | **-0.56** | -0.29 | 0.27 | 0.02 | 0.36 | -0.2 | **0.92** | 1.00 | | | | | | | | | | | | | | | |
| **DUC TS** | 0.04 | -0.46 | -0.29 | -0.34 | 0.45 | -0.31 | -0.16 | -0.22 | -0.15 | -0.33 | 0.01 | 0.09 | -0.14 | -0.48 | -0.02 | -0.14 | 0.34 | **0.9** | 0.12 | -0.10 | 1.00 | | | | | | | | | | | | | | |
| **DUC SL** | 0.06 | **-0.65** | -0.36 | **-0.65** | 0.38 | **-0.64** | **-0.63** | **-0.70** | **-0.71** | -0.48 | 0.18 | -0.38 | **-0.72** | **-0.67** | 0.37 | **-0.53** | 0.31 | 0.2 | **0.65** | **0.55** | 0.30 | 1.00 | | | | | | | | | | | | | |
| **DUC NJ** | -0.16 | -0.33 | -0.08 | -0.26 | 0.25 | -0.06 | -0.15 | -0.27 | -0.10 | -0.14 | 0.25 | -0.02 | **-0.64** | -0.36 | -0.16 | -0.01 | **0.64** | 0.2 | **0.63** | **0.57** | 0.21 | **0.61** | 1.00 | | | | | | | | | | | | |

TABLE 4 continues on the next page...

...Table 4 cont'd

| | pH | EC | $Ca^{2+}$ | $Mg^{2+}$ | $CO_3^2$ | $HCO_3$ | TC | TTC | TSS | TDS | $Mn^+$ | $Fe^+$ | $S^+$ | $Na^+$ | LSI | Tur | T | QR TS | QR SL | QR NJ | DUC TS | DUC SL | DUC NJ | Q TS | Q SL | Q NJ | RQR TS | RQR SL | RQR NJ | CVQ TS | CVQ SL | CVQ NJ | US TS | US SL | US NJ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Q TS** | 0.42 | 0.05 | -0.30 | 0.01 | 0.09 | -0.19 | -0.02 | 0.12 | -0.09 | -0.21 | -0.48 | -0.24 | **0.57** | 0.10 | 0.16 | -0.17 | **-0.72** | -0.4 | **-0.54** | -0.34 | -0.37 | -0.44 | -0.51 | 1.00 | | | | | | | | | | | |
| **Q SL** | -0.09 | **-0.64** | -0.36 | **-0.68** | 0.24 | **-0.54** | **-0.68** | **-0.54** | **-0.59** | -0.49 | 0.06 | -0.29 | **-0.73** | **-0.67** | 0.39 | -0.48 | 0.35 | 0.2 | **0.78** | **0.65** | 0.23 | **0.84** | **0.57** | -0.45 | 1.00 | | | | | | | | | | |
| **Q NJ** | -0.06 | -0.40 | -0.17 | -0.41 | 0.18 | -0.34 | -0.28 | -0.26 | **-0.53** | -0.27 | 0.13 | -0.28 | **-0.71** | -0.41 | 0.22 | -0.33 | 0.30 | 0.2 | **0.67** | **0.67** | 0.25 | **0.82** | **0.74** | -0.46 | **0.83** | 1.00 | | | | | | | | | |
| **RQR TS** | 0.09 | 0.34 | 0.17 | 0.25 | -0.26 | 0.27 | 0.11 | 0.13 | 0.09 | 0.20 | -0.02 | -0.07 | 0.20 | 0.36 | 0.02 | 0.13 | -0.34 | **-1.0** | -0.08 | 0.17 | **-0.94** | -0.26 | -0.17 | 0.42 | -0.26 | -0.24 | 1.0 | | | | | | | | |
| **RQR SL** | 0.13 | 0.49 | 0.18 | **0.52** | -0.12 | 0.43 | **0.55** | 0.45 | 0.46 | 0.31 | -0.21 | 0.21 | **0.76** | **0.52** | -0.35 | 0.34 | -0.34 | -0.2 | **-0.81** | **-0.71** | -0.12 | **-0.81** | **-0.63** | 0.50 | **-0.97** | **-0.86** | 0.2 | 1.00 | | | | | | | |
| **RQR NJ** | 0.15 | 0.22 | 0.00 | 0.21 | -0.08 | 0.18 | 0.04 | 0.11 | 0.30 | 0.08 | -0.27 | 0.18 | **0.69** | 0.24 | 0.01 | 0.14 | -0.32 | -0.2 | **-0.60** | **-0.65** | -0.16 | **-0.70** | **-0.81** | 0.48 | **-0.66** | **-0.93** | 0.2 | **0.76** | 1.00 | | | | | | |
| **CVQ TS** | 0.09 | 0.33 | 0.19 | 0.22 | -0.35 | 0.20 | -0.01 | 0.07 | 0.04 | 0.21 | -0.01 | -0.10 | 0.12 | 0.34 | 0.19 | 0.10 | -0.34 | **-0.9** | 0.07 | 0.30 | **-0.95** | -0.19 | -0.17 | 0.39 | -0.08 | -0.14 | **0.9** | -0.01 | 0.11 | 1.0 | | | | | |
| **CVQ SL** | -0.01 | **0.59** | 0.29 | **0.56** | -0.41 | **0.53** | 0.48 | **0.59** | **0.60** | 0.40 | -0.23 | 0.30 | **0.76** | **0.61** | -0.23 | 0.43 | -0.39 | -0.3 | **-0.64** | **-0.56** | -0.32 | **-0.97** | **-0.74** | 0.48 | **-0.79** | **-0.87** | 0.3 | **0.80** | **0.82** | 0.2 | 1.0 | | | | |
| **CVQ NJ** | 0.14 | 0.28 | 0.02 | 0.20 | -0.27 | 0.06 | 0.04 | 0.18 | 0.08 | 0.09 | -0.31 | -0.03 | **0.60** | 0.32 | 0.17 | -0.03 | **-0.57** | -0.2 | **-0.56** | **-0.52** | -0.28 | **-0.60** | **-0.98** | **0.54** | **-0.54** | **-0.77** | 0.2 | **0.61** | **0.86** | 0.3 | **0.8** | 1.0 | | | |
| **US TS** | -0.09 | -0.33 | -0.19 | -0.22 | 0.35 | -0.20 | 0.01 | -0.07 | -0.04 | -0.21 | 0.01 | 0.10 | -0.12 | -0.34 | -0.19 | -0.10 | 0.34 | **0.9** | -0.07 | -0.30 | **0.95** | 0.19 | 0.17 | -0.39 | 0.08 | 0.14 | **-0.9** | 0.01 | -0.11 | **-1.0** | -0.2 | -0.3 | 1.0 | | |
| **US SL** | 0.01 | **-0.59** | -0.29 | **-0.56** | 0.41 | **-0.53** | -0.48 | **-0.59** | **-0.60** | -0.40 | 0.23 | -0.30 | **-0.76** | **-0.61** | 0.23 | -0.43 | 0.39 | 0.3 | **0.64** | **0.56** | 0.32 | **0.97** | **0.74** | -0.48 | **0.79** | **0.87** | -0.3 | **-0.80** | **-0.82** | -0.2 | **-1.0** | **-0.8** | 0.2 | 1.0 | |
| **US NJ** | -0.14 | -0.28 | -0.02 | -0.20 | 0.27 | -0.06 | -0.04 | -0.18 | -0.08 | -0.09 | 0.31 | 0.03 | **-0.60** | -0.32 | -0.17 | 0.03 | **0.57** | 0.2 | **0.56** | **0.52** | 0.28 | **0.60** | **0.98** | **-0.54** | **0.54** | **0.77** | -0.2 | **-0.61** | **-0.86** | -0.3 | **-0.8** | **-1.0** | 0.3 | **0.8** | 1.0 |

**Note:** In red, significant values at the significance level of $p \leq 0.05$. pH - pH – potential of hydrogen; EC – electrical conductivity (dS $m^{-1}$); $Ca^{2+}$ - calcium (mmolc $L^{-1}$); $Mg^{2+}$ - magnesium (mmolc $L^{-1}$); $CO_3^{2-}$ carbonate (mmolc $L^{-1}$); $HCO_3^-$ - bicarbonate (mmolc $L^{-1}$); TC total coliforms (CFU 100 $mL^{-1}$); TTC –thermotolerant coliforms (CFU 100 $mL^{-1}$); TDS – total dissolved solids (mg $L^{-1}$); TSS – total suspended solids (mg $L^{-1}$); $Mn^+$ – manganese (mg $L^{-1}$); $Fe^+$ – iron (mg $L^{-1}$); $S^+$ – sulfur (mg $L^{-1}$); $Na^+$ - sodium (mmolc $L^{-1}$); LSI –Langelier saturation index; Tur – turbidity (UNT); T – temperature ºC; QR –relative flow rate; DUC – distribution uniformity coefficient (%); Q – flow rate (L $h^{-1}$); RQR – relative flow rate reduction (%); CVQ – flow rate variation coefficient (%); Us – statistical uniformity coefficient.

Table 2 presents the results for the water quality attributes of AW and its dilutions in WA. Note that the concentrations of these attributes varied throughout the experiment. Such variation occurred for two reasons: first, because of the hot and dry climate (Alvares et al., 2013); and second, because of the diversity of experiments conducted in the aquaculture sector at UFERSA. The hot and dry climate favors water loss through evaporation during the system's operation, necessitating the replenishment of the reservoirs with AW and its dilutions in WA. The numerous experiments at UFERSA generate complex effluents with a wide variability of attributes over time, affecting the collection of wastewaters used for replenishing.

The complexity of the AW contributes to increased variability in the levels of electrical conductivity, calcium ($Ca^{2+}$), and magnesium ($Mg^{2+}$), resulting from the use of saline water in the experimental production of aquatic species such as Nile tilapia (*Oreochromis niloticus*), Zanzibar tilapia (*Oreochromis urolepis hornorum*), tambaqui (*Colossoma macropomum*), tambatinga (*Piaractus brachypomus*), and shrimp (Caridea), in ponds containing both fresh and saline water. Some of these species are grown in ponds using brine obtained from the production of sea salt in the salt marshes of Mossoró.

It is crucial to monitor the salinity levels of water used in drip irrigation systems because $Ca^{2+}$ and $Mg^{2+}$ are known as major clogging agents in emitters operating with wastewater from cashew nut processing (Batista et al., 2018) and in waters with high salinity levels (Zhangzhong et al., 2019).

TSS and sulfur ($S^{2-}$) are two additional key attributes (Table 2). Their concentrations in AW is influenced by the type and frequency of feed used in the diets of aquatic organisms in the experiments conducted in the aquaculture sector. Residues from the feed and from animals' physiological needs affect the concentrations of TSS and $S^{2-}$.

According to Capra & Scicolone (1998), TSS increase the risk of emitter clogging. Sulfur can also be a limiting factor for the hydraulic performance of emitters operating with AW and its dilutions in WA (Paiva et al., 2024).

Table 3 presents the results for hydraulic performance coefficients of the three emitters operating with AW diluted in WA at 0 h, 80 h, and 160 h. Note that the hydraulic performance coefficients worsen over time, indicating that, after 160 h of operation, emitter clogging causes reduced flow rates and non-uniformity in application, which result in agronomic and economic losses for irrigators.

This finding is consistent with that of other studies, which found the same reduction in flow rate and in uniformity after 160 h of operation of drip irrigation systems using dairy wastewater (Cunha et al., 2017), wastewater from cashew nut processing (Batista et al., 2018), and produced water from oil extraction (Vale et al., 2020).

**Discriminant analysis**

The variables assessed in this study fall into two categories: water quality attributes and hydraulic performance of drippers. These variables are classified according to the AW dilutions in WA and to the operational times of the drip irrigation system. Thus, the classification functions derived from DA should consider these two groups of variables.

The variables used for these groups were obtained based on the highest significant correlation between water quality attributes and hydraulic performance coefficients, as shown in the correlation matrix (Table 4). Therefore, three classification functions were established: the first for the ST emitter, the second for the SL emitter, and the third for the NJ emitter.

In this case, the classification matrix was constructed for the variables of each classification function. The three classification matrices (Table 5) show the success rates of the classification of samples for the TS, SL, and NJ drippers.

TABLE 5. Evaluation of the classification success rates for the dilution groups (1st and 2nd matrices) and system operational time groups (3rd and 4th matrices) using the discriminant analysis classification functions.

| Groups | Classification matrices | | | | | | | | | | | | | | | Success rates of the matrices |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TS dripper | | | | | SL dripper | | | | | NJ dripper | | | | | |
| | D1 | D2 | D3 | D4 | D5 | D1 | D2 | D3 | D4 | D5 | D1 | D2 | D3 | D4 | D5 | |
| **D1** | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 100 |
| **D2** | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 100 |
| **D3** | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 100 |
| **D4** | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 100 |
| **D5** | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 | 100 |
| **Total** | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 100 |

**Note:** D1 - 100% aquaculture wastewater (AW), D2 - 75% AW and 25% well water (WA), D3 - 50% AW and 50% WA, D4 - 25% AW and 75% WA, and D5 - 100% WA.

The success rate for the three classification matrices was 100%. This finding suggests that the groups are different from each other. This success rate also demonstrated consistency of group formation, validating the values found for $Mg^{2+}$ concentration, TC, TSS, $S^{+}$, water temperature, and hydraulic performance coefficients of flow rate (Q), and distribution uniformity coefficient (DUC) for the three drippers.

Based on the seven variables extracted from the correlation matrix (Table 4), classification functions were derived for each of the emitters operating with the five dilutions of AW mixed with WA (Table 6).

TABLE 6. Classification functions derived from discriminant analysis for characterizing the dilutions applied with the TS, SL, and NJ drippers.

| Drippers | Dilution | Classification functions |
|---|---|---|
| TS | **D1 =** | - 34.77 * (**$Mg^{2+}$**) + 1.39 * (**TC**) + 2.42 * (**TSS**) – 305.80 * (**$S^{+}$**) + 36.69 * (**T**) + 19.05 * (**DUC**) + 66.15 * (**Q**) – 1107.69 |
| | **D2 =** | - 41.73 * (**$Mg^{2+}$**) + 1.55 * (**TC**) + 2.81 * (**TSS**) – 373.85 * (**$S^{+}$**) + 45.61 * (**T**) + 20.06 * (**DUC**) + 78.34 * (**Q**) - 1326.97 |
| | **D3 =** | - 49.99 * (**$Mg^{2+}$**) + 1.87 * (**TC**) + 3.42 * (**TSS**) – 464.34 * (**$S^{+}$**) + 53.01 * (**T**) + 24.02 * (**DUC**) + 92.13 * (**Q**) – 1843.84 |
| | **D4 =** | - 56.12 * (**$Mg^{2+}$**) + 2.11 * (**TC**) + 4.21 * (**TSS**) – 384.38 * (**$S^{+}$**) + 57.49 * (**T**) + 26.32 * (**DUC**) + 103.14 * (**Q**) – 2180.99 |
| | **D5 =** | - 66.16 * (**$Mg^{2+}$**) + 2.45 * (**TC**) + 5.01 * (**TSS**) – 450.57 * (**$S^{+}$**) + 67.63 * (**T**) + 29.25 * (**DUC**) + 119.83 * (**Q**) – 2826.33 |
| SL | **D1 =** | 14.87 * (**$Mg^{2+}$**) – 0.07 * (**TC**) – 0.07 * (**TSS**) + 486.37 * (**$S^{+}$**) – 4.55 * (**T**) + 2.70 * (**DUC**) + 1142.58 * (**Q**) – 1003.82 |
| | **D2 =** | 12.85 * (**$Mg^{2+}$**) – 0.22 * (**TC**) – 1.80 * (**TSS**) + 757.89 * (**$S^{+}$**) + 2.61 * (**T**) – 0.27 * (**DUC**) + 1204.15 * (**Q**) – 911.17 |
| | **D3 =** | 10.73 * (**$Mg^{2+}$**) – 0.24 * (**TC**) – 2.71 * (**TSS**) + 967.15 * (**$S^{+}$**) + 7.47 * (**T**) – 1.75 * (**DUC**) + 1187.32 * (**Q**) – 869.48 |
| | **D4 =** | 10.82 * (**$Mg^{2+}$**) – 0.18 * (**TC**) – 1.99 * (**TSS**) + 841.88 * (**$S^{+}$**) + 4.62 * (**T**) – 0.77 * (**DUC**) + 1152.99 * (**Q**) – 833.16 |
| | **D5 =** | 7.50 * (**$Mg^{2+}$**) – 0.17 * (**TC**) – 2.61 * (**TSS**) + 985.93 * (**$S^{+}$**) + 9.24 * (**T**) – 1.94 * (**DUC**) + 1031.51 * (**Q**) – 699.02 |
| NJ | **D1 =** | 7.76 * (**$Mg^{2+}$**) - 0.59 * (**TC**) – 0.12 * (**TSS**) + 2096.83 * (**$S^{+}$**) + 38.31 * (**T**) - 26.64 * (**DUC**) + 4286.41 * (**Q**) – 2320.90 |
| | **D2 =** | 6.20 * (**$Mg^{2+}$**) - 0.63 * (**TC**) – 0.59 * (**TSS**) + 2280.85 * (**$S^{+}$**) + 42.73 * (**T**) - 28.21 * (**DUC**) + 4340.52 * (**Q**) – 2343.94 |
| | **D3 =** | 4.77 * (**$Mg^{2+}$**) – 0.63 * (**TC**) – 1.11 * (**TSS**) + 2601.04 * (**$S^{+}$**) + 49.92 * (**T**) - 31.27 * (**DUC**) + 4523.36 * (**Q**) – 2525.46 |
| | **D4 =** | 4.94 * (**$Mg^{2+}$**) – 0.58 * (**TC**) – 0.59 * (**TSS**) + 2348.16 * (**$S^{+}$**) + 43.64 * (**T**) - 28.27 * (**DUC**) + 4317.44 * (**Q**) – 2321.72 |
| | **D5 =** | 3.13 * (**$Mg^{2+}$**) – 0.53 * (**TC**) – 0.90 * (**TSS**) + 2478.63 * (**$S^{+}$**) + 46.82 * (**T**) – 28.78 * (**DUC**) + 4215.55 * (**Q**) – 2231.93 |

**Note:** Variables in red were significant ($p \leq 0.05$); $Mg^{2+}$ - magnesium ($mmol_c\ L^{-1}$); TSS – total suspended solids (mg $L^{-1}$); TC – total coliforms (CFU 100 $mL^{-1}$); $S^{+}$ – sulfur (mg $L^{-1}$); T – temperature (ºC); Q – dripper flow rate (L $h^{-1}$); DUC – distribution uniformity coefficient (%); CVQ – flow rate variation coefficient (%); D1 - 100% aquaculture wastewater (AW), D2 - 75% AW and 25% well water (WA), D3 - 50% AW and 50% WA, D4 - 25% AW and 75% WA, and D5 - 100% WA.

The significant variables (in red) in the discriminant functions are the most important for characterizing AW dilutions in WA. Therefore, $Mg^{2+}$ stands out as the main discriminant variable among the three functions, as it was significant ($p \leq 0.05$) in the equations for the TS, SL, and NJ drippers.

The significant representation of $Mg^{2+}$ can be attributed to its high concentration in AW, which likely results from the bitter water from the salt ponds, used in studies involving aquatic species at the Aquaculture Sector of UFERSA, and also from the material used to feed these aquatic species.

$Mg^{2+}$ increases the risks of clogging in drippers because of its precipitation as magnesium carbonate, causing incrustation in emitters and pipe walls (Zhangzhong et al., 2019), as observed in drip irrigation systems operating with treated domestic sewage (Costa et al., 2019) and produced water from oil extraction (Vale et al., 2020).

The classification functions for the SL and NJ drippers indicated only $Mg^{2+}$ as a significant variable, whereas the functions for the TS dripper also included TC, DUC, and Q as significant variables. The population level of TC is an attribute that poses a clogging risk to drippers owing to biofilm formation, which begins with the interaction between bacteria and the inner parts of drippers (Yuan & Olivier, 2019).

Flow rate (Q) is another significant discriminant variable in the classification functions for the TS dripper. As the most important hydraulic performance coefficient, Q is the first indicator of possible dripper clogging. Therefore, this highlights that flow rate is essential in determining the ideal dilution for effective operation, especially of the TS dripper.

Studies have demonstrated the importance of flow rate in determining clogging susceptibility, using this coefficient to evaluate the hydraulic performance of drippers that operate with landfill leachate (Vale et al., 2018), dairy wastewater (Cunha et al., 2017), and AW (Soliman et al., 2020).

DUC is another significant variable in the discriminant functions of the TS dripper. This hydraulic performance coefficient indicates the degree of uniformity of water application along the entire lateral line. As a result, this coefficient has been used as an important clogging indicator for drippers that operate with wastewater, such as landfill leachate (Vale et al., 2018) and produced water from oil extraction (Vale et al., 2020).

All variables incorporated into the classification functions, regardless of their statistical significance, act as input data for the model. With such an input, the model calculates the most suitable dilutions for the conditions under consideration. Therefore, the selection of the appropriate type of emitter is the first step in applying the classification functions.

Users who own one of the three drippers (TS, SL, or NJ) have two options: they can use the classification function specific to their emitter or they can employ the universal model that includes all three drippers, choosing the most appropriate dripper based on the results obtained. Figure 1 presents the operational framework for utilizing the classification functions generated by DA.

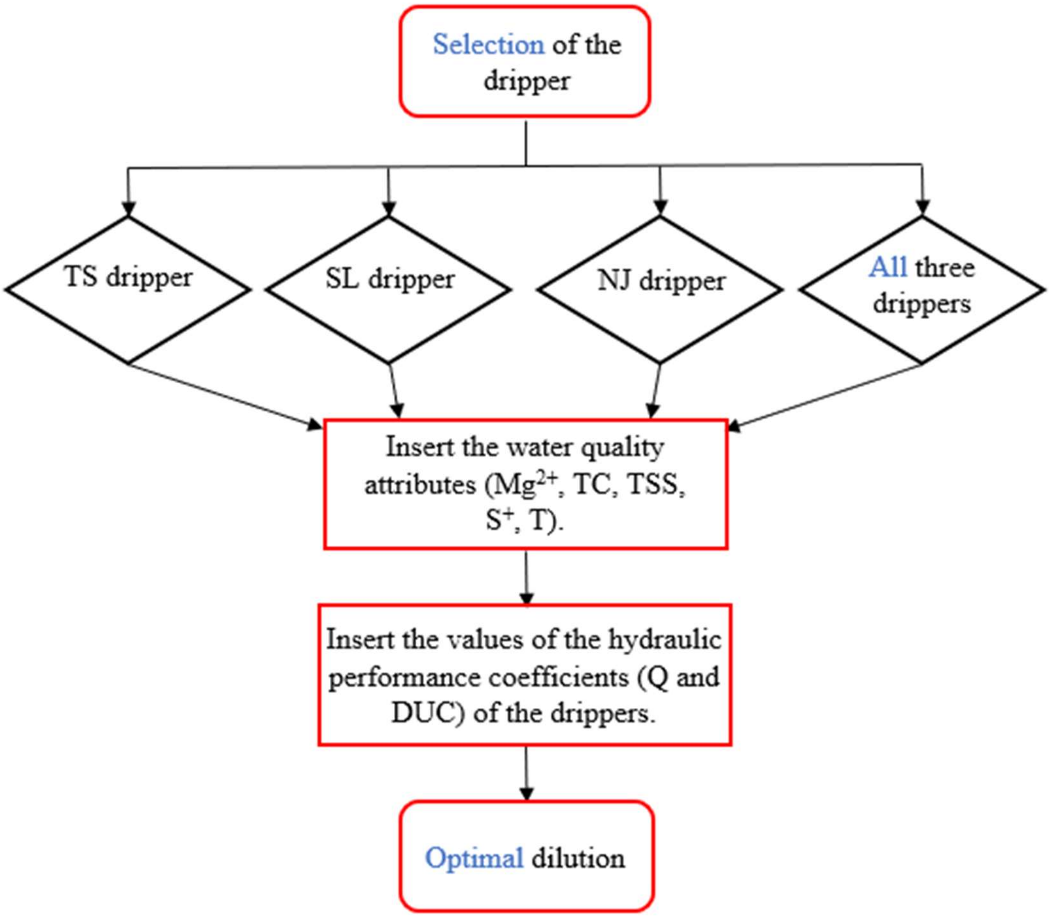


FIGURE 1. Algorithm for use of the classification functions generated by discriminant analysis.

This model is particularly advantageous for irrigation systems that rely on available AW, allowing for the irrigation of crops that can generate additional revenue. Successful applications of AW in crops such as onion (*Allium cepa*) (Soliman et al., 2020), cucumber (*Cucumis sativus*) (Groenveld et al., 2019), forage sorghum (*Sorghum bicolor*) (Guimarães et al., 2018), and even Caatinga species such as *Mimosa verrucosa* (Almeida et al., 2017) underscore its potential for sustainable agricultural reuse.

If the concentrations of the water quality attributes are too high for direct application on plants, producers can mix the effluent with higher-quality water, such as well water, and dilute it to meet the regulatory standards and crop requirements. To achieve that, producers can rely on the classification functions generated for the dilutions.

For instance, consider a producer with a hypothetical volume of AW whose water quality analyses show an $Mg^{2+}$ concentration of 19.23 $mmol_c$ $L^{-1}$, TC of 130 CFU 100 $mL^{-1}$, 13.07 mg $L^{-1}$ of TSS, 0.10 mg $L^{-1}$ of $S^+$, and an irrigation water temperature of 29.5 ºC (mean values extracted from the data shown in Table 2). If the irrigation system requires a DUC of at least 80% for the three drippers, deemed satisfactory by Merriam & Keller (1978), and a minimum flow rate of 1.25 L $h^{-1}$, the classification functions in Table 6 can be applied to find the ideal dilution for each of the three drippers.

By replacing these data in the classification functions, the equation with the highest result will indicate the most suitable dilution for the specific case. Therefore, for this hypothetical situation, the ideal dilution for the TS dripper should be D2 (75% AW + 25% WA). In contrast, for the SL and NJ drippers, the ideal dilution should be D3 (50% AW + 50% WA).

Based on these findings, producers can choose the dilution that best meets their needs and choose the dripper that best fits the dilution chosen. This opportunity to enhance irrigation planning offers an effective means to minimize future clogging problems. These problems are easier to manage when they can be anticipated, thus preventing larger economic losses (Camargo et al., 2014).

## CONCLUSIONS

The variables that generated the discriminant functions for the three drippers were $Mg^{2+}$, TC, TSS, $S^+$, temperature, Q, and DUC. Notably, $Mg^{2+}$ was the only variable found to be significant in the discriminant functions for the TS, SL, and NJ drippers. TC, Q, and DUC were significant in the discriminant function for the TS dripper. With the help of discriminant functions, users can choose the best AW dilution in WA for their needs and choose the dripper that best matches that dilution.

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