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Effect of NaCl or Macronutrient-Imposed Salinity on Basil Crop Yield and Water Use Efficiency

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Abstract: Cascade hydroponics, that is, the application of the circular economy concept in greenhouse hydroponic crops, may be considered as an alternative means to increase water and nutrient use efficiency in greenhouses. In such systems, the drained nutrient solution from a crop may be used as input in a second crop. However, the second (secondary) crop in the loop must be a crop that is less sensitive to salinity than the first (primary) crop. In the present study, the salinity tolerance of basil plants grown in rockwool and nutrient film technique (NFT) systems was investigated in order to study the potential of using a basil crop as a secondary crop in a cascade hydroponic system. In total, 4 electrical conductivity (EC) levels of the irrigation nutrient solution were tested (2, 4, 6, and 8 dS m⁻¹), and salinity was imposed by NaCl or by macronutrients. Plant growth varied across the different substrates, with those grown in the NFT system being less affected as opposed to the rockwool-grown basil plants, which showed a significant growth decrease with EC values higher than 4 dS m⁻¹. This relatively low growth pattern was associated with a decrease in water use efficiency (WUE) in the rockwool system. On the contrary, in the NFT system, the continuous flow of the nutrient solution in the root zone of the plants contributed to the alleviation of negative salinity effects, yielding up to 30 kg FM m⁻² WUE even for the plants irrigated with the highest salinity treatment (8 dS m⁻¹). The majority of macro- and micronutrients in the leaf tissue of basil were positively affected by the higher levels of conductivity in the nutrient solution. Therefore, basil cultivation could be efficiently incorporated as a secondary crop in a cascade NFT cropping system. This would contribute to drainage management in hydroponics, as the crop could be irrigated through the moderately saline drainage from a primary crop due to either NaCl or high nutrient accumulation in the leachates.

Keywords: circular economy; resources; recirculation; salinity; water use efficiency

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1. Introduction

The challenge to produce higher amounts of food with less resource use and low energy consumption presents a critical opportunity for the development of a circular economy (CE) in agriculture. The aim is to address the recycling of agricultural waste, by-products, and co-products using innovative technologies and profitable business practices. The development of CE requires the adoption of closed-loop system layouts that work towards the goal of upgrading economic and environmental sustainability. The improvement of such systems is a departure from the traditional linear systems of production which act through the transformation of natural resources to products and then to waste [1].

In agriculture, greenhouse cultivation, especially of soilless crops, is a very resource-intensive cultivation method and may be as considered circular since plants can grow in closed systems where water and nutrients are recirculated [2]. However, closed or

recirculating hydroponic systems can significantly reduce (but not eliminate) fertilizer runoff, and the spent nutrient solution (NS) must eventually be collected and treated at the end of the crop cycle [3]. Closed systems involve higher installation and operating costs and require a high degree of automation and technical skill. Their cost-effectiveness is controversial in the horticultural industry. As a result, most high-value horticultural production, especially in the Mediterranean region, is done using “open” systems [3].

Collecting and re-using the drainage of soilless crops to cover the actual needs of a secondary greenhouse crop could be an alternative method for reducing fertilizer and water use and, therefore, the environmental impact. However, in a cascade hydroponic system there is a need to use a demanding crop such as tomato or cucumber as the main (primary) crop and a less demanding secondary crop with a shorter cultivation cycle [2]. The proper choice of a secondary crop that can efficiently grow at a wider range of nutrient concentrations will define the sustainability of the system.

According to Elvanidi et al., (2020) [2], basil could be efficiently incorporated as a secondary crop in cascade systems since it can accumulate up to 50% NaCl. The composition and quantity of the essential oils produced from basil crops, however, could be markedly affected by nutrient supply [2] and to lesser extent by salinity level.

To date, basil's salinity tolerance has been extensively studied over a wide range of electrical conductivity values mainly derived from NaCl accumulation in nutrient solution over time [4]. However, an important consequence of salinity stress in plants is the excessive generation of harmful reactive hydroxyl radicals (OH⁻) because of the nitrate derivative, particularly in chloroplasts and mitochondria [5,6]. Moreover, a high concentration of fertilizers like sulfate can quickly become damaging in recirculation as the plant uptake is often low, which results in rapid accumulation on the root surface [7]. Consequently, almost all nutrients are salts which in water split into positively charged cations and negatively charged anions, where high concentrations may cause salinity stress in the crops.

In the literature, most studies [4,8–11] have investigated basil's salt tolerance by adding NaCl to the NS to achieve higher EC values. The present study assessed basil's tolerance to salinity not only by adding NaCl but also high quantities of fertilizers. The aim was to investigate different conditions of salinity stress in basil crops in order estimate their performance as a possible secondary crop in a cascade system that will be irrigated with the effluent of a primary crop (e.g., tomato). In this sense, basil plants were grown in rockwool cubes and in an NFT system under different salinity levels. To achieve this, basil plants were irrigated with nutrient solution, with the electrical conductivity values varied between 2 and 8 dS m⁻¹ under controlled climate conditions. High EC values were obtained either by adding NaCl or by increasing the nutrient element concentration. To evaluate the crop growth quality, a series of yield measurements were carried out, while the water use efficiency achieved in each of the salinity indicators was calculated to assess the environmental impact.

2. Materials and Methods

2.1. Experimental Setup

Preliminary experiments were conducted at the Laboratory of Agricultural Constructions and Environmental Control of the University of Thessaly in Velesino (latitude 39°44', longitude 22°79', altitude 85 m), Greece. The experiments were performed in a controlled growth chamber with a ground area of 28 m². A climate control computer (Argos Electronics, Evia, Greece) was set up to automatically monitor the air temperature, relative humidity (R.H.), and light intensity, as well as the concentration of CO₂ prevailing in the chamber. The mean day and night temperatures were 25 °C and 18 °C, respectively, while the R.H. was set from 35% to 50%. The CO₂ concentration in the environment of the chamber was approximately 400 ppm. Moreover, 4 clusters of 6 high-pressure sodium light lamps (MASTER Green Power 600 W EL 400 V Mogul ISL, Philips, Amsterdam, the Netherlands) were placed on the ceiling of the chamber to provide the appropriate light intensity to the crop. All lamps were set to operate for 15 h a day to simulate the actual

external conditions. Contrariwise, all lamps were progressively turned off during the evening hours. The total light intensity, in the case where all lamps were activated, was 230 W m^{-2} .

To test the efficiency of reusing the saline drainage solution (DS) of a primary crop for the irrigation of basil for secondary or tertiary cultivation, different conditions of salinity stress were used in a 2-period experiment from August to October 2019 (first period) and from October to November of the same year (second period).

During the first period, 160 basil plants (8 plants m^{-2}) were cultivated on rock-wool cubes (Grodan®, Delta, Atlanta, GA, USA) in 8 individually closed hydroponic systems. Each of those systems contained a metallic channel ($180 \text{ cm} \times 20 \text{ cm}$) consisting of 15 rockwool cubes in which basil plants were grown. The plants were irrigated manually after calculating the average weight by a representative sample of each treatment of 5 random cubes (totally 40 cubes) each day to add the required amount of the nutrient solution to each cube. The weight of each rockwool cube under water saturation conditions was estimated to be 284 g. The resulting irrigation dose changed according to the salinity treatment and the plant growth. In total, the irrigation dose was more or less than 100 mL daily according to the treatment during the first 25 days and was increased to 150–200 mL during the last 16 experimental days as the plant growth increased. The pH setpoint of the irrigation solution (IS) varied from 5.6 to 6.0. The plants were transplanted into the cubes 26 days after sowing. The different irrigation strategies were applied directly after transplantation, while the entire experimental period lasted 41 days after transplanting (DAT).

During the second period, 96 basil plants (5 plants m^{-2}) were cultivated in a nutrient film technique (NFT) system consisting of 12 individually closed hydroponic systems that used gravity to assist the water flow (Figure 1). Each of these systems contained a metallic channel ($180 \text{ cm} \times 20 \text{ cm}$), a white tank (20 L) made of polyethylene, the irrigation system, and the pump used to operate the irrigation system. Each of the NFT channels consisted of 8 plants with each plant growing in a hole of 55 mm in diameter, while the distance between the holes was 20 cm. The water pump was placed within the white tank filled with water and nutrients. The nutrient solution was moved by the water pump to the highest point of the NFT channel through a small-size irrigation tube to flow constantly under the roots. To aid flow, the channels were placed on a slight incline, so gravity moved the nutrients along. Then, the irrigation solution flowed naturally to return to the reservoir tank with no further assistance. The irrigation was controlled by a time program which was connected to the lighting operation. In total, the irrigation dose varied from 150 to 200 mL per plant daily, with a pH setpoint around 5.6. The 20 L white tank was refilled with the proper solution every 2 days, ensuring that the surface level did not exceed the lower limit of 10 L. The plants were transplanted into the NFT system 36 days after sowing. The irrigation strategies started at DAT 14, while the whole experimental period lasted 35 days.

In the current research, 2 salinity strategies were tested during the first period comprising 4 salinity treatments. In the first period the salinity level was set at 4, 6, and 8 dS m^{-1} by adding either (i) salt-NaCl (Grodan saline solution, G-SS treatment) up to the EC “target” indication or (ii) nutrient solution (Grodan nutrient solution, G-NS treatment) in different concentrations. The treatments of the first period are presented as follows: (i) standard fresh nutrient solution with electrical conductivity (EC) set at 2.0 dS m^{-1} , comprising the control treatment, and nutrient solution with EC set at (ii) 4.0 dS m^{-1} , (iii) 6.0 dS m^{-1} , and (iv) 8.0 dS m^{-1} comprising the salinity treatments. The control plants were irrigated according to Puccinelli et al., (2017) [12]: 11.0 mM N-NO_3^- , 1.0 mM N-NH_4^+ , $1.0 \text{ mM P-H}_2\text{PO}_4$, $2.44 \text{ mM S-SO}_4^{2-}$, 4.0 mM Ca^{2+} , 5.0 mM K^+ , 2.0 mM Mg^{2+} , $1.0 \text{ }\mu\text{M Cu}^{2+}$, $40.0 \text{ }\mu\text{M Fe}^{2+}$, $5.0 \text{ }\mu\text{M Mn}^{2+}$, $1.0 \text{ }\mu\text{M Mo}^{2+}$, and $5.0 \text{ }\mu\text{M Zn}^{2+}$. In the second period, only salt (nutrient film technique saline solution, NFT-SS) was added to achieve the EC target indication at 2, 4, 6, and 8 dS m^{-1} . However, the control plants were irrigated with a fresh nutrient solution like the NS control plants in the first period. The aim was to study the effect of the irrigation of the basil crop through an NS of increasing EC (mainly due to the increase in nutrients or salinity) on the morphological and physiological characteristics of the basil.

Figure 1. Basil crop cultivated in the NFT system within the closed automatic growth chamber.

2.2. Measurements

Air temperature (T , in $^{\circ}\text{C}$) and relative humidity (RH , in $\%$) were measured using a temperature humidity sensor (model HD9008TR, Delta Ohm, Italy), calibrated before the experimental period and placed 1.8 m above ground level. Irradiance (R_g , i , in W m^{-2}) inside the greenhouse was recorded using a solar pyranometer (model SKS 1110, Skye instruments, Powys, UK) located 1.8 m above ground.

In total, 3 destructive samplings were performed during the first period at DAT 13, 27, and 41 to estimate the fresh (FM) and dry matter (DM) of the crops. During the 2 first sampling dates, only 5 plants per treatment were harvested, while the number of samples collected on the last date increased to 10 ($n = 10$). On the other hand, only 2 destructive measurements were taken during the second period, at DAT 25 and 35. On each sampling date, 3 (1 plant/repetition) plants per treatment were collected, weighed, and then dried in a forced-air oven for 72 h at 70°C .

Additionally, in each destructive sampling process the number of leaves during both periods was also measured. In the first period, the measurements were recorded using 5 plants per treatment and repetition during the first 2 sampling dates, and 10 plants per treatment and repetition during the last date. In the second period, the recorded data were obtained measuring the number of leaves of 3 plants per treatment on both sampling dates.

The plant leaf chlorophyll content was measured during the destructive sampling dates in the first period and twice a week in the second period. The measurements were recorded using non-destructive sensing by means of an Opti-Science sensor performing measurements in contact with the leaf (CCM 200, Opti-Science, Hudson, NH, USA). In total, 25 and 10 measurements per treatment were taken from young and fully developed leaves in the first and in the second period, respectively. The CCM 200 sensor records relative measurements of chlorophyll content index (CCI).

In both periods, the plant height was estimated by measuring the distance between the upper boundary and the ground level (accuracy: ± 0.5 cm) using a calibrated ruler once a week. The measurements were recorded by 10 plants per treatment and repetition during the first period and 12 plants per treatment during the second period.

On the last sampling date of both periods (DAT 41 and DAT 35), dry leaf samples were used to estimate the nutrient element concentration (nitrate $^{-}$, K^{+} , Ca^{2+} , Na^{+} , and Mg^{2+} concentration) in the leaf tissue. Dry samples were carried out by 10 plants per

treatment and repetition during the first period, and 4 plants per treatment and repetition (total $n = 12$ per treatment) during the second period. The extraction was performed using the Kjeldahl nitrogen method (TKN) based on the Kjeldahl protocol [13]. Nutrient elements were determined by ICP (ICP-OES, SPECTRO Analytical Instruments GmbH, Kleve, Germany).

In addition, in the first period the nutrient concentration was analyzed using the rockwool cube effluent solution after rinsing the cube with 1 L of tap water. The analysis was performed at the end of the first 2 harvest dates (DAT 13 and DAT 27) using 5 random cubes per treatment and repetition. The sampling number was increased to 10 cubes per treatment and repetition at the last harvest date. The extraction and the nutrient element estimation was determined following a similar protocol to that of the dry leaf samples. However, in this process, no electrical conductivity (dS m^{-1}), and pH measurements were recorded in the drainage solution (DS), as there would be no representative indicator. In the second period, on the other hand, measurements of the EC (dS m^{-1}) and the pH values in the DS were recorded without managing further nutrient concentration analysis. The EC and pH measurements were recorded manually twice a week using a portable sensor (Combo, Hanna Instruments, Woonsocket, RI, USA). In the same period, the volume of the NS absorbed by the plants was also measured. This measurement was achieved by measuring the height between the solution surface and the bottom of the white tank before each tank refill every 2 days using a calibrated ruler.

2.3. Calculations

During the first period, the total sum of the solution absorbed by the crop was considered equal to the total sum of the IS (L) imposed on the plants during the cultivation period and was divided by the total number of plants m^{-2} (L m^{-2}) in each treatment group. However, in the second period, to calculate the water absorption corresponding to the plants of each treatment group, the difference between the amount of solution contained in the tank before refilling it and the amount of the maximum water threshold (20 L) had to be calculated. Then, after summing the values obtained from the above calculation for each treatment and dividing this result by the number of plants per treatment multiplied by the total number of m^{-2} of plants, the total water absorption was calculated (L m^{-2}).

In both periods, the water use efficiency (WUE, kg m^{-3}) was estimated after dividing the biomass, considering the produced FM or DM by the volume of the applied nutrient solution.

2.4. Statistical Analysis

Multiple comparison of means was performed by applying 1-way ANOVA using the Tukey–Kramer HSD test at the 5% level ($p \leq 0.05$). In the case the data did not follow a normal distribution, a non-parametric Kruskal–Wallis test ($p \leq 0.05$) was applied. Significance values were also evaluated by the LSD test. All comparisons were performed using the Statistical Package for the Social Sciences (SPSS, IBM, Armonk, NY, USA, 2012) [14]. The mean values along with the standard deviation ($\pm\text{SD}$) of the parameters measured are reported.

3. Results

3.1. Water Status and Nutrient Solution Analysis

Based on the calculations of water absorption, the total absorption of basil plants grown on rockwool cubes was 40 L m^{-2} for all salinity regimes and 38 L m^{-2} when the plants were cultivated in the NFT system. As shown in Figure 2, the NS uptake rate showed a gradual decrease, especially in the case of the NFT-SS4, NFT-SS6, and NFT-SS8 treatments, as NaCl was added in the NS from DAT 14 to DAT 22. However, from DAT 25 the fresh water needs increased with plant growth to the level of uptake recorded before the enrichment of NS with NaCl.

Figure 2. Total fresh water needs (L m^{-2}) of the basil crop grown in the NFT system irrigated by means of the NFT-SS treatments during the second period.

The different salinity levels did not affect the quantity of the IS that the plants absorbed. This hypothesis was confirmed, since no significant changes occurred ($p > 0.05$) in the concentration of the main nutrient elements detected in the solution drained from the rockwool cubes after flushing them with water (Table 1).

Table 1. Mean values ($\pm$ SE) of the nutrient concentrations (mmol L^{-1}) found in the drainage solution resulting from plants irrigated by means of G-NS and G-SS during the first period.

Treatments	NO_3^-	P	K	Ca	Mg	Na
G-NS2 ^a	$28.5 \pm 18.9 \text{ a}^1$	$0.05 \pm 0.0 \text{ b}$	$8.7 \pm 5.7 \text{ c}$	$6.3 \pm 3.0 \text{ b}$	$4.3 \pm 1.8 \text{ a}$	$10.0 \pm 7.1 \text{ a}$
G-NS4	$29.2 \pm 14.3 \text{ a}^*$	$0.06 \pm 0.0 \text{ b}$	$9.6 \pm 4.3 \text{ bc}$	$5.9 \pm 2.2 \text{ bc}$	$3.3 \pm 0.9 \text{ a}$	$10.8 \pm 11.1 \text{ a}$
G-NS6	$39.5 \pm 15.9 \text{ a}^*$	$0.16 \pm 0.1 \text{ a}^*$	$14.5 \pm 5.8 \text{ ab}^*$	$7.8 \pm 2.6 \text{ ab}^*$	$3.9 \pm 1.0 \text{ a}^*$	$13.0 \pm 12.5 \text{ a}$
G-NS8	$43.5 \pm 23.9 \text{ a}^*$	$0.25 \pm 0.2 \text{ a}^*$	$16.0 \pm 9.0 \text{ a}^*$	$9.2 \pm 4.4 \text{ a}^*$	$4.2 \pm 1.5 \text{ a}^*$	$8.3 \pm 4.6 \text{ a}$
G-SS2 ^b	$23.5 \pm 18.5 \text{ a}$	$0.03 \pm 0.0 \text{ a}$	$7.3 \pm 5.8 \text{ a}$	$5.6 \pm 2.9 \text{ a}$	$3.8 \pm 1.6 \text{ a}$	$9.8 \pm 6.1 \text{ c}$
G-SS4	$12.5 \pm 7.5 \text{ a}$	$0.04 \pm 0.0 \text{ a}$	$4.0 \pm 2.2 \text{ a}$	$3.7 \pm 1.2 \text{ a}$	$2.7 \pm 0.7 \text{ ab}$	$21.5 \pm 10.5 \text{ b}^*$
G-SS6	$16.4 \pm 8.4 \text{ a}$	$0.04 \pm 0.0 \text{ a}$	$5.5 \pm 2.8 \text{ a}$	$3.7 \pm 1.1 \text{ a}$	$2.7 \pm 0.7 \text{ ab}$	$34.1 \pm 15.0 \text{ a}^*$
G-SS8	$15.7 \pm 11.2 \text{ a}$	$0.04 \pm 0.0 \text{ a}$	$5.3 \pm 3.8 \text{ a}$	$3.7 \pm 1.3 \text{ a}$	$2.5 \pm 0.6 \text{ b}$	$36.2 \pm 18.1 \text{ a}^*$

¹ Means followed by different lowercase letters (a, b, c) differ significantly according to the Tukey–Kramer HSD test at $p < 0.05$ across irrigation treatments for each of the tested EC regimes (e.g., G-NS2 and G-NS4). Within each column, means followed by an asterisk differed significantly across irrigation treatments for the same EC regime (e.g., G-NS2 and G-SS2). ^a Grodan nutrient solution; ^b Grodan saline solution.

In the case of the results obtained from the G-NS and G-SS treatments analysis, no significant differences were recorded between the treatments ($p > 0.05$) in terms of the NO_3^- , Mg, and Na elements. However, the mean values of P, K, and Ca, were strongly affected by the increase in the EC target in the irrigation solution. As a result, higher nutrient concentrations of those elements were recorded in the case of the G-NS6 and G-NS8 treatments. Remarkably, the P content detected in the G-NS8 treatment was 5 times higher as compared to the corresponding value of the control treatment.

On the other hand, in the case of the results obtained from the G-SS treatment analysis, the P, K, Ca, and NO_3^- elements were not affected by the different salinity regimes imposed on the plants with each treatment ($p > 0.05$). Notwithstanding, the addition of NaCl in the G-SS led to an increase by 70% in the Na concentration of the G-SS6 and G-SS8 treatments

in comparison with the control treatment. Remarkably, the irrigation of plants with the G-NS6 and G-NS8 treatments resulted in two- and three-fold concentrations of NO_3^- , P, K, Ca, and Mg in the DS as opposed to the G-SS6 and G-SS8 treatments, respectively. However, the Na content in the G-SS treatment was significantly higher compared to the G-NS treatment.

The pH of the recycled solution (RS) measured in the second period was increased in comparison to the pH value of the IS. The mean EC of the RS was approximately 1.5 times higher for all treatments as compared to the initial EC of the IS of each treatment.

3.2. Yield Measurements

3.2.1. Crop Height Evolution

The evolution of the height during the first and second period is presented in Figure 3a–c. In the first period, according to the data the mean height was decreased as the targeted salinity level increased in the IS, especially during the last days of the experimental period. At that time, basil plants grown under the control treatment presented the highest mean height among all treatments. The final mean height for the control plants was 48.7 cm, whereas in the case of G-NS8 and G-SS8 treatments the mean height was less than 32 cm. These values indicate a 36% height reduction of plants irrigated through high EC values as compared with the control treatments. Notably, no significant differences ($p > 0.05$) were observed after the comparison of the plant height measured for plants grown under the G-NS and G-SS solutions for the same EC values (e.g., G-NS2 and G-SS2). Figure 3c shows the height evolution of basil during the cultivation cycle of the second period. The irrigation of basil plants with different saline solutions did not significantly alter the average height of plants grown in the NFT system. Since the plants in all treatment group of this period were irrigated with fresh NS up to DAT 14, it is assumed that the salinity did not affect the height of the plants. Plant fertigation through either low or high salinity regimes resulted in a mean total height of 44 cm.

Figure 3. Cont.

Figure 3. Mean height (cm) of basil irrigated by means of (a) G-NS or (b) G-SS during the first period and (c) NFT-SS during the second period. Means followed by different lowercase letters (a, b) differ significantly according to the Tukey–Kramer HSD test at $p < 0.05$ across the fertigation treatments.

3.2.2. Number of Leaves

The number of leaves during the first and the second experimental period are presented in Figure 4a–c. In the first period, similarly to the plant height progress, the mean number of leaves decreased as the targeted salinity level increased. Results obtained up to DAT 41 indicated that EC values of 6 and 8 dS m^{-1} diminished the total number of leaves for both the G-NS and G-SS treatments. As shown in Figure 4a,b, salinity regimes of 2 and 4 dS m^{-1} led to the highest leaf growth, yielding approximately 365 leaves per plant. However, no significant differences were recorded between the plants grown under the same EC values but with different irrigation solutions. In contrast to the mean number of leaves of the first period, no significant differences were observed in the second period.

Figure 4. Cont.

Figure 4. Mean number of leaves of basil irrigated by means of a (a) G-NS or (b) G-SS during the first period and (c) NFT-SS during the second period. Means followed by different lowercase letters (a, b, c) differ significantly according to the Tukey–Kramer HSD test at $p < 0.05$ across the fertigation treatments.

3.2.3. Chlorophyll Content

Figure 5 shows the mean chlorophyll content expressed in CCI values during the first (Figure 5a,b) and second (Figure 5c) experimental periods. In the first period, the mean chlorophyll content was 34.2 CCI for all the treatments, regardless of the nutrient solution and the salinity regime imposed on the tested plants. However, the leaf chlorophyll concentration obtained from the second period followed a different pattern as opposed to that of the first period. During the last week of the second period, NFT-SS4 treatment resulted in a significant decrease in chlorophyll concentrations amongst all the tested samples ($p < 0.05$).

Figure 5. Mean chlorophyll content (CCI) of basil leaves irrigated by means of (a) G-NS, or (b) G-SS during the first period and (c) NFT-SS during the second period. Means followed by different lowercase letters (a, b, c) differ significantly according to the Tukey–Kramer HSD test at $p < 0.05$ across the fertigation treatments.

3.2.4. Fresh and Dry Matter

The fresh and dry matter of basil leaves and stems during the first period is presented in Table 2. As the salinity regime increased, a significant decrease in the FM and DM of leaves was observed from DAT 27 to DAT 41. The FM and DM of stems followed the same course as those obtained from the FM and DM of leaves. The high salinity regimes induced a reduction in the fresh matter of stems in all destructive measurements taken on DAT 13, 27, and 41. In particular, the FM and DM of the stems of the control treatment presented up to 67.4% higher values as compared to the G-NS8 treatment during DAT 41.

As shown in Table 3, the evolution of FM and DM of plants grown under the G-SS treatments did not deviate from the G-NS values presented in Table 2 during the first period. Remarkably, the FM values of both leaves and stems during the final sampling date were 191 and 125 g m⁻² for the plants of the G-NS2 treatment, while the total FM values of the G-NS8 treatment were 77 and 34 g m⁻², respectively. Notwithstanding, after comparing the FM and DM values presented in Table 2 with those presented in Table 3, no significant differences were observed between the different solutions (G-NS and G-SS) imposed on the crop.

Table 2. Mean fresh and dry matter (g) ($\pm$ SE) of leaves and stems of basil plants irrigated by means of the G-NS during the first experimental period.

DAT	Treatments	Fresh Matter (g m ⁻²)		Dry Matter (g m ⁻²)	
		Leaves	Stems	Leaves	Stems
13	G-NS2 ^a	12.0 $\pm$ 1.25 a ¹	5.70 $\pm$ 1.55 a	1.57 $\pm$ 0.43 a	0.53 $\pm$ 0.17 a
	G-NS4	9.79 $\pm$ 5.14 a	4.01 $\pm$ 2.36 c	1.15 $\pm$ 0.59 a	0.41 $\pm$ 0.26 a
	G-NS6	7.81 $\pm$ 4.07 a	3.32 $\pm$ 2.53 d	0.96 $\pm$ 0.54 a	0.42 $\pm$ 0.34 a
	G-NS8	9.62 $\pm$ 3.15 a	4.29 $\pm$ 2.00 b	1.19 $\pm$ 0.41 a	0.54 $\pm$ 0.26 a
27	G-NS2	71.0 $\pm$ 17.2 a	42.2 $\pm$ 7.53 a	10.1 $\pm$ 2.07 a	5.79 $\pm$ 1.93 a
	G-NS4	52.5 $\pm$ 13.0 a	27.0 $\pm$ 7.97 ab	6.96 $\pm$ 1.61 a	4.50 $\pm$ 1.32 a
	G-NS6	27.4 $\pm$ 12.3 b	14.0 $\pm$ 4.05 b	5.65 $\pm$ 1.98 b	3.89 $\pm$ 1.06 a
	G-NS8	27.0 $\pm$ 15.7 b	16.0 $\pm$ 11.3 b	5.21 $\pm$ 1.86 b	3.40 $\pm$ 1.72 a
41	G-NS2	190.8 $\pm$ 21.9 a	125.8 $\pm$ 13.2 a	25.7 $\pm$ 3.28 a	21.8 $\pm$ 3.02 a
	G-NS4	129.1 $\pm$ 25.1 b	68.3 $\pm$ 15.6 b	16.5 $\pm$ 3.34 b	13.2 $\pm$ 3.74 b
	G-NS6	89.0 $\pm$ 49.6 bc	36.9 $\pm$ 17.6 c	11.1 $\pm$ 5.32 c	7.1 $\pm$ 2.35 c
	G-NS8	77.1 $\pm$ 28.9 c	34.0 $\pm$ 9.20 c	11.1 $\pm$ 3.71c	7.1 $\pm$ 2.25 c

¹ Within each column, means followed by the same lowercase letter are not significantly different concerning the different salinity regimes. ^a Grodan nutrient solution.

Table 3. Mean fresh and dry matter (g) ($\pm$ SE) of leaves and stems of basil plants irrigated by means of the G-SS during the first experimental period.

DAT	Treatments	Fresh Matter (g m ⁻²)		Dry Matter (g m ⁻²)	
		Leaves	Stems	Leaves	Stems
13	G-SS2 ^a	9.96 $\pm$ 2.93 a ¹	4.67 $\pm$ 1.19 b	1.29 $\pm$ 0.16 a	0.42 $\pm$ 0.10 a
	G-SS4	5.85 $\pm$ 2.45 a	2.43 $\pm$ 1.26 c	0.67 $\pm$ 0.24 a	0.22 $\pm$ 0.10 a
	G-SS6	4.93 $\pm$ 1.39 a	2.08 $\pm$ 0.54 c	0.58 $\pm$ 0.16 a	0.22 $\pm$ 0.05 a
	G-SS8	10.19 $\pm$ 5.96 a	5.26 $\pm$ 3.62 a	1.22 $\pm$ 0.70 a	0.53 $\pm$ 0.41 a
27	G-SS2	55.2 $\pm$ 15.1 a	34.6 $\pm$ 7.83 a	7.47 $\pm$ 0.83 a	4.59 $\pm$ 0.96 a
	G-SS4	44.2 $\pm$ 15.3 ab	26.6 $\pm$ 10.3 ab	5.76 $\pm$ 1.86 ab	4.06 $\pm$ 1.79 a
	G-SS6	22.2 $\pm$ 10.0 b	12.2 $\pm$ 5.48 b	2.59 $\pm$ 1.57 b	1.74 $\pm$ 1.13 a
	G-SS8	22.8 $\pm$ 9.94 b	13.6 $\pm$ 7.44 b	3.11 $\pm$ 1.23 b	2.12 $\pm$ 1.36 a
41	G-SS2	170.5 $\pm$ 27.8 a	127.0 $\pm$ 18.1 a	25.3 $\pm$ 4.34 a	22.4 $\pm$ 4.53 a
	G-SS4	80.1 $\pm$ 15.6 b	48.0 $\pm$ 10.9 b	10.9 $\pm$ 2.43 b	9.2 $\pm$ 3.52 b
	G-SS6	44.8 $\pm$ 22.1 bc	23.9 $\pm$ 12.5 c	5.64 $\pm$ 2.84 c	4.4 $\pm$ 2.35 b
	G-SS8	37.4 $\pm$ 10.6 c	19.3 $\pm$ 6.82 c	5.10 $\pm$ 1.59 c	3.9 $\pm$ 1.59 b

¹ Within each column, means followed by the same lowercase letter are not significantly different with respect to the different salinity regimes. ^a Grodan saline solution.

In contrary to the results of the first experimental series, the FM and DM of the basil leaves and stems during the second period did not seem to be affected by the increase in salinity in the NFT-SS. The fresh and dry matter of basil leaves and stems increased successfully from DAT 25 to 35. No significant differences were recorded between treatments for both the FM and DM harvests conducted on DAT 25 and DAT 35 (Table 4).

Table 4. Mean fresh and dry matter (g m⁻²) ($\pm$ SE) of leaves and stems of basil plants irrigated through different saline regimes during the second experimental period.

DAT	Treatments	Fresh Matter (g m ⁻²)		Dry Matter (g m ⁻²)	
		Leaves	Stems	Leaves	Stems
25	NFT-SS2 ^a	287.2 $\pm$ 54.7 ¹	208.2 $\pm$ 57.3	24.5 $\pm$ 8.7	20.7 $\pm$ 5.5
	NFT-SS4	275.0 $\pm$ 95.0	179.5 $\pm$ 56.6	25.3 $\pm$ 5.7	20.3 $\pm$ 7.8
	NFT-SS6	294.3 $\pm$ 59.6	169.8 $\pm$ 19.4	27.2 $\pm$ 3.2	20.8 $\pm$ 2.0
	NFT-SS8	310.3 $\pm$ 15.9	173.2 $\pm$ 20.3	29.8 $\pm$ 1.5	23.3 $\pm$ 4.0
35	NFT-SS2	406.8 $\pm$ 13.4	322.3 $\pm$ 23.5	35.3 $\pm$ 12.5	37.8 $\pm$ 10.4
	NFT-SS4	420.3 $\pm$ 44.5	290.8 $\pm$ 64.7	34.6 $\pm$ 5.3	40.3 $\pm$ 5.6
	NFT-SS6	463.6 $\pm$ 60.1	281.3 $\pm$ 56.5	35.9 $\pm$ 2.7	42.9 $\pm$ 3.6
	NFT-SS8	454.2 $\pm$ 59.4	283.3 $\pm$ 60.8	38.1 $\pm$ 3.9	47.9 $\pm$ 3.9

¹ No statistically significant differences are identified. ^a Nutrient film technique saline solution.

3.2.5. Leaf Nutrient Analysis

The nutrient concentrations obtained from the basil leaf tissue analysis during the first and the second periods are presented in Table 5. The N concentration increased by 13% for G-NS4, G-NS6, and G-NS8 as compared to the control treatment in the first period. Similar results were recorded for the K leaf content, as a significant nutrient increase of up to 50% was observed as the EC of the G-NS reached 6 and 8 dS m⁻¹ in comparison to the control treatment. Contrariwise, the concentration of Mg in basil leaves was higher in the control than in the other treatments. No significant differences in Ca content were observed among the treatments. In the case of the G-SS treatments, the concentrations of N and P at 8 dS m⁻¹ were increased by 22.3% and 15.6% as compared to the control treatment, respectively. Increasing the EC to 8 dS m⁻¹ resulted in a 29% increase in the K and Mg leaf content compared to the control treatment. Contrariwise, the Ca concentration decreased significantly under the highest salinity regime.

Table 5. Mean values ($\pm$ SE) of leaf nutrient concentration expressed in mg g⁻¹ of dry leaf matter performed during the first and the second experimental period.

Period	Treatments	N	P	K	Ca	Mg
First period	G-NS2 ^a	36.3 $\pm$ 2.9 b ¹	4.9 $\pm$ 1.2 b	42.9 $\pm$ 6.4 b	21.6 $\pm$ 4.0 a	7.6 $\pm$ 1.0 a
	G-NS4	43.0 $\pm$ 4.7 a *	11.9 $\pm$ 1.9 a *	60.8 $\pm$ 9.4 b	21.3 $\pm$ 3.5 a	6.4 $\pm$ 0.9 ab
	G-NS6	40.8 $\pm$ 3.9 ab	6.3 $\pm$ 1.3 b	86.9 $\pm$ 15.8 a *	25.0 $\pm$ 2.8 a *	5.9 $\pm$ 0.7 b
	G-NS8	41.6 $\pm$ 12.5 ab	6.9 $\pm$ 1.9 b	86.2 $\pm$ 15.8 a *	23.7 $\pm$ 3.1 a *	5.7 $\pm$ 0.9 b
	G-SS2 ^b	38.0 $\pm$ 2.9 b	5.4 $\pm$ 0.8 b	40.6 $\pm$ 4.6 b	20.7 $\pm$ 3.5 a	7.3 $\pm$ 0.8 b
	G-SS4	35.6 $\pm$ 4.7 b	7.1 $\pm$ 2.0 a	48.3 $\pm$ 6.9 b	17.5 $\pm$ 3.6 bc	9.9 $\pm$ 1.2 a *
	G-SS6	37.3 $\pm$ 3.0 b	6.5 $\pm$ 1.3 ab	45.0 $\pm$ 4.0 b	19.4 $\pm$ 2.4 ab	8.7 $\pm$ 0.9 ab *
	G-SS8	48.9 $\pm$ 12.5 a	6.4 $\pm$ 1.1 ab	56.0 $\pm$ 8.4 a	16.1 $\pm$ 2.2 c	10.4 $\pm$ 1.1 a *
Second period	NFT-SS2 ^c	37.5 $\pm$ 2.7 a	9.8 $\pm$ 1.9 a	45.1 $\pm$ 4.7 b	30.1 $\pm$ 1.9 a	7.7 $\pm$ 0.7 a
	NFT-SS4	36.1 $\pm$ 2.7 a	7.3 $\pm$ 1.1 b	45.8 $\pm$ 9.7 b	26.3 $\pm$ 3.4 ab	7.0 $\pm$ 1.2 a
	NFT-SS6	38.1 $\pm$ 2.9 a	7.4 $\pm$ 1.6 b	52.6 $\pm$ 3.6 a	24.1 $\pm$ 3.7 b	6.7 $\pm$ 0.8 a
	NFT-SS8	35.9 $\pm$ 3.6 a	6.5 $\pm$ 1.3 b	52.9 $\pm$ 8.8 a	24.3 $\pm$ 3.4 ab	7.0 $\pm$ 0.5 a

¹ Means followed by different lowercase letters (a, b) differ significantly according to the Tukey–Kramer HSD test at $p < 0.05$ across irrigation treatments (e.g., G-SS2 and G-SS4). Within each column, means followed by an asterisk differ significantly across irrigation treatments for the same EC regime (e.g., G-NS2 and G-SS2) during the first period. ^a Grodan nutrient solution. ^b Grodan saline solution. ^c Nutrient film technique saline solution.

As higher amounts of nutrients were supplied to the plants irrigated through the G-NS treatments, a variety of significant differences were observed between the G-NS and G-SS treatments. Particularly, plants irrigated through the G-NS4 solution had higher concentrations of N (17%), P (40%) as compared to the G-SS4 treatment. In addition, as EC levels increased to 6 and 8 dS m⁻¹, K (48% and 35%), Ca (22% and 32%) contents were significantly higher in the G-NS treatment group. However, the Mg content increased by 35%, 32%, and 45% in the G-SS treatment group for the G-SS4, G-SS6, and G-SS8 sub-treatment groups, respectively.

As shown in Table 5, P and K contents were strongly affected by the higher salinity regimes. Control plants showed 9.8 mg P g⁻¹ in DM, as opposed to NFT-SS8 plants where the P content was less than 7.0 mg P g⁻¹ in DM. On the other hand, K leaf content increased under higher salinity regimes, ranging from 45.0 mg g⁻¹ found in the control treatment to 53.0 mg g⁻¹ in DM under the highest salinity regime. Finally, Ca concentrations varied among treatments, with the highest amounts observed in the plants under the control treatment. No significant differences were observed for the N and the Mg content among the treatments.

3.3. Water Use Efficiency

The WUE value during the first period is shown in Figure 6a,b. Regarding the increase in salinity in the G-NS and G-SS groups, it is concluded that high salinity regimes significantly reduced the WUE values for both treatments, with the values of 6 and 8 dS m⁻¹ being the lowest. As shown in Figure 6a, significant differences were noted for the WUE values between the G-NS and G-SS treatments at 4 and 8 dS m⁻¹. However, in terms of WUE (kg DM m⁻³), the G-NS treatment followed a similar downward trend, with the

G-SS treatment emphasizing the reduction of WUE as a result of the increased salinity regardless of the irrigation solution provided to the plants (Figure 6b).

Figure 6. Water use efficiency (WUE, kg m⁻³) based on the (a) fresh matter (FM) and (b) dry matter (DM) of basil crops during the first experimental period. Lowercase letters indicate the differences between salinity regimes, whilst uppercase letters show the differences amongst G-NS and G-SS treatments for the same salinity regime. Means followed by the different letters differ significantly across treatments according to the Tukey–Kramer HSD test at $p < 0.05$.

WUE values were also calculated considering both the FM and the DM of basil plants during the second experimental period. Following the results concerning the water consumption of basil (Figure 2) as well as those from Table 4, WUE values did not differ significantly among treatments. As shown in Figure 7a,b, the water use efficiency based on the fresh matter of basil was 27.9 kg FM m⁻³, whilst in the case of the dry matter, the recorded WUE was 3.0 kg DM m⁻³ for all treatments, respectively.

Figure 7. Water use efficiency (WUE, kg m⁻³) based on the (a) fresh matter (FM) and (b) dry matter (DM) of basil crops during the second experimental period. Means followed by different lowercase letters (a, b) differ significantly according to the Tukey–Kramer HSD test at $p < 0.05$ across the fertigation treatments.

4. Discussion

4.1. Effects of Salinity on Nutrient Absorption

According to Attia et al., (2009) [15], one of the main factors contributing to the medium salt tolerance found in basil plants is the selectivity of potassium in favor of sodium, as well as the redirection potential of sodium ions from the upper leafy parts to the root zone. Salt tolerance is also signified by the maintenance of a stable element uptake

rate preventing the absorbance and allocation of saline ions from the roots to the upper part of the crop [16]. Notwithstanding, the tolerance of basil is reported to be significantly reduced when plants are exposed to salt concentrations higher than the threshold limit of 5.0 dS m^{-1} .

The results of the present study confirm the aforementioned theory, as K^+ leaf content was significantly increased for all treatments in both experimental periods when high NaCl concentrations were imposed on the crop, suggesting that mineral nutrition was not negatively affected by the increase of salinity in the NS. These results are in line with those of Scagel et al., (2019) [8] who found a significant increase in the K^+ uptake in basil leaves when exposed to up to 20 dS m^{-1} salinity. It is well-stated that when the increase in EC in a solution is linked to the increase in nutrients in the IS, K^+ uptake is promoted as it is highly absorbed by the plant's rooting system as opposed to other elements such as Ca^{2+} and Mg^{2+} [17]. In the present study, K^+ uptake was increased for the G-NS4, G-NS6, and G-NS8 treatments in the first period in favor of Mg^{2+} , as its concentration was significantly lower in the highest salinity regimes.

In this context, Sonneveld and Voogt (1990) [18] indicated a decrease in the Ca^{2+} accumulation in relation to K^+ and Mg^{2+} antagonism when greater amounts of nutrients were used to increase the EC value of the nutrient solution. These results are not corroborated with those of the present study since the aforementioned effect on the nutrient elements was observed when the EC values were increased after NaCl addition. The basil biomass during the second period was not affected by the different salinity regimes imposed on the crop. Scagel et al., (2019) [8] reported that the increase in the nutrient concentration in the leaf area of the plants characterized by the same biomass was an indicator of the high absorption rhythm of these substances in the root zone. As a result, the higher K^+ and lower P leaf contents recorded for the plants in the second period are strongly associated with an increase or decrease, respectively, in the uptake rate of these elements by the crop. However, Ahmad and Prasad (2011) [19] argued that K^+ uptake is inhibited when plants are exposed to saline conditions. In contrary to this claim, in the present work K^+ uptake was increased during both tested periods under the highest salinity regimes.

The Ca^{2+} reduction in the NFT-SS treatment in the second period may have occurred due to insufficient root expansion as a result of the high salt accumulation in the growth medium. Our results are in accordance with those of Elhindi et al., (2017) [20], who demonstrated a reduction in the leaf Ca^{2+} content in response to the highest salinity regime. In the current study, the interaction of Ca^{2+} and K^+ content was not affected by the greater amounts of nutrients added in the G-NS, and the increase in K^+ accumulation in the leaves was correlated with an increase in salinity [8]. Moreover, our results are corroborated by those of Scagel et al., (2017) [21], who indicated higher accumulation of K^+ and Mg^{2+} in the leaves of basil when NaCl was added to the SS. According to Katsoulas and Voogt (2014) [17], the increase in the irrigation time intervals results in an increment in the EC levels in the growth medium. This may explain the upward trend in most macronutrients found in the DS of the G-NS treatments in relation to the increase in salinity in the IS.

4.2. Effect of Salinity on Basil's Yield

In the current research, a 35% decrease was observed in the height and the number of leaves of the plants that were cultivated in rockwool slabs. The current decrease, that occurred only in the treatments in which plants were irrigated with G-NS of 6 ds m^{-1} and 8 ds m^{-1} , was confirmed by the studies of Ding et al., (2020) [22] and Maia et al., (2017) [23]. According to their results, a significant decrease (by 27%) was found in the basil plants irrigated with NS of 8 ds m^{-1} . Maia et al., (2017) [23] and Munns and Tester (2008) [24] sustained that plants irrigated with saline NS, i.e., NS with high Na^+ and Cl^- concentrations, tend to develop adaptive mechanisms by lowering their growth trend and transpiration capacity to maintain water and nutrients at adequate levels. Exposure of plants to high levels of salinity can reduce the stomatal conductivity of plants by reducing their transpiration to achieve a better adaptation of plants to such conditions [25].

Moreover, under salt stress, plant growth can be significantly reduced due to the decrease in the formation of substances responsible for plant growth such as cytokinin [26]. In addition, osmotic stress and ion toxicity are the most common consequences of salt stress, generating a repression of plant growth [24].

Salinity values lower than 4 dS m^{-1} did not cause any specific nutritional imbalance or toxicity to the plants, irrespective of the salts used to achieve them. In the current research, the salinity source had no specific effect on plant growth. Similarly, Savvas and Lenz (2000) [27] found that the salinity source had no effect on the morphological characteristics of the eggplants.

The increase in the water supply to the salt-stressed plants, on the other hand, drastically reduces the impacts of the salinity on plant growth [28]. That is why the plants cultivated in the NFT system where the NS flows incessantly presented similar growth evolution among treatments without being affected by the salinity increase. Savvas et al., (2007) [29] reported that irrigation frequency is crucial for the increase in NaCl accumulation in the root zone. Thus, salt dilution is more likely to occur in the case of the NFT system as opposed to the rockwool treatment, as in the first case the NS flows continuously without remaining accumulated for a long interval in the root environment [17].

Similar to the height of the plants cultivated in the rockwool slabs, the FM and DM gradually decreased as the salinity level in the irrigated NS increased. The total DM of both leaves and stems in the current research significantly decreased with G-NS8 treatment (from 25.7 and 21.8 g m^{-2} to 11.1 and 7.1 g m^{-2} , respectively) and G-SS8 treatment (from 25.3 and 22.4 g m^{-2} to 5.1 and 3.9 g m^{-2} , respectively). Moreover, in a recent study Avdouli et al., (2021) [30] explored the salinity tolerance of basil when irrigated either through enriched nutrient solutions to achieve salinity levels of 5, 10, and 15 dS m^{-1} , or through the runoff drained from a cucumber crop in a cascade cropping system, with the EC of the drainage solution reaching up to 3.2 dS m^{-1} . The results obtained from that study showed a significant reduction in height, leaf area, and fresh and dry matter of the plants in both experimental setups when EC values exceeded the threshold of 5 dS m^{-1} . However, the biochemical characteristics of basil, such as the total amino acid content and the antioxidant capacity, were strongly associated with the increase in salinity, suggesting 5 dS m^{-1} as the upper threshold limit in the irrigation solution of basil. On the other hand, an increase occurred in both the FM and DM values of the plants cultivated in NFT system as the EC was increased. However, in all the treatments in both periods the ratio between the FM and DM remained stable around 13. This constant ratio indicates that the DM values were defined according to the FM values and were not affected by the salinity treatments.

According to Heidari (2012) [31], plants susceptible to salinity tend to show decreased leaf chlorophyll content when exposed to high salt accumulations. In the present work, however, no chlorophyll variation was observed among the treatments when the plants were cultivated in rockwool slabs, although the FM values in the salty treatments were quite low. Heidari et al., (2014) [32] and Papp et al., (1983) [33] support that this was achieved due to the increase of the leaf thickness, which occurred as a result of the leaf area reduction. In the case of plants cultivated in the NFT system, the chlorophyll content was increased when plants were irrigated through the highest salinity regimes, showing the salinity tolerance of basil when grown in an NFT system.

4.3. Solution Absorption Rate and Water Use Efficiency

During the first period the daily absorption could not be determined, as the irrigation of the plants grown in rockwool substrates did not lead to leachates. As a result, the absorption was considered to be equal to the volume of the irrigated nutrient solution. In the present study, WUE was significantly decreased as salinity increased in both treatment groups (G-NS and G-SS) due to the negative effect of salinity on the fresh and dry matter of basil plants. In a recent study, Elvanidi et al., (2020) [2] studied the WUE of basil plants grown as a secondary crop in a cascade cropping system which were irrigated through a mixture of 25% cucumber leachates diluted with fresh solution, i.e., a saline

solution. The results obtained from this study showed a significantly higher WUE in the case where plants were irrigated with the aforementioned solution as compared to monoculture cultivations, emphasizing the moderate salt tolerance of basil.

Although salinity is inextricably linked to toxicity and osmotic pressure, increased water uptake from a crop can alleviate the disadvantages of abiotic stress [27]. Despite the gradual decrease in the absorption rate observed in all salinity regimes during the second period over time, the total water consumption did not alter between salinity treatments. Our results showed that WUE followed a similar trend for all NFT-SS treatments despite the increase in NaCl in the irrigation solution, confirming the efficacy in terms of plant productivity and water use in such systems.

5. Conclusions

Salinity is one of the major abiotic stresses inhibiting plant growth. The salinity tolerance of basil was investigated for further adaptation as a secondary or tertiary crop in a cascade cropping system. The findings of the current study showed a different growth rate and water/nutrient status of basil plants in response to salinity when grown in rockwool and NFT systems. Plants grown in the NFT system presented a significant tolerance to salinity, as no quality deterioration or nutrient imbalances were recorded. Plants grown in the rockwool substrate presented a relatively low growth pattern under saline conditions, showing the susceptibility of basil in regimes greater than 4 dS m⁻¹. However, there were no significant differences in the morphological properties of the plants irrigated either through a nutrient or salt-enriched solution. In conclusion, basil could be cultivated in agriculture as a secondary crop, as it seems to be tolerant to the moderately saline regimes that can occur in a closed hydroponic system due to the accumulation of salts in the nutrient solution after its recycling.

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