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Effects of Leachate Fertilization and the Addition of Hydrogen Peroxide on Growth and Nutrient Balance in *Dracaena deremensis* Potted Plants

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Abstract: The reuse of drainages for cultivating more salt tolerant crops can be a useful tool especially in arid regions, where there are severe problems for crops water management. *Dracaena deremensis* L. plants were cultured in pots with sphagnum peat-moss and were subjected to three fertilization treatments for 8 weeks: control treatment or standard nutrient solution (D₀), raw leachates from *Chrysalidocarpus lutescens* H. Wendl plants (D_L) and the same leachate blending with H₂O₂ (1.2 M) at 1% (v/v) (D_L + H₂O₂). After harvesting, ornamental and biomass parameters, leaf and root proline and total soluble sugar concentration and nutrient balance were assessed in each fertilization treatment. Plant height, leaf and total dry weight had the highest values in plants fertilized with leachates with H₂O₂, whereas root length, leaf number, RGB values and pigment concentration declined significantly in plants fertilized with leachates from *C. lutescens* with or without H₂O₂. The fertilization with leachates, regardless of the presence or absence of H₂O₂ increased root and leaf proline concentration. Nevertheless, root and leaf total soluble sugar concentration did not show a clear trend under the treatments assessed. Regarding nutrient balance, the addition of H₂O₂ in the leachate resulted in an increase in plant nutrient uptake and efficiency compared to the control treatment. The fertilization with leachates with or without H₂O₂ increased nitrogen and potassium leached per plant compared to plants fertilized with the standard nutrient solution. The reuse of drainages is a viable option to produce ornamental plants reducing the problematic associated with the water consumption and the release of nutrients into the environment.

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



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1. Introduction

Nowadays, the production of potted plants is an important economic source in the horticultural industry. They are appreciated worldwide for gardening and landscaping projects [1]. It is estimated that the ornamental plant sector generates around 300 billion USD [2]. There is a high demand for ornamental plants due to the urban expansion and attention to plant functions and aesthetical advantages [3].

The production of containerized ornamental plants has some drawbacks since it requires a frequently fertilization due to the confinement of roots in a limited volume in a substrate with low capacity of water and nutrient retention resulting in the pollution of ground and surface water [4]. Although the leachates generated by these plants are usually rich in nutrients, they also contain a high concentration of Na and Cl which can be excessive for the non-salt tolerant cultures [5].

Under these adverse conditions generated by the excessive leachate, the implementation of a Serial Biological Concentration (SBC) or cascade cropping system could be an

environmentally sustainable option. The cascade cropping system is based on the collection of the leachate from beneath one crop to be used for the irrigation of the consequent more salt tolerant crop in the series with the main aim of reducing almost entirely the leachate volume from the last crop [6].

Oxygation is a technology based on the increase in O_2 concentration in the root zone and can be achieved through mixing air or chemical compounds such as hydrogen peroxide (H_2O_2) with irrigation water before to be distributed in the irrigation lines [7]. Hydrogen peroxide was used many years ago in agriculture for seed sterilization [8] and currently can be used for cleaning drippers or controlling pests [9]. Besides the effects already mentioned, a higher level of oxygation in the root zone due to the application of H_2O_2 in the irrigation water and the consequent enhancement of crop growth has been reported by several researchers [10,11]. Moreover, the exogenous application of H_2O_2 has been reported as ameliorative in the damage caused by saline conditions in several crops [12,13].

Dracaena deremensis is a foliage plant of high importance belonging to the family Agavaceae. Leaf color ranges from green to grey-green with various white striped patterns available. This species is well valued as interiorscapes because of its attractive form, color, and durability [14].

We have already investigated the potential use of a cascade cropping system with horticultural and ornamental plants to achieve the concomitant production of several species with water and nutrient savings [15,16]. Although the results were positive with improved yields and water and nutrient savings, the following step was to include some chemical compound in the leachate generated by the cascade cropping system in order to ameliorate the damages caused by salt accumulation in the substrate. Therefore, in this work, a pot experiment with *D. deremensis* was conducted to test how the reuse of the leachates from *Chrysalidocarpus lutescens* plants and the addition of hydrogen peroxide in the leachate affects biomass, pigment concentration, biochemical parameters, and water and nutrient uptake efficiencies and their losses.

2. Materials and Methods

2.1. Experimental Site and Growing Conditions

Seedlings of *Dracaena deremensis* plants (height: 30.1 cm, and plant dry weight: 6.5 g) were transferred to plastic containers with a volume of 1.5 L. The substrate used in the experiment was sphagnum peat-moss. The experiment was carried out over 8 weeks in a plastic greenhouse in the University of Almeria ($36^{\circ}49' N$, $2^{\circ}24' W$). During the experimental period, the climatic conditions were recorded with HOBO SHUTTLE sensors (model H08-004-02). The average temperature was 16.5 ± 1.5 °C, relative humidity (RH) was $55.6 \pm 2.9\%$, and photosynthetically active radiation (PAR) was 55.4 ± 4.4 $\mu\text{mol m}^{-2} \text{s}^{-1}$. The experiment consisted of the irrigation of *Dracaena deremensis* plants with three different fertigation treatments: standard nutrient solution or control treatment (D_0) proposed by Jiménez and Caballero [17] adapted for the culture of ornamental plants under Mediterranean conditions and two sequential reuse treatments: one of them was composed of raw leachates from *Chrysalidocarpus lutescens* plants (D_L) and the other was the same leachate blending with H_2O_2 (1.2 M) at 1% (v/v) ($D_L + H_2O_2$) (Figure 1). The plants were manually fertigated using a test tube and the same volume of 30 mL (2% of the volume container) was added to each container every day, resulting in $1.7 \text{ L pot}^{-1} \text{ treatment}^{-1}$. The planting density was 6 plants m^{-2} . The experimental design was composed of three fertigation treatments, four blocks and four plants (pots) per block giving a total of 48 plants plus adjacent plants.

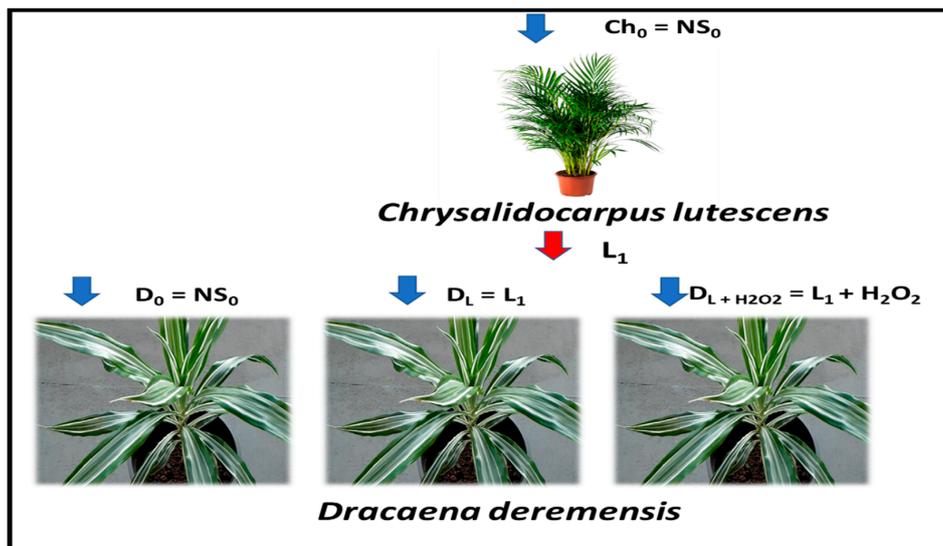


Figure 1. Schematic overview of the experimental design.

2.2. Monitoring of Irrigation and Leachate Composition

The samples of nutrient solution applied and the leachates resulting from each fertigation treatment of *D. deremensis* plants were collected weekly during the whole experimental period (8 weeks). The collection of the leachate was performed by placing 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. Aliquots of 5 mL of nutrient solution or leachates were collected and filtered using membrane filters (0.45 μ m) and frozen for further analysis. The determination of pH and EC was assessed with pH meter and conductivity meter (models Milwaukee pH52 and C66), respectively. The chemical determinations of anions and cations concentration were conducted through high performance liquid chromatography (HPLC) following the protocol reported by Csáky and Martínez-Grau [18].

2.3. Yield and Water Productivity

At the end of the harvesting, four plants per fertigation treatment were randomly selected. For each plant, we calculated the volume of applied water, leached and the percentage of leachate over the experimental period. The same plants were used for the determination of fresh weight (FW). Then, we calculated the water productivity in each treatment as the increase in FW between the beginning and the end of the experimental period divided by the volume of total water applied (grams of FW per L of water applied).

2.4. Ornamental Parameters and Pigments Concentration

Morphological parameters such as plant height, root length, leaf number, RGB values and pigment concentrations were recorded after harvesting. The plant height was measured with a ruler from the top of the last open leaf of the plant to the substrate line and the longest root length was then measured with a ruler from the crown to the tip of the root. Leaf number was counted directly. The determination of color index in leaves (RGB values) was assessed using the protocol recommended by García-Caparros et al. [19,20] and 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 the leaf pixels. The same leaves used for the determination of color index were then used for the determination of pigments concentration. Fresh samples of leaves (0.2 g) were submerged in methanol for 24 h under dark conditions at room temperature (RT). The supernatant

was removed, and the pigments concentration was recorded spectrophotometrically using the protocol reported by Wellburn [21].

2.5. Biomass Parameters

At the end of the experimental period, four plants were randomly selected per treatment and splitted into three fractions: roots, stems, and leaves. Then, these fractions were washed with distilled water and dried with blotting paper. To determine the dry weight of these fractions, each fraction was oven dried at 60 °C for 48 h. These dry weights were used to determine several plant parameters as relative leaf weight ratio (LWR; leaf DW per unit plant DW), stem weight ratio (SWR; stem DW per unit plant DW), and root weight ratio (RWR; root DW per unit plant DW) described by Garcia-Caparrós et al. [22,23]. The total plant dry weight (TDW) was calculated as the DW sum of the roots, stems, and leaves. The fresh and dry weight of roots, stems and leaves were used to calculate the plant water content (WC) (–) as indicated by Ben Amor et al. [24].

2.6. Biochemical Determinations

At the end of the experimental period, four plants were randomly selected per treatment for the determination of total soluble sugar and proline concentration in roots and leaves. Fresh material of roots and leaves (0.5 g) was crushed with ethanol (5 mL at 96%) and then washed with ethanol (5 mL at 70%). The alcoholic extract was centrifuged for 10 min (3500 × g) and then the supernatant was stored at 4 °C for further analysis. The alcoholic extract supernatant was used to determine the total soluble sugar and free proline concentrations. The anthrone reagent method was used to determine the total soluble sugar concentrations (expressed in mg glucose g⁻¹ FW). 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. [25].

2.7. Nutrient Balance

At the end of the experiment, a nutrient balance for each fertigation treatment was recorded using the protocol established by García-Caparrós et al. [26,27]. The amount of nutrient supplied per plant (expressed in mg) in each treatment was calculated by multiplying the volume applied in each fertigation treatment by the nutrient concentration. To determine the plant nutrient uptake, the oven-dried samples were ground with a mill and split into two subsamples. The determination of the soluble N-NO₃⁻ was carried out through HPLC in one subsample. The other subsample was mineralized with H₂SO₄ (96%) and hydrogen peroxide (P-free) at 300 °C for the determination of total P [28], organic N [29], and K⁺ [30] concentration. The total N concentration in the different organs assessed was calculated as the sum of the organic N and N-NO₃⁻ concentration. From these determinations and with the previous recording of the dry weight in the different fractions, we computed the plant nutrient uptake as the difference of plant nutrient content at the end and at the beginning of the experiment. An initial harvest at the beginning of the experiment gave an average of 76 ± 4 mg N, 8 ± 0.5 mg P, and 276 ± 15.8 mg K per plant. The percentage of nutrient uptake efficiency was calculated as the ratio between plant nutrient uptake (mg) and plant nutrient supplies (mg) expressed in percentage. The nutrient leached per plant (expressed in mg) in each treatment was calculated using the data recorded in the chemical composition of the leachate by their respective leached volume. The percentage of nutrient leachates was calculated as the ratio between nutrient leached per plant and nutrient supplied per plant expressed as a percentage. Nutrients available in the substrate were extracted in ultrapure water (1:10 v/v, substrate-water) using the protocol reported by Sonneveld et al. [31]. The mixture of substrate-water was subjected to shaking for 1 h and the extract was filtered. An aliquot of 5 mL of the filtered extract was determined by HPLC as described by Csáky and Martínez-Grau [18]. From these determinations, the amount of nutrient available in the substrate per pot was obtained multiplying by the apparent density of the substrate and by the pot's volume. The amount

of nutrients retained in the substrate were calculated as the difference between the amount of nutrients at the end and at the beginning of the experiment. Unaccounted nutrients were calculated as the difference between nutrient supplies per plant, nutrient leached and nutrient retained in the substrate. Unaccounted loss was expressed as a percentage dividing the value of unaccounted loss by the total nutrient supplied per plant expressed as a percentage.

2.8. Statistical Analysis

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

3. Results

3.1. Chemical Composition of the Nutrient Solution

The fertigation with leachates from *Chrysalidocarpus lutescens* with and without H₂O₂ (D_L and D_L + H₂O₂) had higher values of pH and EC with respect to the control treatment or standard nutrient solution (D₀). The fertigation with the leachates with and without H₂O₂ (D_L and D_L + H₂O₂) showed higher concentrations of NO₃⁻, Cl⁻, Ca²⁺, Mg²⁺, K⁺ and Na⁺. Regarding H₂PO₄⁻ concentration, there were no statistical differences among fertigation treatments. The control treatment or standard nutrient solution showed the highest H₂PO₄⁻ and SO₄²⁻ concentration (Table 1).

Table 1. Chemical properties of the fertigation in each treatment: D₀—standard nutrient solution or control treatment, D_L—raw leachate treatment and D_L + H₂O₂—raw leachate blended with H₂O₂ treatment. The experiment simulates a cascade cropping system with different leachate treatments of *Chrysalidocarpus lutescens* as primary or “donor” and *Dracaena deremensis* as a secondary or “acceptor” plant culture. The nutrient concentration was expressed in mmol L⁻¹ and EC was expressed in dS m⁻¹. The results are the average values ± standard deviation of four samples per fertigation treatment during the experimental period.

Parameters	D ₀	D _L	D _L + H ₂ O ₂
pH	6.60 ± 0.10 b	7.96 ± 0.11 a	7.88 ± 0.12 a
EC	1.90 ± 0.12 b	4.55 ± 0.24 a	4.61 ± 0.25 a
Cl ⁻	3.50 ± 0.11 b	20.94 ± 2.85 a	20.88 ± 2.63 a
NO ₃ ⁻	6.05 ± 0.51 b	15.87 ± 1.61 a	14.32 ± 1.54 a
H ₂ PO ₄ ⁻	0.70 ± 0.06 a	0.30 ± 0.03 b	0.26 ± 0.03 b
SO ₄ ²⁻	2.01 ± 0.04 a	1.69 ± 0.09 b	1.68 ± 0.11 b
Na ⁺	2.60 ± 0.08 b	12.12 ± 0.88 a	12.28 ± 0.98 a
K ⁺	3.08 ± 0.06 b	8.14 ± 0.50 a	8.18 ± 0.45 a
Ca ²⁺	2.03 ± 0.05 b	9.55 ± 0.55 a	9.53 ± 0.54 a
Mg ²⁺	1.41 ± 0.04 b	4.44 ± 0.38 a	4.40 ± 0.32 a

In each row, different letters indicate significant differences ($p < 0.05$).

It is worthwhile to mention that the chemical composition of the standard nutrient solution or control treatment remained constant over the experiment. As far as anions concentrations was concerned, Cl⁻ concentration in the leachates from *C. lutescens* with and without H₂O₂ showed higher values than the control treatment and did not show a clear trend during the experimental period. Nitrate concentration in the leachates showed the highest values in the first weeks of the experimental period and then tended to decrease over the experiment, being always higher than in the control treatment. In the case of phosphate concentration, the fertigation with leachates with and without H₂O₂ showed similar values over the experiment (around to 0.4 mmol L⁻¹) being lower than the control treatment (around 0.7 mmol L⁻¹). Regarding sulphate concentration, the different treatments

assessed ranged from 1.7 to 2.5 mmol L⁻¹ (Figure 2A). Considering cations concentration, it is necessary to point out that the control treatment or standard nutrient solution showed the lowest values during the experimental period. Sodium concentration in the leachates from *C. lutescens* with and without H₂O₂ tended to increase over the experimental period, whereas potassium, calcium and magnesium showed a slight trend to decrease throughout the experiment (Figure 2B).

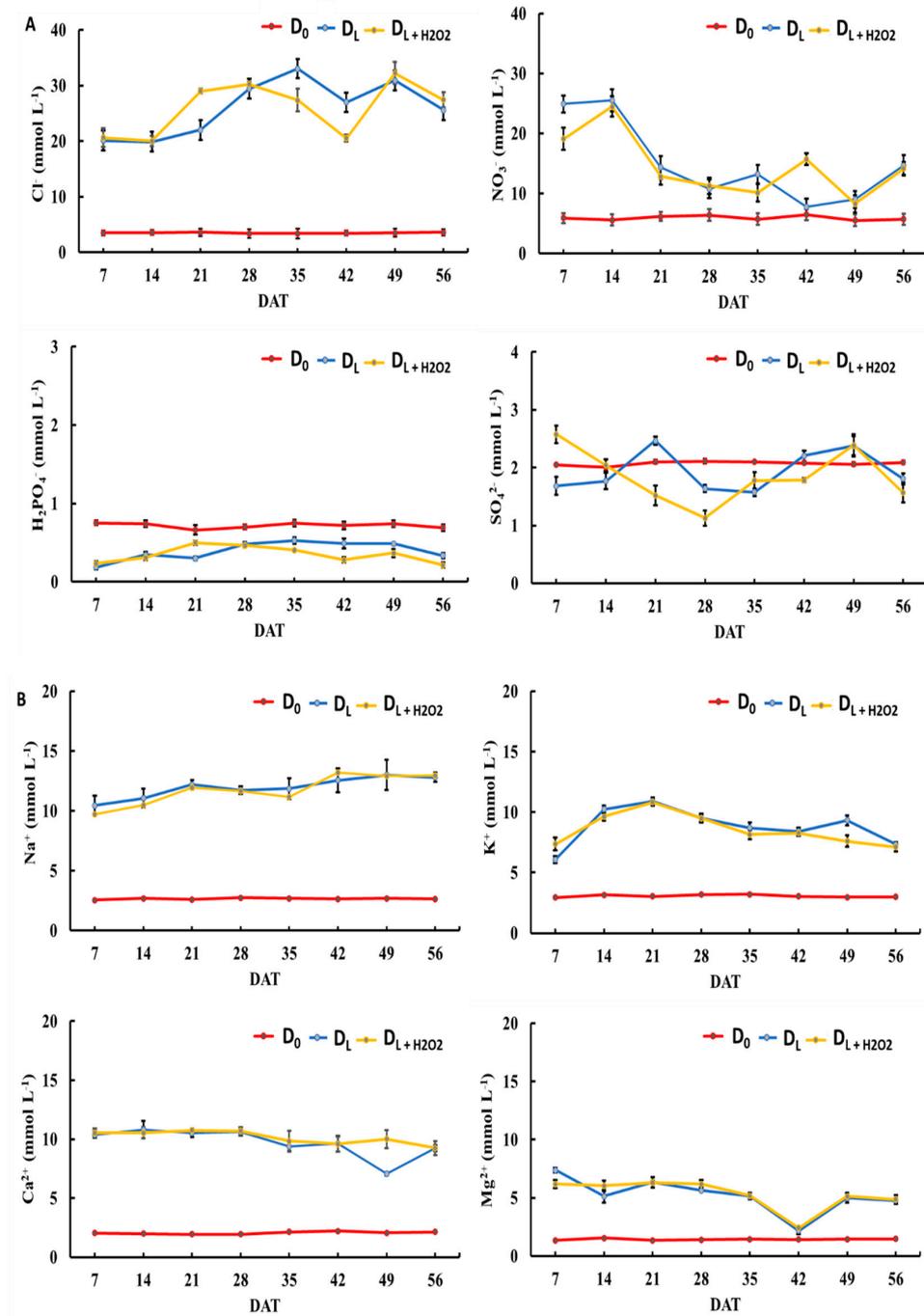


Figure 2. Anions and cations concentration (A,B) in the different fertigation treatments throughout the experimental period. D₀—standard nutrient solution or control treatment, D_L—raw leachate treatment and D_L + H₂O₂—raw leachate blended with H₂O₂ treatment. The experiment simulates a cascade cropping system with different leachate treatments of *Chrysalidocarpus lutescens* as primary or “donor” and *Dracaena deremensis* as a secondary or “acceptor” plant culture. The results are the average values ± standard deviation of four samples per fertigation treatment during the experimental period. DAT = days after transplanting.

3.2. Yield and Water Productivity in Plants

The plants subjected to different fertigation treatments received the same volume during the experimental period (10.2 L m^{-2}). The volume of leachate generated and consequently the leachate fraction and the water uptake were similar in all treatments. *Dracaena deremensis* fertigated with leachates with H_2O_2 showed the highest values in total yield (expressed in g of plant fresh weight (FW) m^{-2}) and water productivity (expressed in g of fresh weight per L of water applied) (Table 2).

Table 2. Volume of irrigation water applied, water uptake, leachate volume collected, leachate fraction, yield and water productivity of *D. deremensis* plants in each fertigation treatment: D_0 —standard nutrient solution or control treatment, D_L —raw leachate treatment and $\text{D}_L + \text{H}_2\text{O}_2$ —raw leachate blended with H_2O_2 treatment. The experiment simulates a cascade cropping system with different leachate treatments of *Chrysalidocarpus lutescens* as primary or “donor” and *Dracaena deremensis* as a secondary or “acceptor” plant culture. The results are expressed as means \pm standard deviation ($n = 4$). In each row, same letters indicate non-significant differences ($p < 0.05$).

Parameters	D_0	D_L	$\text{D}_L + \text{H}_2\text{O}_2$
Irrigation water applied (L m^{-2})	10.2 a	10.2 a	10.2 a
Water uptake	7.0 ± 0.5 a	7.1 ± 0.5 a	7.0 ± 0.6 a
Leachate (L m^{-2})	3.1 ± 0.3 a	2.9 ± 0.3 a	3.1 ± 0.3 a
Leachate fraction (%)	30 a	30 a	30 a
Yield (g FW m^{-2})	150.1 ± 12.7 b	122.5 ± 10.8 c	241.3 ± 19.8 a
Water productivity (g of FW per L of water applied)	14.2 ± 1.0 b	12.1 ± 0.8 c	23.9 ± 2.5 a

3.3. Ornamental Parameters and Pigments Concentrations

Root length and leaf number had the highest value in plants fertigated with the standard nutrient solution. The fertigation with leachates from *C. lutescens* did not vary the plant height with respect to the control treatment (fertigation with standard nutrient solution), but the addition of H_2O_2 to the leachate improved the plant height compared to the control treatment. Regarding color index, *D. deremensis* plants fertigated with leachates with or without H_2O_2 showed a decline in the values of R, G and B compared to the control treatment. Chlorophyll a, b and chl (a + b) showed the highest value in plants fertigated with the standard nutrient solution (Table 3).

3.4. Biomass Parameters

Dracaena deremensis plants fertigated with leachates from *C. lutescens* without H_2O_2 showed the lowest value of root and shoot dry weight. Leaf and total dry weight were higher in plants fertigated with leachate with H_2O_2 . The root, shoot and leaf weight ratio remained without changes under the different fertigation treatments. Plant water content showed the highest value in plants fertigated with leachate with H_2O_2 (Table 4).

3.5. Biochemical Determinations

Plants fertigated with leachates from *C. lutescens* with and without H_2O_2 increased proline concentration in roots and leaves compared to plants fertigated with the standard nutrient solution. With respect to total soluble sugar concentration, plants fertigated with leachates had the highest value of total soluble sugar concentration in root while plants fertigated with the standard nutrient solution had the highest value of leaf total soluble sugar concentration (Table 5).

Table 3. Effects of fertigation treatments (D_0 —standard nutrient solution or control treatment, D_L —raw leachate treatment and $D_{L+H_2O_2}$ —raw leachate blended with H_2O_2 treatment) on root length and plant height (expressed in cm), leaf number, color index (RGB) and pigment concentrations (expressed in $mg\ g^{-1}$ FW) in *D. deremensis* plants at the end of the experimental period. The experiment simulates a cascade cropping system with different leachate treatments of *Chrysalidocarpus lutescens* as primary or “donor” and *Dracaena deremensis* as a secondary or “acceptor” plant culture. The results are expressed as means \pm standard deviation ($n = 4$). In each column, same letters indicate non-significant differences ($p < 0.05$).

Treatments	Root Length	Plant Height	Leaf Number	Color Index			Pigment Concentrations		
				Red	Green	Blue	Chl a	Chl b	Chl (a + b)
D_0	41.25 \pm 2.75 a	35.53 \pm 1.74 b	23.00 \pm 2.04 a	111.25 \pm 7.66 a	109.07 \pm 6.92 a	86.05 \pm 6.58 a	0.06 \pm 0.01 a	0.70 \pm 0.06 a	0.75 \pm 0.06 a
D_L	33.75 \pm 2.22 b	34.13 \pm 1.65 b	17.50 \pm 1.29 b	88.50 \pm 5.72 b	85.18 \pm 5.05 b	56.55 \pm 3.43 b	0.02 \pm 0.01 b	0.42 \pm 0.04 c	0.45 \pm 0.04 c
$D_{L+H_2O_2}$	34.13 \pm 2.46 b	40.25 \pm 1.89 a	19.00 \pm 1.63 b	84.10 \pm 4.69 b	87.25 \pm 5.25 b	53.95 \pm 3.68 b	0.03 \pm 0.01 b	0.55 \pm 0.05 b	0.60 \pm 0.06 b

Table 4. Effects of fertigation treatments (D_0 —standard nutrient solution or control treatment, D_L —raw leachate treatment and $D_{L+H_2O_2}$ —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), leaf weight ratio (LWR) (-) and plant water content (WC) (-) in *D. deremensis* plants at the end of the experiment. The experiment simulates a cascade cropping system with different leachate treatments of *Chrysalidocarpus lutescens* as primary or “donor” and *Dracaena deremensis* as a secondary or “acceptor” plant culture. The results are expressed as means \pm standard deviation ($n = 4$). In each column, same letters indicate non-significant differences ($p < 0.05$).

Treatments	RDW	SDW	LDW	TDW	RWR	SWR	LWR	WC
D_0	2.56 \pm 0.24 a	1.27 \pm 0.07 a	6.97 \pm 0.61 b	10.60 \pm 0.64 b	0.23 \pm 0.02 a	0.12 \pm 0.01 a	0.65 \pm 0.05 a	1.27 \pm 0.10 b
D_L	1.88 \pm 0.16 b	1.10 \pm 0.07 b	7.08 \pm 0.60 b	9.17 \pm 0.56 c	0.21 \pm 0.02 a	0.12 \pm 0.01 a	0.67 \pm 0.05 a	1.22 \pm 0.09 b
$D_{L+H_2O_2}$	2.45 \pm 0.21 a	1.31 \pm 0.08 a	8.78 \pm 0.72 a	12.30 \pm 0.68 a	0.21 \pm 0.02 a	0.11 \pm 0.01 a	0.68 \pm 0.06 a	2.33 \pm 0.19 a

Table 5. Effects of fertigation treatments (D₀—standard nutrient solution or control treatment, D_L—raw leachate treatment and D_{L + H₂O₂}—raw leachate blended with H₂O₂ treatment) on root and leaf proline and total soluble sugar concentration in *D. deremensis* plants at the end of the experiment. The experiment simulates a cascade cropping system with different leachate treatments of *Chrysalidocarpus lutescens* as primary or “donor” and *Dracaena deremensis* as a secondary or “acceptor” plant culture. The results are expressed as means ± standard deviation (*n* = 4). In each column, same letters indicate non-significant differences (*p* < 0.05).

	Treatments	Roots	Leaves
Proline (µg g ⁻¹ FW)	D ₀	25.56 ± 2.21 b	83.45 ± 6.32 b
	D _L	34.89 ± 2.52 a	103.90 ± 8.52 a
	D _{L + H₂O₂}	34.12 ± 2.45 a	105.18 ± 8.45 a
Total soluble sugars (mg g ⁻¹ FW)	D ₀	5.49 ± 0.29 c	7.37 ± 0.54 a
	D _L	7.07 ± 0.36 a	3.57 ± 0.23 c
	D _{L + H₂O₂}	6.44 ± 0.32 b	5.39 ± 0.30 b

3.6. Nutrient Balance

The amount of N and K supplied per plant declined in plants fertigated with leachates from *C. lutescens* with and without H₂O₂, whereas in the case of P, there were no significant differences between fertigation treatments. Plant nutrient uptake showed the highest value in plants fertigated with leachates with H₂O₂. Nitrogen and P uptake efficiency showed the highest value in plants fertigated with leachates with H₂O₂, whereas in the case of K, the fertigation with leachates without H₂O₂ showed the lowest value. Nitrogen and K leached per plant increased in plants fertigated with leachates with and without H₂O₂ compared to plants fertigated with the standard nutrient solution, while in phosphorus, plants fertigated with the nutrient solution showed the highest value. The percentages of nutrient runoff in our experiment were for N (32–41%), P (31–58%) and K (36–37%). Regarding nutrients in substrate, N and P had the highest value in plants fertigated with leachates with H₂O₂, whereas in K, the highest value was in plants fertigated with leachates without H₂O₂. Unaccounted nitrogen remained without changes under different fertigation treatments, while in the case of P and K, plants fertigated with leachates without H₂O₂ showed the highest value (Table 6).

Table 6. Nutrient balance of *D. deremensis* plants under different fertigation treatments (D₀—standard nutrient solution or control treatment, D_L—raw leachate treatment and D_{L+H₂O₂}—raw leachate blended with H₂O₂ treatment). The experiment simulates a cascade cropping system with different leachate treatments of *Chrysalidocarpus lutescens* as primary or “donor” and *Dracaena deremensis* as a secondary or “acceptor” plant culture. The results are expressed as means ± standard deviation ($n = 4$). In each column, same letters indicate non-significant differences ($p < 0.05$).

	Treatments	Nutrient Supplied per Plant (mg)	Plant Nutrient Uptake (mg)	Nutrient Uptake Efficiency (%)	Nutrient Leached per Plant (mg)	Nutrient Leachates (%)	Substrate (mg)	Unaccounted Nutrient (mg)	Unaccounted Loss (%)
N	D ₀	145.1 ± 14.3 a	20.1 ± 1.7 c	13.9 ± 1.1 c	45.9 ± 4.7 b	31.9 ± 2.5 b	4.7 ± 0.3 c	76.5 ± 8.1 a	50.9 ± 5.0 a
	D _L	269.4 ± 26.2 b	60.5 ± 5.4 b	22.5 ± 2.0 b	110.7 ± 9.8 a	41.1 ± 3.8 a	7.5 ± 0.6 b	90.4 ± 8.7 a	33.6 ± 3.3 b
	D _{L+H₂O₂}	287.2 ± 28.0 b	91.3 ± 8.6 a	31.8 ± 3.0 a	105.1 ± 10.7 a	36.6 ± 3.5 a	12.3 ± 1.1 a	78.6 ± 7.4 a	27.3 ± 2.9 b
P	D ₀	37.6 ± 2.8 a	3.7 ± 0.3 b	9.8 ± 0.9 b	21.8 ± 2.1 a	57.9 ± 5.3 a	4.2 ± 0.3 b	7.6 ± 0.8 b	21.1 ± 2.0 b
	D _L	33.5 ± 2.7 a	1.1 ± 0.1 c	3.2 ± 0.3 c	11.8 ± 1.0 b	35.5 ± 3.1 b	2.5 ± 0.2 c	18.1 ± 1.6 a	53.8 ± 5.2 a
	D _{L+H₂O₂}	35.7 ± 3.1 a	9.1 ± 0.8 a	24.5 ± 2.4 a	11.2 ± 0.9 b	31.4 ± 2.9 b	8.7 ± 0.8 a	6.7 ± 0.5 b	18.7 ± 2.0 b
K	D ₀	200.6 ± 20.3 a	114.2 ± 11.1 b	56.9 ± 5.3 a	72.4 ± 6.8 b	36.1 ± 3.3 a	0.2 ± 0.01 c	13.8 ± 1.5 c	6.8 ± 0.6 c
	D _L	451.5 ± 40.7 b	120.0 ± 10.5 b	26.6 ± 2.4 b	167.2 ± 15.8 a	37.1 ± 3.9 a	0.6 ± 0.02 a	163.6 ± 13.9 a	36.2 ± 3.2 a
	D _{L+H₂O₂}	481.3 ± 39.8 b	238.4 ± 21.7 a	49.5 ± 4.4 a	173.3 ± 14.4 a	35.9 ± 3.4 a	0.4 ± 0.03 b	69.8 ± 6.4 b	14.4 ± 1.2 b

4. Discussion

Regarding fertigation treatments of *D. deremensis*, there was a rise of pH after irrigation with leachates from *Chrysalidocarpus lutescens* with and without H₂O₂ compared to the fertigation with a standard nutrient solution, and this fact can be related to the release of OH⁻ as it has been reported in similar systems [32]. The EC increase in the leachate can be ascribed to the increase in Na⁺ and Cl⁻ concentration as has been reported in other crops irrigated with leachates [27,33]. The reuse of leachates and the high presence of Cl⁻, Ca²⁺, Mg²⁺ and Na⁺ in the tap water could be due the reason for their accumulation in the fertigation with leachates over time as previously reported by Massa et al. [34]. The decrease in H₂PO₄⁻ and SO₄²⁻ in leachates over time may be related to specific nutrient requirements of the previous crop for the maintenance of some physiological processes [35].

Considering the same volume of fertigation in each treatment and also that the water uptake and the volume of leachate was similar among fertigation treatments, it is necessary to highlight that the percentage of leachate fraction obtained in our experiment (30%) was in line with the range from 25% to 30% previously reported by García-Caparrós et al. [27] in a cascade cropping system with melon and rosemary plants. Although the fertigation with leachates resulted in a significant reduction in yield and water productivity with respect to the control treatment, the addition of H₂O₂ resulted in an improvement in yield and crop water productivity in *D. deremensis* plants. Similar results were reported in several crops such as zucchini and tomato by Bhattarai et al. [10,36] in enhanced oxygation conditions, which are also achieved through the addition of hydrogen peroxide to the fertigation treatments.

The addition of hydrogen peroxide in the leachate from *C. lutescens* used for fertigation enhanced the plant height in *D. deremensis* plants. The increase in plant height can be due to a higher amount of oxygen available for root respiration [37] as a consequence of the addition of hydrogen peroxide and also may be due to the enhancement of auxins synthesis via H₂O₂ signaling as reported by Joo et al. [38]. The decrease in root length and leaf number in *D. deremensis* plants fertigated with leachates with and without H₂O₂ with respect to the control treatment can be ascribed to the fact that leachates with higher EC resulted in a reduction in root length and leaf number mainly due to the high presence of toxic ions (Na⁺ and Cl⁻) [2].

The decline in color index (R, G and B) in *D. deremensis* plants fertigated with leachates from *C. lutescens* with or without H₂O₂ agree with the reports obtained by García-Caparrós et al. [39], where the irrigation with leachates resulted in a decline in color parameters in *Maytenus senegalensis* plants. Although there was a decline in color parameters, the leaf color ranges characteristic of this species allowed the obtention of saleable plants considering the sales threshold established by local nurseries, since there were no symptoms of chlorosis or necrosis associated with the increase in salinity in the leachate.

The fertigation of *D. deremensis* with leachates from *C. lutescens* resulted in a decline in Chl b and (a + b) concentration compared to the fertigation with the control treatment. It has been argued that under high EC or saline conditions, there is a reduction in chlorophyll synthesis and the activation of its degradation by the enzyme chlorophyllase [40]. Nevertheless, the addition of H₂O₂ to the leachate for the fertigation resulted in an increase in pigment concentration compared with plants fertigated only with leachates. This enhancement of pigment concentration can be due to the addition of hydrogen peroxide and the consequent improvement in plant root respiration and photosynthetic rate as reported by Li et al. [41] and Zhao et al. [42] under oxygation conditions.

Dracaena deremensis plants fertigated with leachates resulted in a significant decline in the different biomass parameters assessed compared to the fertigation with the standard nutrient solution, but the addition of H₂O₂ to the leachate enhanced significantly these biomass parameters, being higher than the control treatment in the case of leaf and total dry weight. This biomass enhancement obtained in our experiment agrees with the results obtained by Hameed et al. [43] in wheat and Gil et al. [44] in avocado. These results are indicative of the positive effect of the addition of hydrogen peroxide in the fertigation

treatment for the growth of this species. No variations in root, shoot and leaf weight ratio reported in our experiment in *D. deremensis* plants under different fertigation treatments can be ascribed to the duration of the experiment. The increase in plant water content in plants fertigated with leachates with H_2O_2 can be ascribed to the ameliorative effect of the exogenous supply of H_2O_2 in crops already mentioned.

The fertigation with leachates from *C. lutescens* with and without H_2O_2 resulted in an increase in root and leaf proline concentration in *D. deremensis* plants with respect to fertigated plants with the standard nutrient solution. The proline increase as a consequence of the fertigation with leachates can be associated with the protective role of this osmolyte against stressful conditions such as the salt increase level in the nutrient solution as reported by Szabados and Savoure [45]. In our experiment, the fertigation with leachates with and without H_2O_2 increased root and decreased leaf total soluble sugars with respect to the control treatment. This evidence may suggest a translocation of soluble sugars from leaves to roots as has been already reported under increasing saline conditions [46].

From a nutritional point of view, the decrease in N and K supplies in the fertigation with leachates can be ascribed to the nutrient uptake of the previous crop (*C. lutescens*) as has been reported in other cascade cropping systems [5]. The highest value of nutrient uptake and efficiency in *D. deremensis* plants fertigated with leachates with H_2O_2 led to increased plant height and also the total plant dry weight previously explained. Nevertheless, the lower values in nutrient uptake and efficiency in plants fertigated with leachates without H_2O_2 did not result in any visual symptoms of nutrient deficiency. Analogously, the fertigation with leachates in a cascade cropping system with rosemary plants [27] resulted in lower nutrient uptake and efficiencies. The ranges of N (14–32), P (10–25) and K (27–57%) uptake efficiencies reported in this work in all fertigation treatments were similar with the data reported by García-Caparrós et al. [27]. The amount of N and K leached per plant expressed in mg or as percentage increased in plants fertigated with leachates. In our experiment, the amount of nutrient leached per plant ranged from 46 to 110 mg in N, from 11 to 21 mg in P and from 72 to 173 mg in K. Different results were reported by Ristvey et al. [47], since they recorded values of leachates per plant for N (4–152 mg) and P (2–16 mg) in an experiment with different fertilizer rates. The fertigation with leachates with H_2O_2 led to a higher accumulation of N and P in the substrate and this fact may be ascribed to the addition of H_2O_2 in the leachate and the possible consequent increase in NO_3^- -N and $H_2PO_4^-$ -P retention capacity in peat moss [48]. To complete the nutrient balance, unaccounted N remained without changes under different fertigation treatments, whereas in the case of P and K showed the highest values in plants fertigated with leachates without H_2O_2 . The values expressed in percentage form for nutrient loss showed different trends in plants grown under different fertigation treatments.

5. Conclusions

The results obtained in this work reported the positive effect of the addition of H_2O_2 in the leachate from *C. lutescens* on plant height, leaf and total dry weight in *D. deremensis* plants. The fertigation with leachates with or without H_2O_2 led to a decline in root length, leaf number, RGB values and pigments concentration. Root and leaf proline concentration increased under the fertigation with leachates with or without H_2O_2 , whereas in the case of total soluble sugar concentration, there were different trends in roots and leaves, resulting in an accumulation in the root fraction in plants fertigated with leachates. Plant nutrient uptake and efficiency increased significantly in plants fertigated with leachates with H_2O_2 . Nitrogen and potassium leached per plant increased in plants fertigated with leachates from *C. lutescens* with or without H_2O_2 and unaccounted nutrients showed different trends for each nutrient in the fertigation treatments assessed. These results suggest the importance of understanding how the addition of H_2O_2 may affect the metabolism and plant physiology, especially under the reuse of leachates from another ornamental species.

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