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Comparative Behavior of *Dracaena marginata* Plants Integrated into a Cascade Cropping System with the Addition of Hydrogen Peroxide

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Abstract: The reuse of crop drainage into other crops, in the form of a cascade cropping system, is a feasible environmental solution where high inputs of water and fertilizer are used for crop growth and lower efficiency rates, associated with a high discharge of water and fertilizers into the environment, are present. *Dracaena marginata* plants were cultured in containers with sphagnum peat moss and were subjected to three different fertigation treatments for eight weeks: Dm_0 (standard nutrient solution or control treatment), Dm_1 (raw leachates), and Dm_2 (raw leachates with additional H_2O_2), where the leachates were collected from a *Chrysalidocarpus lutescens-Dracaena deremensis* cascade cropping system. At the end of the harvesting, growth parameters, pigment concentration, leaf and root proline, total soluble sugar concentrations, and water and nutrient use efficiencies were assessed for each fertigation treatment. Plant height, root, stem, and total dry weight increased under fertigation with leachates with H_2O_2. The fertigation with leachates with or without H_2O_2 increased the red index value. There were no clear trends between the fertigation treatments with regards to pigment concentrations and biochemical parameters (proline and total soluble sugar concentrations). The addition of H_2O_2 to the leachate increased N concentration in the organs assessed, as well as the water and nutrient use efficiencies. There were no variations in $H_2PO_4^-$, SO_4^{2-}, Na^+, and Mg^{2+} concentration in the chemical composition of the substrate between fertigation treatments. The positive results reported in this experiment suggest the potential growth of *Dracaena marginata* with leachate and hydrogen peroxide in a cascade cropping system.

Keywords: biomass; cascade cropping system; proline; total soluble sugars; ornamental; oxygation

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1. Introduction

Dracaena marginata Lam. var. Tricolor, commonly known as "red-edged dracaena" is well-valued as ornamental foliage plant [1]. It is an evergreen shrub native to Madagascar belonging to the *Agavaceae* family. The common name of this species is ascribed to the presence of multiple stems topped by a rosette of narrow ribbon-like green leaves edged in purplish-red [2].

Nowadays, the production of containerized ornamental plants is facing increasing water and fertilizer costs, with higher efficiency and retention levels of water and nutrient use under constant scrutinization [3]. Nevertheless, the water and nutrient management practices for containerized plants are rather difficult, mainly due to the characteristics of the substrate including low water and nutrient holding capacity, prompting the leaching of nutrients and the pollution of the environment [4].

The reuse of drainage water for fertigation can reduce the water requirements and the overall problems of water pollution. Recycling of leaching in the same crop is the most common process to reuse runoff. This system allows the easy management of leachate, however the reuse of drainage on the same crop leads to an increase in the salinity level of the substrate solution, reducing the yield. To avoid this problem, it is necessary to make a periodic discharge which results in environmental pollution [5]. One strategy for the sequential reuse of the drainage is the implementation of a serial biological concentration (SBC) or cascade cropping system. This system is used to grow increasingly salt-tolerant crops, based on the collection of drainage water from a first crop which is then used for the fertigation of another more salt-tolerant crop in the series, with the main aim of reducing almost entirely the drainage volume from the cascade cropping system [6].

The implementation of this cropping system increases pathogen dispersion through the irrigation system [7]. Under these conditions, the application of disinfectants in the leachate, such as hydrogen peroxide (H_2O_2), may result in a drastic reduction of pathogen dispersion [8]. Besides this disinfectant power, the addition of H_2O_2 to the irrigation water can improve the level of oxygenation in the root zone and the consequent enhancement of the growth of the crop [9,10].

In reviewing the previous literature, we found several references regarding the enhancement of growth through the addition of H_2O_2 in the irrigation water in crops such as wheat [11], zucchini, soybean, and cotton [12], as well as in ornamental plants such as *Calibrachoa × hybrida* and *Lobelia erinus* [13]. Nevertheless, there is scarce information about the application of H_2O_2 in an ornamental cascade cropping system and the consequent effects on crops. Therefore, in the present work, the leachates from an ornamental cascade cropping system under greenhouse conditions, including *Chrysalidocarpus lutescens* and *Dracaena deremensis* plants, were used for the fertigation of *Dracaena marginata* potted plants. In this experiment, we aimed to test both the effect of the addition of H_2O_2 and the effect without this addition in the leachates reused, on biomass, pigment concentration, biochemical parameters, mineral nutrition, and water and nutrient use efficiencies in *D. marginata* plants.

2. Materials and Methods

2.1. Plant Material and Growing Conditions

The experiment was conducted in a greenhouse belonging to the University of Almeria (36°49′ N, 2°24′ W). Initial seedlings of *Dracaena marginata* (height: 34.3 cm, and plant dry weight: 4.1 g) were transferred into 1.5 L containers filled with peat moss. The experiment lasted eight weeks and the climatic conditions were recorded with HOBO SHUTTLE sensors (model H08-004-02) (OnSet computer Corp., Bourne, MA, USA). The average temperature was 16.5 ± 1.5 °C, the relative humidity (RH) was 55.6 ± 2.9%, and the photosynthetically active radiation (PAR) was 55.4 ± 4.4 μmol m^{-2} s^{-1}.

2.2. Experimental Design and Treatments

Dracaena marginata plants were subjected to three different fertigation treatments: Dm_0 (a control treatment based in a standard nutrient solution for containerized ornamental plants) proposed by Jiménez and Caballero [14], Dm_1 (the raw leachates), and Dm_2 (the raw leachates with additional H_2O_2). Each week, the different fertigation treatments were prepared for daily irrigation. The runoff of *Chrysalidocarpus lutescens* (D_1) fertigated with the standard nutrient solution (NS_0) (the same as Dm_0) was collected weekly. Then, this stored drainage water was used to prepare two different nutrient solutions weekly: Dd_1 (raw drainage water) and Dd_2 (raw drainage water blended with H_2O_2 (1.2 M) at 1% (v/v)) to irrigate daily the treatment of *D. deremensis*. Finally, the leachates collected weekly from the fertigation of *D. deremensis* (D_2 and D_3) were used to elaborate two different nutrient solutions weekly: Dm_1 (raw leachates (D_2)) and Dm_2 (raw leachates ((D_3) blended with H_2O_2 (1.2 M) at 1% (v/v)) as shown in Figure 1. The plants were manually fertigated using a test tube and a volume of 10 mL was added to each container every day, resulting in 0.56 L pot^{-1} $treatment^{-1}$ and avoiding the generation of leachate. The experimental design consisted of three fertigation treatments (Dm_0, Dm_1, and Dm_2), each undertaken in

16 plants (organized into four blocks, each containing four plants, with one plant per pot), resulting in a total of 48 plants.

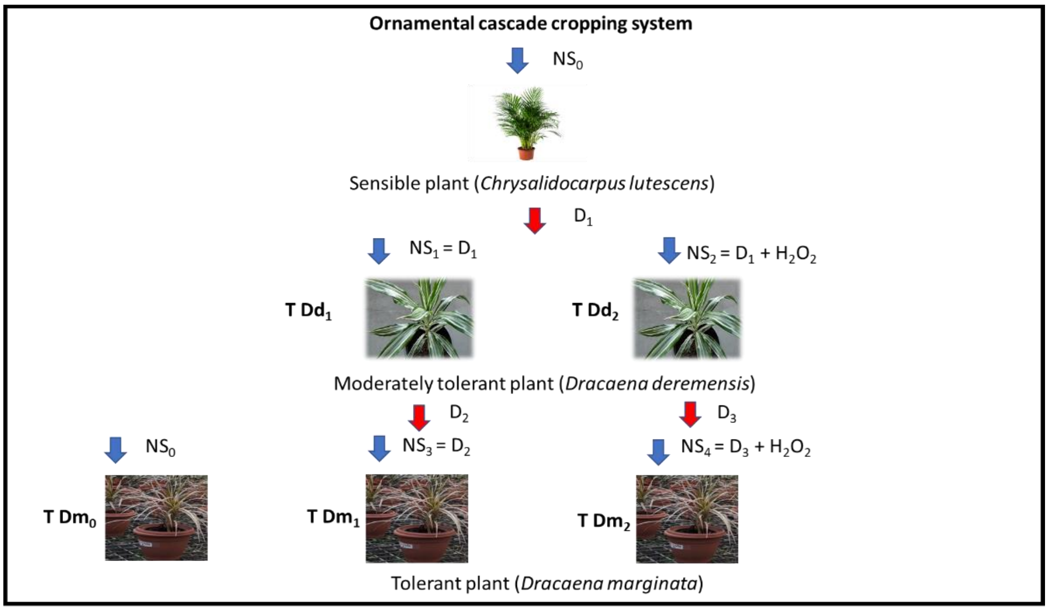

Figure 1. Details of the ornamental cascade cropping system, where NS is the nutrient solution and D is the drainage in each treatment, respectively.

2.3. Nutrient Solution Analysis

The collection of the runoff of each container was performed weekly using a plastic collection bucket under each pot. To prevent evaporation of the leachate treatments during the experimental period, the buckets were tightly fitted to the pots. Throughout the experiment, aliquots (5 mL) of each fertigation treatment were stored weekly, filtered using membrane filters (0.45 µm), and frozen for further analysis. The determination of pH and electrical conductivity (EC) was assessed with a pH meter and a conductivity meter (models Milwaukee pH52 and C66) (Milwaukee Instruments, Rocky Mount, NC, USA), respectively. The chemical determinations of the anion and cation concentrations were conducted through high performance liquid chromatography (HPLC), following the protocol reported by Csáky and Martínez-Grau [15].

2.4. Growth and Biomass Parameters

At the end of the harvesting, four plants per fertigation treatment were randomly selected to assess growth parameters. The plant height was measured with a ruler from the top of the last open leaf of the plant to the substrate line: the longest root length was then measured with a ruler from the crown to the tip of the root. The determination of color index in the leaves (RGB values) was assessed using the protocol recommended by Garcia-Caparros et al. [16]. The values were recorded with an optical scanner (ES-2000; Seiko Epson Corp., Suwa, Japan) and the images were assessed with the program Adobe Photoshop CS6 (Adobe System Software, Dublin, Ireland) by averaging the R, G, and B values (adimensional units) of all of the leaf pixels. For the determination of biomass parameters in each fertigation treatment, four plants were randomly selected. Roots, stems, and leaves were dried in a forced oven at 60 °C for 48 h to determine their dry weights (DW). With the determination of these dry weights, several plant parameters were calculated as the relative leaf weight ratio (LWR), stem weight ratio (SWR), and root weight ratio (RWR), described by Garcia-Caparros et al. [17]. The total plant dry weight (TDW) was calculated as the DW sum of the different organs (roots, stems, and leaves).

2.5. Pigments Concentration

After the determination of growth parameters, the leaves used for the RGB determinations were reused for the determination of pigment concentrations. Fresh leaf samples (0.2 g) were submerged in methanol for 24 h under dark conditions at room temperature. The supernatant was removed, and the pigment concentrations were recorded spectrophotometrically according to the methodology reported by Wellburn [18].

2.6. Biochemical Parameters

At the end of the experimental period, four plants were randomly selected per treatment for the determination of total soluble sugars and proline concentration in the roots and leaves. Fresh samples of roots and leaves (0.5 g per sample) were crushed in ethanol (5 mL, 95% (v/v)) and then washed with ethanol (5 mL, 70% (v/v)). The alcoholic extract was centrifuged for 10 min ($3500\times g$) and then the supernatant was kept at 4 °C for further analysis. The alcoholic extract supernatant was used to determine the total soluble sugars and free proline concentrations. The anthrone reagent method was used to determine the total soluble sugar concentrations (expressed in mg glucose g^{-1} FW (fresh weight)). The ninhydrin reagent method was used to determine the free proline concentration (expressed in µg g^{-1} FW) following the recommendations given by Irigoyen et al. [19].

2.7. Root, Stem, and Leaf Nutrients

The determination of the nutrient concentration in the roots, stems, and leaves was performed in oven-dried samples which were ground in a mill and split into two subsamples. The first subsample of each fertigation treatment was used to determine the concentration of soluble $N\text{-}NO_3^-$ using HPLC. The second subsample was mineralized with H_2SO_4 (96%) and hydrogen peroxide (P-free) at 300 °C for the determination of total P [20], organic N [21], and K^+ [22] concentrations. The total N concentration in the different organs assessed was calculated as the sum of the organic N and $N\text{-}NO_3^-$ concentration.

2.8. Water and Nutrient Use Efficiencies

At the end of the experimental period, the water and nutrient use efficiencies in *D. marginata* plants under different fertigation treatments were calculated as the increase of the dry weight between initial plants and at the end of the experiment divided by the volume of water applied or the nutrients supplied during the experimental period (expressed in g DW divided by the total volume of water applied (in L) or the total amount of nutrient supplies (in g)).

2.9. Chemical Composition of the Substrate

At the beginning and at the end of the experimental period (eight weeks), four randomly chosen samples of substrate per fertigation treatment were dried in a forced oven at 40 °C for 48 h. Then, these samples were sieved and subjected to water suspensions (1:10). The determination of the chemical composition of the substrate was conducted in water suspensions by HPLC following the protocol reported by Csáky and Martínez-Grau [15].

2.10. Statistical Analysis

The experiment was designed with randomized block design, where each parameter assessed in each plant was considered an independent replicate. Statgraphics Centurion XVI.II (Statpoint Technologies, Inc., Warrenton, VA, USA) was used for comparison between treatments, applying one-way analysis of variance (ANOVA) and Fisher's Least Significant Difference (LSD) tests.

3. Results

3.1. Analytical Data of the Nutrient Solution

The analytical data of the fertigation treatments showed an increase in the values of pH and EC in the plants fertigated with leachates with or without H_2O_2. Regarding nutrient concentrations, the fertigation with leachates with or without H_2O_2 showed higher values than the control treatment, except for $H_2PO_4^-$ and SO_4^{2-}, which remained unchanged (Table 1).

Table 1. The chemical parameters and nutrient concentrations of each treatment: Dm_0—standard nutrient solution, Dm_1—raw leachate treatment, and Dm_2—raw leachate blended with H_2O_2 treatment. The electrical conductivity (EC) was expressed in dS m^{-1} and nutrient concentration was expressed in mmoL L^{-1}. The results are expressed as means ± standard deviation ($n = 4$). In each row, different letters indicate significant differences ($p < 0.05$).

Parameters	Dm_0	Dm_1	Dm_2
pH	6.60 ± 0.10 b	8.03 ± 0.08 a	8.12 ± 0.08 a
EC	1.90 ± 0.12 b	5.11 ± 0.45 a	5.21 ± 0.42 a
NO_3^-	6.05 ± 0.51 b	16.26 ± 1.61 a	15.98 ± 1.53 a
$H_2PO_4^-$	0.70 ± 0.06 a	0.78 ± 0.05 a	0.75 ± 0.05 a
Cl^-	3.50 ± 0.11 b	25.98 ± 2.50 a	25.93 ± 2.41 a
SO_4^{2-}	2.01 ± 0.04 a	2.03 ± 0.15 a	2.11 ± 0.09 a
Ca^{2+}	2.03 ± 0.05 b	9.41 ± 0.78 a	9.55 ± 0.85 a
Mg^{2+}	1.41 ± 0.04 b	5.19 ± 0.48 a	5.24 ± 0.50 a
K^+	3.08 ± 0.06 b	8.82 ± 0.70 a	8.76 ± 0.74 a
Na^+	2.60 ± 0.08 b	12.05 ± 1.14 a	11.96 ± 1.10 a

3.2. Growth and Biomass Parameters

Dracaena marginata plants fertigated with leachates plus H_2O_2 were the tallest (48.50 cm). The root length remained unchanged between fertigation treatments. Regarding the color index, *D. marginata* plants fertigated with leachates with or without H_2O_2 showed an increase in red value compared to the control treatment, whereas in the case of green and blue there were no statistical differences between the treatments (Table 2).

Table 2. The effects of different fertigation treatments (Dm_0—standard nutrient solution, Dm_1—raw leachate treatment, and Dm_2—raw leachate blended with H_2O_2 treatment) on plant height and root length (expressed in cm) and color index (RGB) in *D. marginata* plants at the end of the experiment. The results are expressed as means ± standard deviation ($n = 4$). In each column, the same letters indicate non-significant differences ($p < 0.05$).

Treatments	Plant Height	Root Length	Color Index		
			Red	Green	Blue
Dm_0	43.75 ± 2.06 b	25.50 ± 1.87 a	92.51 ± 7.49 b	108.48 ± 6.35 a	70.75 ± 4.27 a
Dm_1	43.50 ± 2.65 b	25.88 ± 1.75 a	117.42 ± 6.48 a	106.21 ± 6.25 a	71.43 ± 4.58 a
Dm_2	48.50 ± 2.08 a	26.25 ± 1.71 a	119.10 ± 6.89 a	110.78 ± 6.25 a	73.17 ± 4.63 a

Plants fertigated with leachates without H_2O_2 showed the lowest root and total dry weight. The fertigation with leachates with H_2O_2 resulted in the highest shoot dry weight (1.76 g) in *D. marginata* plants, whereas leaf dry weight remained unchanged under different fertigation treatments. Root and leaf weight ratios did not vary under different fertigation treatments, whereas in the case of shoots, plants irrigated with the standard nutrient solution showed the lowest value (0.16) (Table 3).

Table 3. The effects of different fertigation treatments (Dm_0—standard nutrient solution, Dm_1—raw leachate treatment, and Dm_2—raw leachate blended with H_2O_2 treatment) on root, stem, leaf, and total plant dry weight (RDW, SDW, LDW, and TDW, respectively) (g), relative root weight ratio (RWR), stem weight ratio (SWR), and leaf weight ratio (LWR) (−) in *D. marginata* plants at the end of the experiment. The results are expressed as means ± standard deviation (n = 4). In each column, the same letters indicate non-significant differences ($p < 0.05$).

Treatments	RDW	SDW	LDW	TDW	RWR	SWR	LWR
Dm_0	2.43 ± 0.21 a	1.15 ± 0.07 b	3.10 ± 0.29 a	6.98 ± 0.53 a	0.34 ± 0.03 a	0.16 ± 0.01 b	0.50 ± 0.05 a
Dm_1	1.66 ± 0.08 b	1.15 ± 0.08 b	2.94 ± 0.19 a	5.56 ± 0.42 b	0.31 ± 0.03 a	0.22 ± 0.02 a	0.47 ± 0.05 a
Dm_2	2.32 ± 0.18 a	1.76 ± 0.10 a	3.18 ± 0.26 a	7.26 ± 0.59 a	0.32 ± 0.03 a	0.24 ± 0.02 a	0.44 ± 0.05 a

3.3. Pigment Concentrations

Plants fertigated with leachates plus H_2O_2 showed the highest chlorophyll a (Chl a) (0.12 mg g^{-1} FW), and the lowest chlorophyll b (Chl b) (0.26 mg g^{-1} FW) concentration. Total chlorophyll (Chl a + b) concentration did not vary under different fertigation treatments (Table 4).

Table 4. The effects of different fertigation treatments (Dm_0—standard nutrient solution, Dm_1—raw leachate treatment, and Dm_2—raw leachate blended with H_2O_2 treatment) on pigment concentrations (expressed in mg g^{-1} FW) in *D. marginata* plants at the end of the experiment. The results are expressed as means ± standard deviation (n = 4). In each column, the same letters indicate non-significant differences ($p < 0.05$).

Treatments	Chl a	Chl b	Chl (a + b)
Dm_0	0.02 ± 0.01 c	0.40 ± 0.04 a	0.41 ± 0.04 a
Dm_1	0.05 ± 0.01 b	0.36 ± 0.03 a	0.41 ± 0.03 a
Dm_2	0.12 ± 0.01 a	0.26 ± 0.02 b	0.39 ± 0.04 a

3.4. Biochemical Parameters

Dracaena marginata plants showed the highest root proline concentration under fertigation with leachates plus H_2O_2 (55.94 µg g^{-1} FW), whereas plants fertigated only with leachates without H_2O_2 had the highest leaf proline concentration (90.61 µg g^{-1} FW). Regarding total soluble sugars, fertigation with leachates with H_2O_2 decreased their concentration in roots. In leaves, plants fertigated with leachates without H_2O_2 showed the highest leaf total soluble sugar concentration (8.11 mg glucose g^{-1} FW) (Table 5).

Table 5. The effects of different fertigation treatments (Dm_0—standard nutrient solution, Dm_1—raw leachate treatment, and Dm_2—raw leachate blended with H_2O_2 treatment) on root and leaf proline and total soluble sugars (TSS) concentrations in *D. marginata* plants at the end of the experiment. The results are expressed as means ± standard deviation (n = 4). In each column, the same letters indicate non-significant differences ($p < 0.05$).

	Treatments	Roots	Leaves
Proline	Dm_0	24.41 ± 2.18 c	69.40 ± 6.34 b
	Dm_1	33.87 ± 2.59 b	90.61 ± 8.32 a
	Dm_2	55.94 ± 4.85 a	63.01 ± 5.76 b
TSS	Dm_0	3.34 ± 0.21 a	6.20 ± 0.35 b
	Dm_1	3.16 ± 0.20 a	8.11 ± 0.63 a
	Dm_2	2.58 ± 0.18 b	5.97 ± 0.24 b

3.5. Root, Stem, and Leaf Nutrients

Nitrogen concentration in the different organs assessed showed the highest value in plants fertigated with leachates and H_2O_2. Phosphorus root concentration showed the highest value in plants fertigated with the standard nutrient solution (control treatment)

(7.51 mg g^{-1} DW). In stems and leaves, the lowest P concentration was found in plants fertigated with leachates with H_2O_2. Potassium root concentration declined in plants fertigated with leachates with H_2O_2, whereas with this fertigation the leaf showed the highest K concentration (51.89 mg g^{-1} DW). In stems, there were no variations in the K concentration under the different fertigation treatments (Table 6).

Table 6. The effects of different fertigation treatments (Dm_0—standard nutrient solution, Dm_1—raw leachate treatment, and Dm_2—raw leachate blended with H_2O_2 treatment) on nutrient concentrations (expressed in mg g^{-1} DW) in roots, stems, and leaves in *D. marginata* plants at the end of the experiment. The results are expressed as means ± standard deviation (n = 4). In each column, the same letters indicate non-significant differences ($p < 0.05$).

	Treatments	**Roots**	**Stems**	**Leaves**
N	Dm_0	41.10 ± 4.10 b	39.30 ± 3.38 b	30.82 ± 2.72 b
	Dm_1	46.61 ± 5.02 b	40.03 ± 4.34 b	34.60 ± 4.23 b
	Dm_2	64.26 ± 5.72 a	62.86 ± 5.56 a	58.59 ± 4.35 a
P	Dm_0	7.51 ± 0.54 a	5.53 ± 0.50 a	6.78 ± 0.57 a
	Dm_1	1.35 ± 0.10 c	5.45 ± 0.53 a	6.18 ± 0.53 a
	Dm_2	3.48 ± 0.34 b	4.14 ± 0.37 b	3.43 ± 0.38 b
K	Dm_0	30.87 ± 2.98 a	41.85 ± 3.86 a	36.17 ± 2.72 b
	Dm_1	29.73 ± 3.52 a	45.45 ± 4.14 a	35.60 ± 3.23 b
	Dm_2	22.54 ± 2.72 b	45.64 ± 3.56 a	51.89 ± 4.80 a

3.6. Water and Nutrient Use Efficiencies

The irrigation with the leachates without H_2O_2 declined water and nutrient use efficiencies compared to the control treatment. Nevertheless, the addition of H_2O_2 in the leachate enhanced water and nutrient use efficiencies, showing similar values with the control treatment in the case of WUE, PUE, and SUE (Table 7). It is necessary to point out that in the case of Dm_1 and Dm_2, the calculation of water and nutrient use efficiencies was carried out considering the leachates of the previous crop used in the fertigation of *D. marginata* plants.

Table 7. The effects of different fertigation treatments (Dm_0—standard nutrient solution, Dm_1—raw leachate treatment, and Dm_2—raw leachate blended with H_2O_2 treatment) on water and nutrient use efficiencies in *D. marginata* plants at the end of the experiment. The results are expressed as means ± standard deviation (n = 4). In each column, the same letters indicate non-significant differences ($p < 0.05$).

Parameters	**Dm_0**	**Dm_1**	**Dm_2**
WUE	5.76 ± 0.51 a	2.92 ± 0.20 b	6.32 ± 0.58 a
NUE	0.30 ± 0.02 a	0.06 ± 0.01 c	0.13 ± 0.01 b
PUE	0.83 ± 0.08 a	0.38 ± 0.04 b	0.85 ± 0.09 a
ClUE	0.05 ± 0.01 a	0.01 ± 0.002 c	0.02 ± 0.003 b
SUE	0.27 ± 0.02 a	0.13 ± 0.01 b	0.28 ± 0.03 a
CaUE	0.07 ± 0.01 a	0.01 ± 0.002 c	0.02 ± 0.004 b
MgUE	0.17 ± 0.02 a	0.02 ± 0.006 c	0.05 ± 0.01 b
KUE	0.05 ± 0.01 a	0.01 ± 0.003 c	0.02 ± 0.004 b
NaUE	0.10 ± 0.01 a	0.01 ± 0.004 c	0.02 ± 0.005 b

3.7. Chemical Composition of the Substrate

Regarding the chemical composition of the substrate at the end of the experiment, the fertigation with leachates with H_2O_2 declined the concentration of chloride in the substrate. In the case of nitrate, the fertigation with leachates with and without H_2O_2 (3.74 and 5.43 mM) increased the concentration compared to the control treatment (1.80 mM). Phosphate and sulphate concentration in the substrate remained unchanged under the different fertigation treatments assessed. With regards to the level of cations, Na^+ and Mg^{2+} concentration remained unchanged under the different fertigation treatments with values around 8 mM and 3 mM, respectively. The fertigation with leachates with H_2O_2 decreased the concentration of K^+ and Ca^{2+} in the substrate (Figure 2).

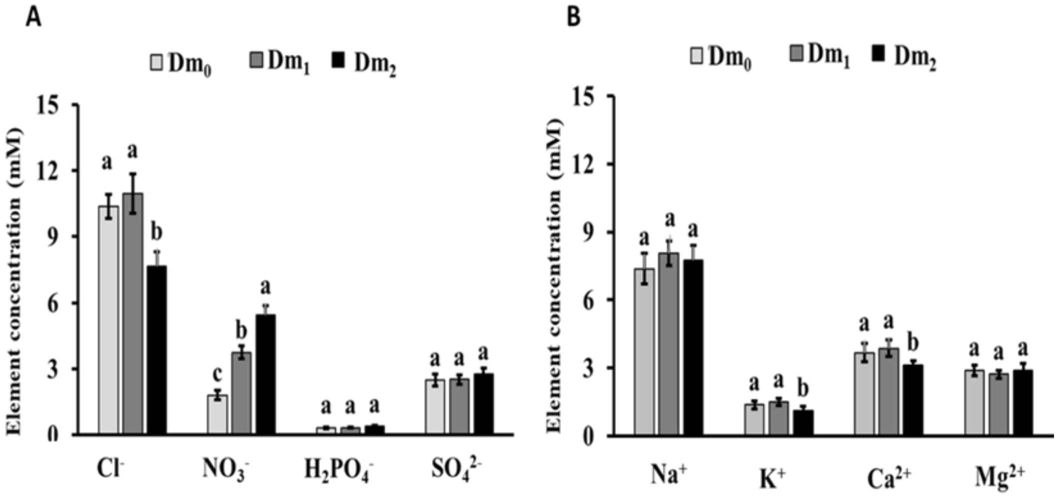

Figure 2. Anion (**A**) and cation (**B**) concentrations in the substrate at the end of the experimental period under the different fertigation treatments (Dm_0—standard nutrient solution, Dm_1—raw leachate treatment, and Dm_2—raw leachate blended with H_2O_2 treatment). Treatments with the same letters are not significantly different at $p < 0.05$ (ANOVA and LSD test). Data are the means ± standard deviation of four plants per treatment.

4. Discussion

The chemical composition of the leachates with or without H_2O_2 was higher in pH and EC with respect to the control treatment. The pH increase can be associated with the release of OH^-, as has been reported in similar systems [23]. On the other hand, the fertigation with leachates with or without H_2O_2 resulted in an increase in EC mainly due to the accumulation of toxic ions such as Na^+ and Cl^- [24,25]. The reuse of the leachate from another crop and the nutrients released by this crop could be the reason for the high concentration of several nutrients in the leachate, as reported by Massa et al. [26].

Our results reported that the *Dracaena marginata* plants fertigated with leachates with H_2O_2 had an increased plant height. Similar results were reported by Almeida-Veloso et al. [27] in soursop (*Annona muricata*) plants fertigated with additional H_2O_2. Better oxygenation, associated with the addition of H_2O_2 to the leachate, may have enhanced root respiration and consequently increased the plant growth as reported Pendergast et al. [28].

No variations in the root length between fertigation treatments can be associated to the availability of water and nutrients, which in some cases was excessive during the experimental period, suggesting that the plants did not need to vary their root length in search of water and nutrients. Also, the short duration of the experimental period can be considered relevant for the data obtained in our work.

The fertigation with leachates with or without H_2O_2 only increased the red index color. Although, the information about the effects of fertigation with leachates with or without H_2O_2 on the aesthetic values of ornamental plants are null, it is necessary to point out that the increase in red index color was highly valued in this species by local nursery growers resulting in more profitable sales.

The results of this experiment reported that the fertigation with raw leachates in *D. marginata* resulted in a reduction in root and total dry weight compared to the fertigation with a standard nutrient solution, but the addition of H_2O_2 to the raw leachate enhanced root, shoot, and total dry weight. The reduction in root and total dry weight in our experiment is in agreement with the results obtained by several researchers studying ornamental plants grown under saline conditions [29–31], and this decline in biomass can be associated with metabolic disorders in plants as a consequence of the osmotic and toxic effects caused by saline conditions [32,33]. On the other hand, the enhancement of the dry weight as a consequence of the addition of H_2O_2 to the leachate was in line with the findings reported in similar experiments. For instance, Hameed et al. [11] noted an increase in the root dry weight of wheat plants with the addition of H_2O_2. Analogously, Bhattarai et al. [12] reported an increase in the plant dry weight of soybean and cotton plants subjected to the application of H_2O_2.

Fertigation with raw leachates and additional H_2O_2 resulted in an increase in chlorophyll a and a decrease in chlorophyll b concentration, without changes in total chlorophyll concentration. Different results have been reported by other researchers who found an enhancement of pigment concentrations associated with the addition of H_2O_2 in several crops such as corn [34], cotton, and soybean [12] agree with our chlorophyll a results. However, there seems to be a compensatory effect occurring between both chlorophylls, without modification of the total amount of both.

Dracaena marginata plants fertigated with raw leachates had increased root proline concentration compared to the control treatment, with this concentration being even higher if the raw leachate had additional H_2O_2. Different results have been reported by other researchers who noted that the exogenous application of H_2O_2 resulted in an increase in proline content in cucumber plants [35]. Nevertheless, leaf proline showed the highest value in plants fertigated with raw leachates without additional H_2O_2. The increase in proline concentration in both organs may be associated with its role as an osmoprotectant under stressed conditions, such as the ones occurring when higher salinity levels were present in the leachate [36–38]. Regarding the concentration of total soluble sugars, the addition of H_2O_2 to the raw leachates decreased the root concentration. In the case of the concentration of leaf total soluble sugars, the fertigation with raw leachates showed the highest value. The decrease in the total soluble sugars in the root concentration can be associated to the consequent increase of proline since both may act as an osmoprotectant in plants, in addition to the fact that under better oxygenation conditions respiration rates may be higher consequently increasing the consumption of sugars at the root level.

As far as nutrient concentrations were concerned, it is necessary to highlight that the results obtained in our experiment revealed that the addition of H_2O_2 to the leachate resulted in an enhancement in N concentration, whereas in the case of P and K, there were no clear trends among the fertigation treatments. Ben-Noah and Friedman [8] also noted a rise in N concentration in pepper plants fertigated with additional H_2O_2. No clear trends in P and K concentration in the different fertigation treatments assessed may be due to the antagonisms between Cl^- and $H_2PO_4{}^-$ and K^+/Na^+ that occur under saline conditions [39]. The leaf N concentration obtained in our experiment in the plants fertigated with the standard nutrient solution and leachates without H_2O_2 were in the range (23 to 50 mg g^{-1} DW) reported by Mills and Jones [40], whereas plants fertigated with leachates with H_2O_2 had a higher value (58.59 mg g^{-1} DW). Regarding leaf P concentration, only plants fertigated with leachates with H_2O_2 (3.43 mg g^{-1} DW) were in the range reported by Mills and Jones [40] (1.8 to 6 mg g^{-1} DW), whereas the other fertigation treatments showed higher values. With respect to K, all the fertigation treatments were in the range proposed by Mills and Jones [40] (25 to 45 mg g^{-1} DW) except for the plants fertigated with leachates with H_2O_2 which showed higher values (51.89 mg g^{-1} DW).

The decrease in water and nutrient use efficiencies in the plants fertigated with leachates compared to the fertigation with the standard nutrient solution may be related to the fact that under higher saline concentrations, as occurs in the leachate, the ability of crops to uptake water and nutrient is reduced mainly due to the osmotic and toxic effects associated with the reduction of growth under saline conditions [41,42]. Nevertheless, the addition of H_2O_2 to the leachate resulted in an enhancement of water and nutrient use efficiencies, agreeing with the results reported by Du et al. [43] who noted that under better oxygenation conditions due to the addition of H_2O_2, there was a marked increase in crop water and fertilizer uptake.

The chemical analysis of the substrate revealed that the fertigation with leachates with H_2O_2 resulted in a significant decline in Cl^-, K^+, and Ca^{2+}. On the other hand, the fertigation with raw leachates increased the concentration of $NO_3{}^-$ in the substrate. The decline of these nutrients in the substrate may be due to the possible modifications in the cation exchange capacity of the substrate as a consequence of the interaction between organic matter, H_2O_2, and reactive intermediates, as reported by Ben-Noah and Friedman [8]. The decline in Cl^- and the increase in $NO_3{}^-$ in the substrate can be ascribed to the fact that under saline conditions some species tends to uptake Cl^- for the maintenance of the osmotic adjustment and consequently reduce their uptake of $NO_3{}^-$ due to antagonisms among these nutrients [44].

5. Conclusions

Our findings reported that the fertigation with leachates increased the red index value, chlorophyll a, and the proline concentration, but decreased the total dry weight, the root P concentration, and the water and nutrients uptake efficiency compared to the control treatment. The fertigation of *D. marginata* with leachates and additional H_2O_2 resulted in taller plants. The addition of H_2O_2 enhanced the root, stem, and total dry weight. Regarding the pigment concentrations and the biochemical parameters assessed, there were no clear trends between fertigation treatments. Nitrogen concentrations increased in the different organs assessed in *D. marginata* plants fertigated with leachates with additional H_2O_2. Nevertheless, in the case of P and K concentrations, there were no clear trends between the treatments evaluated. The addition of H_2O_2 to the leachate enhanced the water and nutrient use efficiencies. The chemical composition of the substrate reported no changes in $H_2PO_4{}^-$, $SO_4{}^{2-}$, Na^+, and Mg^{2+} concentrations between the treatments tested. The ameliorative effects of the addition of H_2O_2 to the leachate for the fertigation of *D. marginata* evidences the importance of this chemical compound as additional complement in the fertigation of this species indicates the need for further studies in other ornamental potted plants. Moreover, the positive results reported in this experiment suggest the potential growth of *Dracaena marginata* with leachate and H_2O_2 into a cascade cropping system.

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