Growth, production and water relations of chicory under saline stress in hydroponic systems

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ABSTRACT

Underground water sources have been used due to the scarcity of surface waters in semiarid regions; however, these waters usually have high salt concentration, limiting their use for conventional irrigation. In this context, to minimize such problem, studies have proposed the hydroponic technique (soiless cultivation) to use brackish waters, because in this system the response of plants to salinity is better than in the soil when irrigated with the water of same salinity. The present study aimed to evaluate the growth and production of chicory (Cichorium endivia L.) using brackish water in DFT (Deep Flow Technique) hydroponic system, and compared the results with those obtained in NFT (Nutrient Film Technique) hydroponic system. The experiment was carried out in a randomized block design, with eight replicates and four treatments. In the DFT system, plants were submitted to three levels of electrical conductivity of water - ECw (0.34, 1.5 and 3.0 dS m⁻¹) and in the NFT under ECw of 0.34 dS m⁻¹. These waters were used both to prepare the nutrient solution and to replace the consumed volume. Plant height, number of leaves, fresh and dry matter of shoot, water consumption, water use efficiency and water content in shoot at 20 and 25 days after transplanting (DAT) were evaluated. Absolute growth rate of shoot fresh matter was also determined for the period of 20-25 DAT. At 25 DAT, in general, the largest reductions in growth, production and water relations of chicory were under higher salinity (ECw 3.0 dS m⁻¹). In the DFT system no symptoms of toxicity that could be attributed to salinity were observed. The maximum water consumption of chicory was 2.32 L plant⁻¹ in the NFT system without saline stress (ECw 0.34 dS m⁻¹) and maximum water use efficiency of shoot fresh matter of 71.70 g L⁻¹ was observed in the DFT system without saline stress at 25 DAT.

Key words: Cichorium endivia L., soilless cultivation, water resources, water use efficiency.

INTRODUCTION

Under natural conditions, plants are frequently exposed to complex interactions which involve numerous environmental factors (Rejeb et al., 2014; Zribi et al., 2017; Prisa, 2019), such as salinity, water deficit, temperature and others (Ramakrishna and Ravishankar, 2011; Szareski et al., 2018).

In arid and semi-arid regions of different parts of the world, such as the Brazilian Northeast (Rocha Neto et al., 2017), among the various abiotic stresses, saline stress, which expresses the concentration of soluble salts in the soil or water (Breš et al., 2016), has been pointed out as the main cause of decrease of yield in most agricultural crops (Younis et al., 2013; Boughalleb et al., 2017; Rezaei et al., 2017).

Soil salinization can be of primary origin (natural) and/or secondary origin, caused by anthropic activity, such as the
use of saline water in irrigation (Shahrayini et al., 2018; Sienkiewicz-Cholewa et al., 2018). Secondary salinization is a consequence of inadequate irrigation management because natural drainage in the semi-arid regions is limited due to the low rainfall (Endo et al., 2011; Suassuna et al., 2017), which is not sufficient to leach the salts from the root zone to deeper soil layers and thus maintain adequate levels of salts in the root zone of crops (Ünlükara et al., 2008; Shrivastava and Kumar, 2015).

Plant species respond differently to salt stress (Tabatabaei and Ehsanzadeh, 2016). Some are able to produce satisfactory yields under saline conditions, while others are not (Zrig et al., 2016; Qrunfleh et al., 2017). The responses of plants are variable among the different organs, species/cultivars, development stages and duration of exposure to the salts (Parvaiz and Satyawati, 2008; Abbas et al., 2015), which usually lead to reductions in phytomass production, yield or survival rates (Munns and Tester, 2008; Xu et al., 2018).

Saline stress can limit the exploitation of most agricultural crops, making the agricultural activity economically unviable. To mitigate the problems of salinity, hydroponic cultivation (soilless cultivation) has been pointed out as a technique suitable for the use of saline water because the response of plants to salinity is better than in soil, when irrigated with the same water (Silva et al., 2018 a). In this system, there is higher and immediate availability of water and nutrients to plants because there is no matric potential, which is one of the main causes of reduction in the free energy of water in the soil.

Studies on the tolerance of several species to salinity in hydroponic systems have demonstrated that, through adequate management of water and cultivation practices, it is possible to produce commercially using brackish waters (Dias et al., 2011), especially leafy vegetables such as lettuce (Soares et al., 2015; Cova et al., 2017; Silva et al., 2018 b). In this context, other crops of economic potential, such as chicory, need to be investigated under hydroponic conditions. According to Cécilio Filho et al. (2015), chicory is a more profitable crop than lettuce on average, and its requirements in terms of management in hydroponic systems are similar.

In Brazil and in several parts of the world, the NFT (Nutrient Film Technique) hydroponic system is the most used commercially. NFT is an active system which requires pumping to recirculate the nutrient solution, usually irrigating at 15 min intervals (Zanella et al., 2008). Thus, the use of NFT systems may be limited in places where there are frequent interruptions in supply of electricity (Santos Júnior et al., 2015; Silva et al., 2016). To overcome this problem, some researchers adopted the DFT (Deep Flow Technique) system in PVC pipes (Santos Júnior et al., 2015; Silva et al., 2016; Cova et al., 2017; Campos Júnior et al., 2018a; Gondim Filho et al., 2018; Santos et al., 2019; Silva Júnior et al., 2019), in which plant roots remain continually immersed in the nutrient solution. Thus, in case of interruption in electricity, supply plants will not undergo water restriction (Silva et al., 2018 a).

Therefore, this study aimed to evaluate the growth, production and water relations of chicory (Cichorium endivia L.) using brackish water in DFT system, and compared the results with those obtained using fresh water in NFT system.

MATERIALS AND METHODS

Experiment location

The study was carried out in a greenhouse (East-West orientation) from June to August 2016. The greenhouse was 7.0 m wide and 24 m long, with ceiling height of 2.8 m, protected on the sides by black shade (50% luminosity) screen and covered by 150 μm thick polyethylene film. The study site was in the Experimental Area of the Graduate Program in Agricultural Engineering of the Federal University of Recôncavo of Bahia, located in the municipality of Cruz das Almas, Bahia, Brazil (12° 40’ 19” S, 39° 06’ 23” W, and at an elevation of 220 m).

Treatments, experimental design and structure

The experiment was carried out in a randomized block design, with four treatments and eight replicates. Chicory plants were submitted to three levels of electrical conductivity of water - ECw (0.34, 1.5 and 3.0 dS m⁻¹) in hydroponics DFT and under ECw of 0.34 dS m⁻¹ in hydroponics NFT. These waters were used both to prepare the nutrient solution and to replace the volume consumed in the respective treatments.

In both systems, channels made of PVC pipes (6-m length and 0.075 m in diameter) were used, with circular holes of 0.05 m in diameter, spaced 0.25 m apart. Benches with trestles made of PVC pipes of 0.05 m in diameter were used to support the hydroponic channels. Three hydroponic channels were used per bench, with horizontal spacing of 0.30 m. One corridor (1-m width) was left between the benches to facilitate transit and operability.

In the DFT hydroponic system, caps were attached to the ends of each hydroponic channels (with zero slope), maintaining a mean level of the nutrient solution of 0.02 m. A drain was installed in the caps at the inlet end of the solution to control the nutrient solution level, conducting the excess solution through a hose back to the solution tank. In the NFT system, the hydroponic channels were with a 4% slope.

Each experimental unit consisted of an independent hydroponic channel, containing a plastic tank (60-L capacity) to store the nutrient solution, and an electric pump to inject the nutrient solution into the channel. The tank had a ballcock valve to maintain a volume of 50 L of
the solution and connected to supply tank, built with PVC pipes of 0.15 m in diameter. A transparent hose with a tape ruler was installed vertically on the outside of the supply system to verify the water level in the tank. The solution and supply tanks were connected by a hose; the water output was manually controlled through a ball valve which was opened daily at prefixed hours to maintain the water level and quantify water consumption.

**Crop conduction and nutrient solution management**

Seeds of broad-leaved chicory cv. ‘Dafne’ were sown on phenolic foam (2 x 2 x 2 cm), by planting one seed per cell. After germination, seedlings were irrigated with public-supply water until 10 days after sowing (DAS). After this period, the seedlings were transferred to a nursery (NFT system), where they received nutrient solution (FURLANI et al., 1999) at 50% concentration for 15 days. Irrigations in the nursery were controlled by an analog timer at intermittent intervals of 15 min, from 06h00 to 18h00. During the period from 18:00 to 06:00 h, the nutrient solution was recirculated once every 2 h, with duration of 15 min. The seedlings were taken to the definitive cultivation system with mean height of 0.133 m and four true leaves, in each cultivation channel 15 seedlings were planted in the central part.

The waters with ECw of 1.5 and 3.0 dS m⁻¹ were prepared by adding adequate amounts of NaCl to public supply water. After that, fertilizer salts according to recommendation of Furlani et al. (1999) were added to these waters to obtain nutrient solution. The electrical conductivity (ECsol) and pH of nutrient solutions were 2.57, 3.43 and 4.75 dS m⁻¹ and 6.1, 6.0 and 6.0, respectively.

The programming to control circulation of the nutrient solution in the cultivation channels was similar to that used during the nursery stage. During the experiment, ECsol and pH of the solution were determined in the central position of each hydroponic channel, using portable conductivity and pH meter.

**Variables evaluated**

Harvests were performed at 20 and 25 days after transplanting (DAT). In each harvest, five plants were collected in each hydroponic channel to determine: plant height, number of leaves and shoot fresh matter. Immediately after weighing the plants, the fresh material was placed in paper bags and dried in an air circulation oven at temperature of 65°C until constant weight, to quantify shoot dry matter.

The daily volume evapotranspired per plant was determined by dividing the volume of nutrient solution consumed in the plot by the number of plants in the plot, according to Equation 1. Cumulative water consumption was calculated for the periods of 1 to 20 and 1 to 25 DAT.

Water use efficiency (WUE) was also determined, based on the relationship between shoot fresh (SFM) or dry matter (SDM) production and the cumulative water consumption per plant (WC), according to Equation 2. Water content in shoot (Equation 3) and absolute growth rate (AGR) of SFM (Equation 4) were also determined:

\[
V_{ETC} = \frac{(Lf - Li) \times \pi \times D^2}{4 \times n \times \Delta T} \times 10^3
\]  
(1)

\[
WUE (gL^{-1}) = \frac{SFM \text{ or } SDM}{WC}
\]  
(2)

\[
\text{Water content} (\%) = \left( \frac{SFM - SDM - 100}{SFM} \right)
\]  
(3)

\[
AGR (g \text{ day}^{-1}) = \frac{SFM_2 - SFM_1}{T_2 - T_1}
\]  
(4)

Where: \(V_{ETC}\) represents the evapotranspiration of crop, in \(L\) plant⁻¹ day⁻¹; \(Li\) and \(Lf\) are the initial and final water levels readings, respectively, in the supply tank, in \(m\); \(D\) is the internal diameter of the supply tank, in \(m\); \(n\) is the number of plants in the hydroponic channel; \(\Delta T\) is the time interval between readings, in \(days\); \(SFM_1\) and \(SFM_2\) are the values of shoot fresh matter at times \(T_1\) (20 DAT) and \(T_2\) (25 DAT).

**Statistical analysis**

The results were subjected to analysis of variance by F test and the means were compared by Tukey test (\(P = 0.05\)). The standard deviations of means were also calculated.

**RESULTS AND DISCUSSION**

**Electrical conductivity (ECsol) and pH of the nutrient solution**

The mean values of ECsol in the NFT and DFT hydroponic systems at ECw of 0.34 dS m⁻¹ remained relatively constant, with slight (<2.2 dS m⁻¹) reductions after 18 DAT (Figure 1A). Such behavior is explained by the reduced incorporation of salts in this water compared with the contents consumed by plants, so that the concentration of salts in nutrient solution tends to reduce. Such reduction in ECsol, when the consumed volume was replaced with fresh water, is consistent with previous studies under hydroponic conditions (Soares et al., 2015; Lira et al., 2018; Silva et al., 2018 b). In the DFT system at ECw levels of 1.5 and 3.0 dS m⁻¹, the values of ECsol did not vary much along the experiment, which is due to the low water consumption by plants, thus incorporating low amounts of salts with the
replacement of the evapotranspired water.

As for pH of solution, in general, the values were lower than 6.0, reaching 4.0 in the DFT system regardless of the ECw level (Figure 1B). Oscillations in pH values were more drastic in the DFT system for all ECw levels, leading to more frequent corrections with calcium hydroxide. These reductions show that chicory plants acidified the nutrient solution, that is, cations were absorbed more rapidly than anions (making the medium acidified).

**Visual symptoms of the chicory plants**

Regarding the visual aspect of chicory plants produced under salt stress (Figures 2A and 2B), there were no symptoms of toxicity by the ions Na\(^+\) and/or Cl\(^-\) which could compromise the product’s quality. Toxicity symptoms appear when the concentrations of Na\(^+\) and/or Cl\(^-\) inside the plant are sufficiently high, resulting in necrosis of older leaves (Parvaiz and Satyawati, 2008). This occurs because
plants virtually lose only water by transpiration, thus leading to accumulation of these ions in the leaves (Acosta-Motos et al., 2017; Ismail and Horie, 2017). The time for the damage by toxicity to be manifested depends on the Na\(^+\) and/or Cl\(^-\) accumulation rate in the leaves and on the effectiveness in the compartmentalization of these ions in leaf tissues and cells (Parvaiz and Satyawati, 2008; Giuffrida et al., 2013).

Only in the NFT system (without salt stress), after 20 DAT, chicory leaves exhibited necrosis on the edges (Figure 2B), an abnormality known as tipburn. Although tipburn symptoms were observed in all plots of this system, but only in some plants, its occurrence is due to the higher growth rate in the period between 20 and 25 DAT (Figure 3D), increasing the demand for calcium. Tipburn symptoms have been reported in chicory under different conditions of cultivation (Feltrim et al., 2008; Sá and Reghin, 2008; Kowalczyk et al., 2016a).

**Growth and production of the chicory**

The F-test of the analysis of variance showed a significant effect of the treatments on the number of leaves, plant height, shoot dry matter and water consumption, only at 25 DAT (Table 1). For shoot fresh matter, the treatments had significant effect at 20 and 25 DAT, and only at 20 DAT on the water content in shoot, water use efficiency and the absolute growth rate (20-25 DAT) based on shoot fresh matter (Table 1).

At 20 DAT, the overall mean for the number of leaves was 8.2, regardless of the hydroponic systems and water consumption (Table 1).
salinity levels. At 25 DAT, the lowest number of leaves (9.4) was observed in plants under the highest salinity (ECw 3.0 dS m⁻¹) as compared with the other treatments (12.3, 11.9 and 11.1 leaves) (Figure 3A). Within a 5-day interval (20 to 25 DAT), the increase in the number of leaves did not exceed 2.0 leaves at ECw of 3.0 dS m⁻¹, while under the other conditions of cultivation, it did not exceed 3.0 leaves, reaching approximately 4.0 leaves in the NFT system without salt stress.

In general, plant height was little influenced by the treatments. On average, plant height at 20 DAT was approximately 30.0 cm. Within a 5-day interval (20 to 25 DAT), the maximum increment of height occurred in the NFT system (2.7 cm), whereas in the DFT system (without and with salt stress) the increments did not exceed 1.0 cm. At ECw of 0.34 dS m⁻¹ and regardless of the hydroponic system, the means did not differ statistically, as well as there was no significant difference among the means of the DFT system alone (Figure 3B).

Differently from the growth variables (Figures 3A and 3B), at 20 DAT, the shoot fresh matter in the DFT system without saline stress (80.40 g plant⁻¹) was 26.4% higher than in the NFT system (63.61 g plant⁻¹). In the DFT system even under saline stress conditions (ECw of 1.5 and 3.0 dS m⁻¹), the means of 70.16 and 65.03 g plant⁻¹ did not differ statistically from that obtained in the NFT system (Figure 3C). Since the means for shoot dry matter at 20 DAT did not differ statistically (Figure 3E), the superiority in the production of fresh matter obtained in the DFT system can be explained by the higher water contents stored in the tissues (Figure 4A), since plants responded similarly in terms of number of leaves and height.

In studies with chicory in NFT hydroponic system, there was no significant effect on the fresh matter and number of leaves at concentrations of 100 mM (Tzortzakis, 2009) and 40 mM of NaCl (Tzortzakis, 2010) in the nutrient solution, as compared with the condition without stress (0 mM of NaCl). The concentration of 30 mM of NaCl did not cause (from 20 to 25 DAT), the accumulation of fresh matter in leaves (Kowalczyk et al., 2012; Kowalczyk et al., 2016b).

In a marked manner, within the interval of only 5-days plants grown in the NFT system was superior to that recorded during the first 20 days, with growth rate of 16.20 g day⁻¹ (Figure 3D), totaling 144.63 g plant⁻¹ at 25 DAT (Figure 3C). This value was statistically similar to the means obtained in the DFT system at ECw of 0.34 and 1.5 dS m⁻¹ (145.04 and 130.36 g plant⁻¹), with the respective growth rates of 12.93 and 12.04 g day⁻¹. At the highest salinity level (ECw 3.0 dS m⁻¹), the mean of 105.69 g plant⁻¹ was statistically inferior than those of the other treatments. Based on the results, plants should be harvested at 25 days after transplanting in the hydroponic system, totaling a 50-days cycle from sowing. For the studied cultivar of chicory, on average, the cycle ranges from 45 to 55 days.

At 25 DAT, a similar behavior to that of fresh matter was observed for shoot dry matter (Figure 3E). The reduction in shoot dry matter was due to the decrease in the number of leaves and plant height, since the mean water content in the shoots of plants under different treatments did not differ statistically (Figure 4A).

In the DFT system, plants were supplied with water and nutrients all the time and this favored plants at young age (with smaller size) to produce more fresh matter than those in the NFT system until 20 DAT. After this period, as the volume of roots increased, the oxygen dissolved was depleted more rapidly, thus decreasing the growth rate (Figure 3D). With the increase in the volume of roots, there is greater demand for oxygen (Kläring and Zude, 2009; Mobini et al., 2015); therefore, reductions in oxygen concentrations are expected to occur in the adult stage of the plants (Kiferle et al., 2012; Niirnola et al., 2014).

The results of present study show that it is possible to produce chicory using brackish waters with reduction of about 27 and 28% in fresh or dry matter, with plants harvested at 25 days after transplanting. Such reduction in the yield under salt stress can be compensated by cultivating plants in the system for a longer period. Another strategy to compensate the reduction of yield may be by reducing spacing between plants, because under conditions of stress plants occupy a smaller area allowing cultivation significant effect on the fresh matter and/or number of More plants per meter length of hydroponic channel as
shown by Silva et al. (2019) in the case of basil. Yet another possibility is to cultivate more than one plant per hole, maintaining the spacing of 0.25 m to reach the ideal weight of the bunch for marketing.

**Water relations of chicory**

The F-test of the analysis of variance showed a significant effect of the treatments on the water content in shoot and water use efficiency based on shoot fresh matter at 20 DAT and on the water consumption at 25 DAT (Table 2).

For the cumulative water consumption in the period of 20 days, the mean consumption was 1.38 L plant$^{-1}$ (Figure 4B) and it was not affected by studied treatments. Thus, higher water use efficiency (60.67 g L$^{-1}$) in the DFT system as compared with the NFT system (45.45 g L$^{-1}$) (Figure 4C) is due to the greater accumulation of fresh matter (Figure 3C). In the DFT system, at ECw levels of 1.5 and 3.0 dS m$^{-1}$, the means of water use efficiency (54.13 and 57.72 g L$^{-1}$) did not differ from those under condition without saline stress.

At 25 DAT, the water consumption of chicory plants in the DFT system (2.08 L plant$^{-1}$) was similar to that of the NFT system (2.32 L plant$^{-1}$) for the condition without saline stress, with significant reduction only at the highest salinity level (ECw 3.0 dS m$^{-1}$) (Figure 4B). Within a 5-day interval
(20 to 25 DAT), plants increased water use efficiency based on shoot fresh matter, that is, within five days the consumed water volume was converted to greater biomass accumulation, with an overall mean of 64.27 g L⁻¹, regardless of the hydroponic systems and water salinity levels (Figure 4C). Under saline stress conditions, plants use stomatal closure as a strategy, reducing transpiration due to lower absorption of water (Aroca et al., 2012; Moosavi, 2012), which results in increased water use efficiency (Acosta-Motos et al., 2017), as reported in various studies under saline stress (Soares et al., 2010; Diniz et al., 2013; Santos Júnior et al., 2013; Soares et al., 2015; Lima et al., 2017).

The low water volume used to produce one chicory plant demonstrates high water use efficiency in the hydroponic cultivation. In this type of cultivation, quantifying water consumption along the crop cycle can contribute to better use of water resources in sites with low water availability because it is possible to estimate in advance the water volume required to produce a certain number of plants within a given period of time. Potentially, in hydroponic cultivation, there is greater possibility of using water more efficiently which is not possible in conventional planting.

Chicory plants positively responded to the cultivation in the DFT system adapted in PVC pipes, with a constant 0.02-m-deep blade of nutrient solution (approximately 6.0 L). With this volume of solution in each cultivation channel and assuming mean daily consumption of 0.144 L plant⁻¹, if there are interruptions in electricity supply, the system will be able to maintain 15 plants without water restriction for about three days. These results complement other studies which have shown feasibility for the cultivation of other plant species in the DFT system in tubes, with lettuce (Cova et al., 2017), rocket (Campos Júnior et al., 2018 b), coriander (Silva et al., 2018 a) and chives (Silva Júnior et al., 2019). Santos et al. (2019) found no significant difference on the growth and production variables of the basil when cultivated in the DFT and NFT in tubes using fresh water.

The lack of significant effect on water use efficiency based on shoot dry matter, with means of 3.22 and 3.71 g L⁻¹ at 20 and 25 DAT (Figure 4D), demonstrates that the significant differences in shoot fresh matter were due to storage of water in plant tissues (Figure 4A).

Conclusions

In hydroponic cultivation of chicory under conditions without salt stress (electrical conductivity of 0.34 dS m⁻¹), the variables of growth, production, water consumption and water use efficiency were not significantly affected by the NFT and DFT hydroponic systems. In the DFT system, no symptoms of toxicity which could be attributed to salinity were observed in chicory plants. Saline water (NaCl) of up to 3.0 dS m⁻¹ can be used in chicory cultivation in DFT system, despite slight reductions in growth and production, but without any negative effects on the commercial quality of the product.

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