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CULTIVO DE ALFACE SOB INTERVALOS DE RECIRCULAÇÕES DAS SOLUÇÕES NUTRITIVAS EM SISTEMAS HIDROPÔNICOS USANDO ÁGUA SALOBRA

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1 RESUMO

Objetivou-se no presente estudo avaliar o crescimento e a produção da alface usando água salobra sob diferentes intervalos de recirculações das soluções nutritivas em sistemas hidropônicos. Dois experimentos foram conduzidos concomitantemente em blocos casualizados com cinco repetições. Três cultivares de alface (‘Gloriosa’, ‘Robusta’ e ‘Tainá’) foram cultivadas no mesmo canal hidropônico, sob as seguintes interações: dois sistemas hidropônicos (NFT – técnica do fluxo laminar de nutrientes e DFT – técnica do fluxo profundo, ambos em tubos de PVC) e dois níveis de condutividade elétrica da água – CEa (0,3 e 5,3 dS m^{-1}), no Experimento I; no Experimento II, os mesmos dois níveis de CEa e três intervalos de recirculações das soluções nutritivas (0,25; 2 e 4 h), apenas no sistema DFT. No Experimento I, em geral, os sistemas hidropônicos não promoveram mudanças significativas nas variáveis de crescimento e produção das alfaces. Para o Experimento II, foi viável adotar intervalos de recirculações das soluções de até 2 h (cultivar ‘Robusta’) e 4 h (cultivares ‘Gloriosa’ e ‘Tainá’) no sistema DFT em tubos. De modo geral, apesar das reduções no crescimento e produção da alface utilizando-se água salobra (CEa 5,3 dS m^{-1}), não houve depreciação da qualidade visual do produto para comercialização.

Palavras-chave: *Lactuca sativa* L., cultivo sem solo, oxigênio dissolvido, salinidade, temperatura da solução nutritiva.

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LETTUCE CULTIVATION UNDER DIFFERENT RECIRCULATION INTERVALS OF THE NUTRIENT SOLUTION IN HYDROPONIC SYSTEMS USING BRACKISH WATER

2 ABSTRACT

This study aimed to evaluate the growth and production of lettuce using brackish water under different recirculation intervals of the nutrient solution in hydroponic systems. Two experiments were conducted concomitantly, in a randomized block design with five replicates.

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Three lettuce cultivars (Gloriosa, Robusta and Tainá) were grown in the same hydroponic channel, under the following interactions: between two hydroponic systems (NFT – Nutrient Film Technique and DFT – Deep Flow Technique, both in PVC tubes) and two levels of electrical conductivity of water – ECw (0.3 and 5.3 dS m^{-1}), in Experiment I; in Experiment II, between the same two levels of ECw (0.3 and 5.3 dS m^{-1}) and three recirculation intervals of the nutrient solution (0.25, 2 and 4 h), only in the DFT system. In Experiment I, in general, hydroponic systems caused no significant changes in the growth and production variables of lettuce. For Experiment II, it was viable to adopt recirculation intervals of the nutrient solution of up to 2 h (cultivar Robusta) and 4 h (cultivars Gloriosa and Tainá) in the DFT system in tubes. Generally, despite the reductions in growth and production of lettuce using brackish water (ECw 5.3 dS m^{-1}), but without deleterious effects on the visual quality of the product for commercialization.

Keywords: *Lactuca sativa* L., soilless cultivation, dissolved oxygen, salinity, nutrient solution temperature.

3 INTRODUCTION

In arid and semiarid regions of various parts of the world, such as Northeast Brazil (ROCHA NETO et al., 2017), among the various abiotic stresses (XU et al., 2018; MAU et al., 2019), salinity has most drastically affected crop yields (REZAEI et al., 2017; YUAN et al., 2019) and is responsible for the transformation of vast areas of land into areas unsuitable for agriculture (FAGERIA; GHEYI; MOREIRA, 2011).

In the presence of excess salts, plant growth is affected, first, by the negative effect of the osmotic potential on water absorption (AZEVEDO NETO et al., 2020), resulting in changes in water relationships in plants (GARCÍA-CAPARRÓS; LAO, 2018); subsequently, the accumulation of ions (Na^+ and Cl^-) at toxic levels (LIU; DU; WANG, 2011; HOSSAIN et al., 2015; RADY et al., 2018) can lead to nutritional disorders (CECCARINI et al., 2019).

To survive adverse conditions, plants expend a metabolic cost of energy, which is diverted from growth and redistributed to maintenance (MUNNS; GILLIHAM, 2015; ASHRAF et al., 2018); consequently, there is a reduction in growth (BERNSTEIN; KRAVCHIK; DUDAI, 2010).

Therefore, to make agricultural production economically viable, improving plant tolerance to salts is essential (XU; MOU, 2015; LI et al., 2019; WANG et al., 2019). Furthermore, it is important to use cultivation techniques that are different from traditional techniques.

The hydroponic technique (cultivation without soil use) is an alternative to the use of brackish water (SIGNORE; SERIO; SANTAMARIA, 2016; NIU; SUN; MASABNI, 2018) and is often unfeasible in conventional soil systems (SILVA et al., 2018b). In hydroponic cultivation, the response of plants to salinity is better than that in soil, considering the greater availability of water for the plants, since in hydroponics, the matric potential tends to zero (SOARES et al., 2007; DIAS et al., 2011), which is one of the causes of the decrease in the free energy of water in the soil (SILVA et al., 2013; SANTOS et al., 2016; SILVA et al., 2020a).

Despite the wide range of hydroponic systems described in the specialized literature, NFT (*nutrient film technique*) and DFT (deep flow technique) are considered to have proven commercial viability (RODRIGUES, 2002). More recent publications have focused on "semihydroponic" systems in inert substrates for phytosanitary reasons (VAN OS; GIELING; LIETH, 2019). However, in Brazil, the predominant and most popular system is still NFT (MATHIAS, 2008), which is very suitable for the cultivation of fast-cycle leafy vegetables, such as lettuce, the main product of Brazilian hydroponics (SOARES et al., 2015; COVA et al., 2017; GUIMARÃES et al., 2017; SILVA et al., 2018a; SOARES et al., 2019).

In the NFT system, only some of the roots remain submerged in the nutrient solution, which aids in gas exchange, including oxygenation (VILLELA JÚNIOR; ARAÚJO; FACTOR, 2004; ANDREAU; GIMÉNEZ; BELTRANO, 2015). It is a closed system characterized by continuous or intermittent recirculation of the nutrient mixture, the latter being more common in Brazil. Typically, recirculation is recommended for 0.25 h intervals and 0.25 h intervals (LUZ et al., 2008; ZANELLA et al., 2008). On the one hand, there appears to be a historical link to this recirculation frequency because analog timers usually allow only multiple intervals of 0.25 h; on the other hand, research conducted with different programs has concluded that it is possible to reduce energy costs by changing the frequency without production losses (FAGAN et al., 2006; LUZ et al., 2008).

Even though it is possible to find optimized values for recirculation frequency and duration, which can be achieved with modern digital timers accessible to producers, it is important to consider whether the slope imposed on the cultivation gutters by the NFT technique will imply substantial susceptibility to failures in the electricity supply.

Owing to this risk and to support recent research in Brazil, which seeks to establish hydroponics as a technique suitable for the conditions of the semiarid region, places where the infrastructure for conducting electricity is generally different, several studies have been carried out using the DFT system adapted in tubular cultivation channels (SANTOS JÚNIOR et al., 2015; SILVA et al., 2016ab; CAMPOS JÚNIOR et al., 2018; SILVA et al., 2018b; ALVES et al., 2019b; MARTINS et al., 2019; SILVA JÚNIOR et al., 2019b; SILVA et al., 2020a, 2020b). In this case, the roots are permanently submerged by a given depth of nutrient solution, which would be sufficient to overcome considerable periods without energy and, therefore, without recirculation of the solution. Another advantage is that the greater volume of solution around the roots provides, according to van Os, Gieling and Lieth (2019), greater buffering against temperature fluctuations.

In the adapted DFT system, it is possible to reduce the recirculation frequency and, therefore, reduce the variable cost of electricity. On the other hand, it is expected that lower recirculation frequencies of the nutrient solution imply a reduction in gas exchange (HORCHANI et al., 2008; KLÄRING; ZUDE, 2009) and a greater increase in its ionic concentration between one recirculation event and another (SAVVAS et al., 2007; SILVA JÚNIOR et al., 2019a); lower oxygenation of the solution makes it difficult for plants to adapt to the use of brackish water (SILVA et al., 2016b); and lower recirculation results in an increase in the temperature of the nutrient solution, with a consequent reduction in the level of dissolved oxygen (SILVA et al., 2020b) and an effect on the electrical conductivity of the solution. Therefore, doubts arise as to how compatible the adapted DFT system can be with the NFT system in terms of the quantity and quality of the final production result.

Within this context, two experiments were conducted concomitantly using fresh and brackish water to evaluate the production and quality of three lettuce cultivars (*Lactuca sativa* L.) in interaction with the NFT and DFT hydroponic cultivation systems in tubes, with different frequencies of recirculation of the nutrient solution being applied only in the DFT system in the tubes.

4 MATERIALS AND METHODS

4.1 Experimental location

Three lettuce (*Lactuca sativa* L.) cultivars were grown between January and March 2015 in a greenhouse (east–west orientation) belonging to the Center for Water and Soil Engineering/NEAS of the Federal University of Recôncavo da Bahia/UFRB, Cruz das Almas, Bahia (12° 40' 19” South latitude, 39° 06' 23” West longitude, and 220 m altitude), Brazil. The greenhouse, made of galvanized steel and with a simple arch tunnel design, was 32 m long and 7 m wide and had a roof covered with 150 µm-thick polyethylene film and a heat-reflective blanket. A 50% shading screen was installed internally at a height of 4 m.

Figure 1. General view, inside the greenhouse, of hydroponically grown lettuce plants.

Inside the greenhouse, temperature and relative humidity data were monitored via a thermohygrometer sensor model HMP45C (Vaisala, Inc.; Helsinki, Finland) installed 1.8 m above the ground. Averages were recorded every 30 min in a CR1000 datalogger (Campbell Scientific, Inc.; Logan, Utah, USA). During the study, the average relative humidity was 73.14%, with minimums ranging from 33.57 to 51.88% and maximums between 87.9 and 94.4%. The average relative humidity is in accordance with the range considered ideal for lettuce cultivation, which, according to Vilas Boas et al. (2008) and Araújo et al. (2010), is between 60% and 80%.

4.2 Experimental design and treatments

Two experiments were conducted concurrently in the same experimental structure, both with a randomized complete block design and five replicates. In each experiment, three lettuce cultivars, two from the American group ('Tainá' and 'Gloriosa') and one from the curly group ('Robusta'), were grown within the same hydroponic channel. In Experiment I, two hydroponic systems (NFT and DFT adapted for tubular channels) were evaluated for their interaction with two levels of water electrical conductivity (ECw values of 0.3 and 5.3 dS $^{m-1}$). For Experiment II, the same two levels of ECw (0.3 and 5.3 dS m $^{-1}$) were used in interaction with three nutrient solution recirculation intervals (0.25, 2, and 4 h), but only in the DFT hydroponic system. These waters were used both to prepare the nutrient solution and to replace the consumed volume.

4.3 Experimental structure

Forty experimental plots were used, each representing a hydroponic system unit. Of these, ten were used as NFT systems, and the remainder were used as DFT systems. In both systems, the hydroponic channels were made from PVC tubing (pigmented blue) with a nominal diameter of 0.075 m and a length of 6 m. Two hydroponic channels were arranged on each cultivation bench, spaced 0.80 m apart.

In the DFT system plots, the hydroponic channels were arranged level on the cultivation bench. Plugs were attached to the ends of each channel to maintain a nutrient solution (NS) depth of approximately 0.03 m, which remained constant after the recirculation period. To maintain NS levels in the channels, a connector was inserted at the outlet of one of the plugs (opposite the NS inlet), and a hose was connected to it to drain excess NS into the storage reservoir. In the NFT system, the channels were placed at a 3% slope so that the NS drained into the reservoir after each recirculation event.

In addition to the independent hydroponic channel, each plot was represented by a plastic reservoir (60 L capacity) for storing the water, which was equipped with a float valve that maintained a constant water volume (50 L) and an electric pump to pump the water back to the channel. An individual water supply reservoir was also attached to each plot and was responsible for replenishing the water consumed by the plants. This water supply was constructed of 0.20 m diameter PVC piping with a 20 L capacity and equipped with a graduated ruler attached to a transparent hose installed vertically to read the water level in the water supply. This water supply reservoir was connected to the water supply reservoir by a hose, to which a closed valve was connected. To quantify water consumption daily, at the predetermined reading time, with the hydroponic systems at rest, the valve was opened, allowing water to flow to the SN reservoir, thus allowing the maintenance of a volume of 50 L.

4.4 Cultivation management and nutrient solution management

Pelleted lettuce seeds were sown in phenolic foam (2 × 2 × 2 cm). Three days after sowing (DAS), the seedlings were transferred to a nursery (NFT system), where they received 50% NS from Furlani et al. (1999) for leafy vegetables for a period of 15 days. Irrigation in the nursery was controlled by an analog timer, with intermittent intervals of 0.25 h being established from 06:00 to 18:00. From 18:00 to 06:00, the NS was recirculated once every 2 h, lasting 0.25 h.

After this period in the nursery, the seedlings were transferred to the hydroponic system, at which point they reached an average height of 0.08 m and had between four and five permanent leaves. Each hydroponic channel was divided into three parts, with seven plants of each cultivar randomly distributed per segment, spaced 0.28 m apart.

In Experiment I, SN recirculation control was performed with the aid of analog timers, with programming similar to that adopted in the nursery phase, at intermittent intervals of 0.25 h. In Experiment II, in addition to the frequency of 0.25 h, recirculations were tested every 2 or 4 h, with the system remaining on for 0.25 h.

Before preparing the SN for the definitive cultivation phase, initially, an ECw of 5.3 dS m–1 was obtained by adding NaCl (commercial and iodine-free) to the local water supply (ECw of 0.3 dS m–1). Fertilizer salts corresponding to the 100% concentration of SN reported by Furlani et al. (1999) were subsequently added to these waters (ECw 0.3 and 5.3 dS m–1), resulting in SN electrical conductivity values (ECsol) of 2.15 and 7.25 dS $^{m-1}$, respectively, and a pH of 6.0. Throughout the experiments, at irregular intervals, the EC and pH values of the solutions were measured with a DM-3P conductivity meter (Digimed Analítica Ltda., São Paulo, Brazil) and a TEC-51 pH meter (Tecnal, Piracicaba, Brazil), with automatic temperature compensation. Throughout the experiment, lettuce acidified the SN, requiring corrections of pH values by applying KOH (1 M) to keep them in the range of 5.5--6.5.

CEsol values were also continuously monitored inside the hydroponic channels of the DFT system via a CE probe model CS547A (Campbell Scientific, Inc.; Logan, Utah, USA). This probe provided two CEsol values, one without temperature compensation ($_{real}$ CEsol) and another standardized at 25°C (CSsol $_{(25°C)}$). This monitoring occurred in two phases of lettuce cultivation and only for two treatments, both under the 4-h recirculation interval with fresh water (CEw 0.3 dS $^{m-1}$) and with brackish water (CEw 5.3 dS $^{m-1}$), at 18 and 24 days after transplanting (DAT), respectively.

For a plot under brackish water cultivation conditions (ECa 5.3 dS m $^{-1}$) and a recirculation interval of 0.25 h and for another plot under fresh water conditions (ECa 0.3 dS m $^{-1}$) and a 4-h interval, type J thermocouples (ferroconstantan) were installed to monitor the SN temperature in the hydroponic channel. The EC probe and thermocouples were connected to the same datalogger used with the thermohygrometer sensor, as described in subitem “4.1 Experiment location”, with averages also stored every 30 min.

4.5 Variables evaluated

4.5.1 Visual appearance

The visual appearance of the lettuce was monitored periodically to identify possible symptoms related to the nutritional deficiency produced and toxicity caused by Na+ and Cl– ^{ions}, as well as any damage caused by pests and/or diseases.

4.5.2 Dissolved oxygen concentrations in the nutrient solution

At 21 DAT, dissolved oxygen (DO) levels in the NSs were measured in the hydroponic channels of the DFT system in both treatments. For the 0.25-h interval treatment, measurements were taken with the hydroponic system at rest; for the 2- and 4-h intervals, measurements were taken 0.25 h before a new NS recirculation, between 9 and 10 a.m., using a portable oximeter.

4.5.3 Lettuce growth and production

For crisp lettuce (cv. 'Robusta'), the experiment ended at 21 DAT. For the iceberg lettuce cultivars ('Gloriosa' and 'Tainá'), in addition to being harvested on the same date (at 21 DAT), the remaining plants remained in the hydroponic channels for an additional seven days (until 28 DAT), thus performing two harvests for these two cultivars. In each plot, two plants of each cultivar were harvested, and the following parameters were evaluated: plant height (AP), number of leaves (NF), shoot diameter (DPA), and shoot fresh mass (MFPA). DPA was obtained by considering the greatest distance from the maximum width obtained when the lettuce leaves were laid flat on a flat surface. Immediately after the fresh plants were weighed, the material was placed in paper bags and placed in a forced circulation oven at 65°C until it reached a constant mass to quantify the shoot dry mass (MSPA). The MFPA and MSPA were obtained on a precision balance (0.01 g).

4.6 Statistical analysis

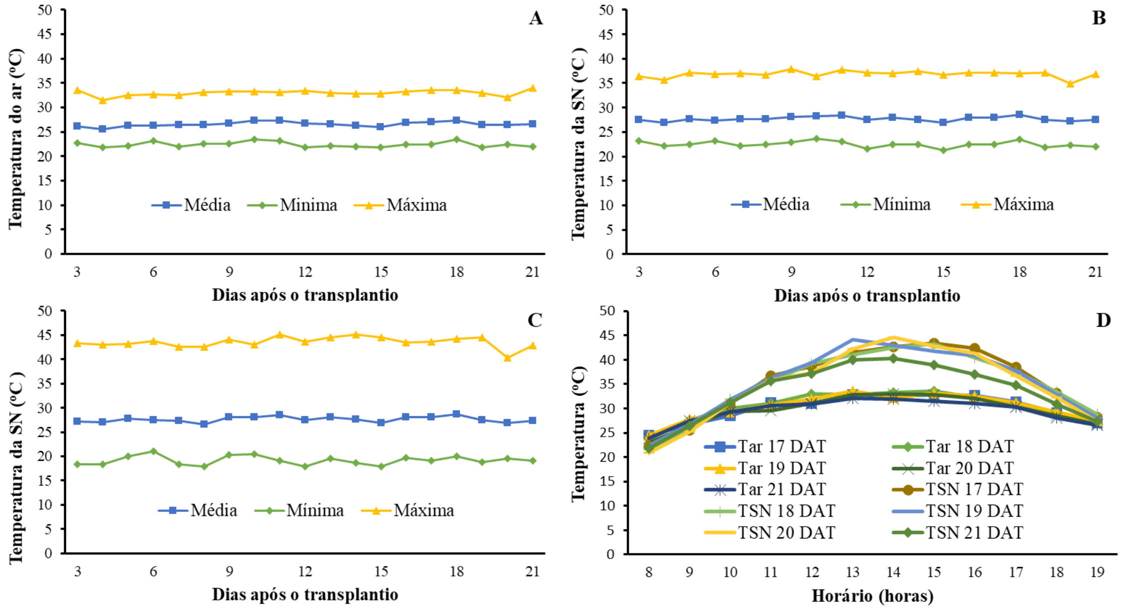
Statistical analysis was performed separately for each lettuce cultivar in both experiments. The data were subjected to analysis of variance via the F test, and the means were compared via Tukey's test at the 0.05 probability level. Statistical analyses were performed via the Sisvar statistical program (FERREIRA, 2014).

5 RESULTS AND DISCUSSION

5.1 Temperatures and electrical conductivity of the nutrient solution

The average air temperature during the study period was 26.75°C, with minimums ranging from 21.8 to 24.41°C and maximums ranging from 31.56 to 37.86°C. The largest daily range in air temperature was 14.64°C at 24 DAT (Figure 2A). The average air temperature was higher than the recommended or ideal limit for lettuce crop development, which is between 15 and 25°C (FELTRIM et al., 2009; SILVA et al., 2017a). Summer, characterized by high temperatures (above 30°C) during the day, shortens the vegetative cycle (AQUINO et al., 2017), which can lead to the elongation of plant stems and, consequently, tasseling (DIAMANTE et al., 2013). This undesirable characteristic makes the product unsuitable for commercialization (LUZ et al., 2009). Although the temperatures were above ideal levels at 21 days, lettuce quality was not affected. This is partly due to genetic improvement work for Brazilian tropical conditions.

Figure 2. Daily average air temperatures – Tar (A), nutrient solution temperatures (TSN) inside the hydroponic channel in the DFT system using brackish water (CEa 5.3 dS m $^{-1}$) and NS recirculation every 0.25 h (B) and with fresh water (CEa 0.3 dS m $^{-1}$) and NS recirculation every 4 h (C), Tar and TSN inside the channel in the DFT system using fresh water and NS recirculation every 4 h (D).



Tar oscillation influenced the TSN measured in the hydroponic channel in the DFT system. Under the conditions of lettuce cultivation with brackish water (ECa 5.3 dS m $^{-1}$) and SN recirculation every 0.25 h (Figure 2B), the average TSN was 27.84°C, with minimums ranging from 21.34 to 24.19°C and maximums ranging from 34.99 to 41.33°C. The largest daily TSN amplitude throughout the cycle was 17.96°C at 24 DAT (Figure 2B), corroborating the highest tar on that day (Figure 2A). Evaluating the oscillation of TSN under freshwater conditions (ECa 0.3 dS m $^{-1}$) and SN recirculation every 4 h, larger thermal amplitudes were observed, one of which was on the order of 26.6°C and recorded at 15 DAT (Figure 2C), the day in which an amplitude of 11.04°C was observed in Tar (Figure 2A).

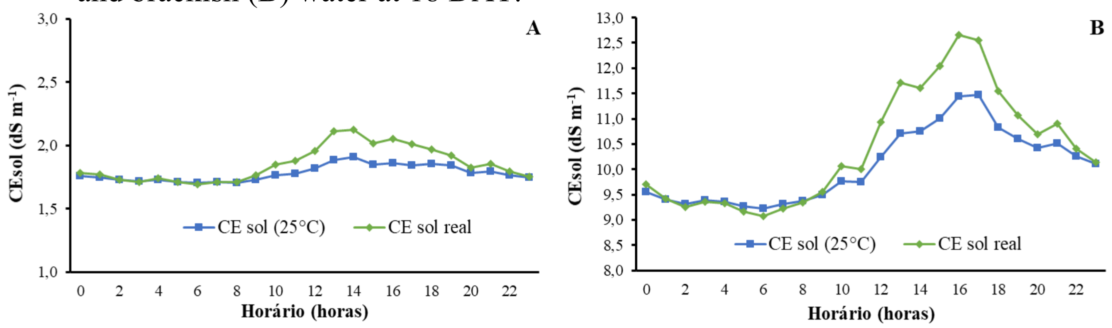
NRS is highly important in hydroponic cultivation, especially in warmer seasons, and can considerably exceed the optimal range required for plant growth (CORTELLA et al., 2014). In general, NRS in the range of 20 to 25°C is considered adequate for maintaining the growth of lettuce plants (MONTOYA et al., 2017). A high NRS can compromise plant physiological functions, such as those involving chlorophyll formation and photosynthetic processes (NXAWE; NDAKIDEMI; LAUBSCHER, 2011) and, consequently, phytomass yield (SAKAMOTO; SUZUKI, 2015). In other studies with lettuce under hydroponic conditions, on average, NRS values above 30°C were recorded (SANTOS et al., 2011; COMETTI et al., 2013; SILVA et al., 2018a).

The average Tar and TSN between 8 am and 7 pm during the period between 17 and 21 DAT (Figure 2D) revealed that between 10 am and 7 pm, the TSN inside the culture channel in the DFT system was greater than that inside the Tar. The maximum TSN inside the channel occurred between 2 pm and 4 pm, with a daily amplitude on the order of 1.94°C in this period (between 17 and 21 DAT), in the culture condition with brackish water and a frequency of 0.25 h (Figure 2D); in the condition with the use of fresh water and a frequency of 4 h, the difference was 10.03°C, which is attributed to the lower heat renewal when the NS recirculation is less frequent, since, according to Schmidt et al. (2017), with the increase in Tar, the temperature of the culture channels rises and part of the heat diffuses to the NS.

This interaction between the TAR and TSN is closely related to the material used in the growing channel, namely, the PVC pipe. Mattos et al. (2001), when evaluating the type of covering material for hydroponic system benches, reported that, compared with PVC channels covered with polyethylene–aluminum–polyethylene–paper–polyethylene films and a double-sided canvas, uncovered PVC provided the highest TSN inside the growing channel. The authors also noted that the thermal regime in the root environment can affect water and nutrient absorption, as well as the growth of the root system and shoots of plants.

The electrical conductivity of the nutrient solution (CEsol) increased throughout the same day as the solution was heated (Figure 3A and 3B). Like the maximum TSN, the maximum CEsol inside the hydroponic channel in the DFT system occurred between 2 and 4 p.m. This behavior was observed independently of the compensation for the effect of temperature on the CEsol measurement; that is, it occurred both for CEsol standardized at 25°C and for $_{\text{real}}$ CEsol. Typically, the $_{\text{real}}$ CEsol was almost always higher than the CEsol $_{(25°C)}$, which is explained by the TSN being almost always above 25°C.

Figure 3. Electrical conductivity of the standardized nutrient solution at 25°C (Cols $_{(25°C)}$) and real without temperature compensation (Cols $_{\text{real}}$) in the DFT hydroponic system under a recirculation interval of every 4 h under cultivation conditions with fresh (A) and brackish (B) water at 18 DAT.



While CEsol at 25°C is an important parameter for establishing treatments and comparing results between studies (BERNERT et al., 2015; VISCONTI; PAZ, 2016), it should not be forgotten that the crop responds to the reality of the rhizosphere, which in the present study was the unplanned interaction of the CE factor with the uncontrolled factor: temperature. This is one of the reasons for the expectation of lower depreciation of crops subjected to saline conditions in milder climates, as predicted by various authors (ANDRIOLO et al., 2008; SILVA et al., 2017b). The CEsol x temperature relationship needs to be considered, especially in warmer climates (such as in the Brazilian semiarid region), when operating with lower frequencies of SN recirculation, and when working with materials with little thermal insulation (such as PVC).

The ECsol $_{(25°C)}$ was not constant throughout the day (Figures 3A and 3B), even after temperature compensation. The incorporation of salts when water losses through evapotranspiration are replaced with brackish water only partially explains the oscillation of ECsol $_{(25°C)}$. This occurred because for brackish water (ECw 5.3 dS $^{m–1),}$ $^{an\ increase\ in}$ ECsol $_{(25°C)}$ was also observed during the hottest hours of the day (Figure 3B). The concentration of salts when the system was temporarily turned off also partially explained the oscillation of ECsol $_{(25°C)}$. A complementary explanation for this effect is that temperature also causes changes in electrical conductivity such that, according to Steidle Neto et al. (2005), if it increases, the resistance of the solution to the passage of current decreases, resulting in an increase in conductivity.

The diurnal amplitude of the $_{real}$ CEsol was 3.58 dS m–1 for the plot with brackish water (CEa 5.3 dS $^{m–1}$) and an SN recirculation interval of every 4 h (Figure 3B). On the basis of the value of the $_{real}$ CEsol (9.42 dS m $^{–1}$) at the beginning of the day (between 0 and 1 h), when the NST in this plot was 25°C, the diurnal amplitude of the $_{real}$ CEsol corresponded to 38.02%. This amplitude of 3.58 dS m–1 was produced by a 24.25°C amplitude in the NST. For the plot that was operated with fresh water (CEa 0.3 dS m $^{–1}$) and an SN recirculation interval of every 4 h, the diurnal amplitude of the $_{real}$ CEsol was 0.43 dS m $^{–1}$ (Figure 3A). On the basis of the value of the $_{real}$ CEsol (1.78 dS m $^{–1}$) at the beginning of the day (between 0 and 1 h), when the temperature in this plot was 25°C, the diurnal amplitude of the $_{real}$ CEsol corresponded to 24.27%.

Such fluctuations exacerbate the effects of salts in an environment that, unlike soil or substrates, is more conditioned by the high specific heat of water, which may require more heat to heat, but when heated, leads to greater difficulty in cooling. To demonstrate the relevance of the amplitude of the $_{real}$ CEsol to temperature, we compare its relative weight resulting from the incorporation of salts in the replacement of evapotranspiration losses: for a $_{real}$ CEsol of 10.13 dS m–1 (treatment with a frequency of 4 h and brackish water) at the end of the day (between 23 and 24 h), when the temperature in this plot was 25°C, salt incorporation corresponded to an increase of 7.52%.

The CEsol values at 25°C were measured with a benchtop conductivity meter, and a reduction was noted throughout the study with the use of freshwater (CEa 0.3 dS $^{m–1}$). This is explained by the fact that replacing evapotranspiration with freshwater does not incorporate ions into the solution at the same rate as their absorption, in agreement with other reports in hydroponic conditions using the same strategy (SILVA et al., 2018a; MARTINS et al., 2019; SILVA JÚNIOR et al., 2019a; SOARES et al., 2019).

On the other hand, the ECsol produced with brackish water (ECa 5.3 dS m $^{–1}$) increased progressively, which can be explained by the fact that evapotranspiration replenished with this water incorporates more toxic ions than the plant can absorb. This progressive salinization is inherent to brackish water replenishment in closed SN recirculation systems. In this same scenario, the osmotic conditions for the crop are further aggravated by the diurnal increase in solution temperature in response to the increase in air temperature.

5.2 Dissolved oxygen in the nutrient solution

The dissolved oxygen (DO) concentrations in the SN (0.25 h before the new recirculation frequency) did not differ significantly among the treatments in the DFT hydroponic system, with an average of 6.51 mg $^{L–1}$. This contradicted the expectation of a detrimental effect of a low recirculation frequency on DO availability. Goto et al. (1996) reported that, up to the minimum dissolved oxygen level of 2.1 mg/L, ^{no} root damage or growth retardation of the aerial parts of lettuce plants was detected. The lack of effect can be explained by the measurement time (9 to 10 h), which did not coincide with the temperature peaks.

Conesa et al. (2015) evaluated lettuce under three different levels of SN aeration/recirculation (no, low, and high recirculation) in a *floating hydroponic system* and reported that different aeration levels were decisive factors in the amount of DO in the SN. The authors also reported that in summer, the increase in temperature had a greater effect on the reduction in DO than did the DO level in the treatments carried out during autumn and winter. The average values recorded for DO during the summer cycle were 6.9, 5.4, and 3.3 mg L–1 for the high, low, and no recirculation treatments, respectively.

In fact, temperature is one of the most important factors determining the availability of DO in the SN of hydroponic crops (TESI; LENZI; LOMBARDI, 2003a; QIN et al., 2007; LENZI; BALDI; TESI, 2011), since the close relationship between them is inverse, such that dissolved oxygen decreases as temperature increases (BONACHELA et al., 2010; SIKAWA; YAKUPITIYAGE, 2010; SILVA et al., 2020bc). In contrast, in the study developed by Bremenkamp et al. (2012) with lettuce in NFT hydroponics under different SN temperatures (24, 26, 28, 30 and 32°C), the DO concentrations did not change significantly, with values of 7.5, 7.4, 7.5, 7.6 and 7.4 mg $^{L-1}$, respectively.

5.3 Quality of the lettuce produced

With respect to the green hue of the lettuce produced (Figures 4, 5, and 6), there was no visual difference, regardless of the hydroponic cultivation system, salinity, or NS recirculation interval. Furthermore, no derogatory symptoms that could be attributed to salinity or recirculation frequency, such as wilting, chlorosis, and leaf necrosis, which could prevent or hinder the marketing of the lettuce, were detected. The appearance of plants produced under saline stress is an important characteristic for product acquisition, as reported by Viana et al. (2018), who concluded that consumers of fresh lettuce purchase the product on the basis of its appearance and textural quality and are likely to repeat their purchase owing to their satisfaction with the flavor. Kim et al. (2008) reported more intense green coloration in lettuce plants subjected to higher salinity levels, whereas Ünlükara et al. (2008) reported that increasing the salinity of irrigation water did not affect the flavor of lettuce, although it increased the Na $^{+\ content}$ in the leaves.

Figure 4. Lettuce cv. 'Robusta' cultivated in the NFT system (first on the left) and in the DFT system under nutrient solution recirculation intervals of 0.25 h (second on the left), 2 h (second on the right) and 4 h (first on the right) when subjected to brackish water at 21 days after transplanting.

Figure 5. Lettuce cv. 'Gloriosa' cultivated in the NFT system (first on the left) and in the DFT system under nutrient solution recirculation intervals of 0.25 h (second on the left), 2 h (second on the right) and 4 h (first on the right) when subjected to brackish water at 28 days after transplanting.

Figure 6. Lettuce cv. 'Tainá' cultivated in the NFT system (first on the left) and in the DFT system under nutrient solution recirculation intervals of 0.25 h (second on the left), 2 h (second on the right) and 4 h (first on the right) when subjected to brackish water at 28 days after transplanting.

Additionally, in the present study, leaf edge burning (tipburn), a symptom commonly found in lettuce plants (related to calcium deficiency), occurred in all the treatments and in random plants; therefore, there was no relationship with the treatments imposed. This phenomenon can be explained by the prominent growth of leafy vegetables without sufficient calcium translocation to younger tissues, as reported by Santos et al. (2010) and Silva et al. (2020a).

5.4 Lettuce growth and production

For Experiment I, there was a significant effect of water electrical conductivity (ECa) on all evaluated variables (plant height – AP, number of leaves – NF, shoot diameter – DPA and fresh matter mass – MFPA and shoot dry weight – MSPA) of 'Robusta' lettuce (at 21 DAT), 'Gloriosa' and 'Tainá' lettuce (at 21 and 28 DAT) (Table 1). The hydroponic cultivation system had a significant effect on NF at 21 and 28 DAT and on MFPA at 21 DAT in 'Tainá' lettuce. Only at 21 DAT was there a significant interaction effect between CEa and the hydroponic system on the MFPA of 'Tainá' lettuce (Table 1).

Table 1. Summary of the F test results of the analysis of variance for plant height (AP), number of leaves (NF), aerial part diameter (DPA) and fresh (MFPA) and dry mass of aerial part (MSPA) of the lettuce plants 'Robusta', 'Gloriosa' and 'Tainá' grown in two different hydroponic systems (SH) and subjected to two levels of water electrical conductivity (CEa).

	Days after transplant (DAT)									
	21	**28**	**21**	**28**	**21**	**28**	**21**	**28**	**21**	**28**
FV	**AP**		**NF**		**DPA**		**MFPA**		**MSPA**	
					cv. 'Robusta'					
Blocks	ns		ns		ns		*		ns	
CEa	**		*		**		**		**	
SH	ns		ns		ns		ns		ns	
CEa x SH	ns		ns		ns		ns		ns	
CV (%)	8.28		14.99		5.70		18.28		21.11	
					cv. 'Gloriosa'					
Blocks	ns	ns	ns	ns	ns	*	ns	ns	ns	**
CEa	**	**	**	**	**	**	**	**	**	**
SH	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CEa x SH	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	7.61	11.52	12.28	10.68	7:30	5.32	26.15	16:31	21.64	8.95
					cv. 'Taina'					
Blocks	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CEa	**	**	**	**	**	**	**	**	**	**
SH	ns	ns	**	*	ns	ns	*	ns	ns	ns
CEa x SH	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	8.55	20.59	8.02	9.54	9.21	7.72	18.16	18.23	19.25	15.82

FV - source of variation; ** and * significant at the 0.01 and 0.05 probability levels, respectively, and ns - not significant according to the F test; CV - coefficient of variation.

For Experiment II, the variables AP, NF, DPA, MFPA and MSPA of the three lettuce cultivars were also significantly influenced by the CEa levels (Table 2). The nutrient solution recirculation intervals significantly influenced the MFPA of 'Robusta' lettuce at 21 DAT and the AP, DC and MSPA of 'Tainá' lettuce at 28 DAT. The variables of 'Gloriosa' lettuce did not undergo significant changes as a function of the recirculation intervals (Table 2).

Table 2. Summary of the F test results of the analysis of variance for plant height (AP), number of leaves (NF), aerial part diameter (DPA) and fresh matter (MFPA) and dry matter mass of aerial part (MSPA) of the lettuce 'Robusta', 'Gloriosa' and 'Tainá' subjected to two levels of water electrical conductivity (CEa) and different intervals of nutrient solution recirculation (IRSN) in the DFT hydroponic system.

	Days after transplant (DAT)									
	21	**28**	**21**	**28**	**21**	**28**	**21**	**28**	**21**	**28**
FV	**AP**		**NF**		**DPA**		**MFPA**		**MSPA**	
					cv. 'Robusta'					
Blocks	ns		ns		ns		ns		ns	
CEa	**		**		**		**		**	
IRSN	ns		ns		ns		*		ns	
CEa x IRSN	ns		ns		ns		ns		ns	
CV (%)	7.35		13.02		7.25		21.05		16.58	
					cv. 'Gloriosa'					
Blocks	**	ns	ns	ns	ns	**	ns	**	ns	*
CEa	**	**	**	**	**	**	**	**	**	**
IRSN	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CEa x IRSN	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	5.31	9.16	11.63	9.19	6.75	5.58	21.72	14.03	19.50	11.68
					cv. 'Taina'					
Blocks	ns	ns	ns	**	ns	ns	ns	*	ns	*
CEa	**	**	**	**	**	**	**	**	**	**
IRSN	ns	ns	ns	ns	ns	*	ns	ns	ns	*
CEa x IRSN	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	8.65	8.55	10.01	9.68	8.91	7.43	21.84	20.09	18.77	15,14

FV - source of variation; ** and * significant at the 0.01 and 0.05 probability levels, respectively, and ns - not significant according to the F test; CV - coefficient of variation.

The marketable production (based on the fresh mass of the aerial part) achieved in the three cultivars evaluated was within expectations. On the basis of the control treatment under an ECa of 0.3 dS $^{m-1}$, at 21 DAT, the average MFPA values for 'Robusta' lettuce were 189.31 and 158.20 g $^{plant-1}$ for experiments I (Table 3) and II (Table 4), respectively. In Experiment I, at 21 and 28 DAT, the average MFPA values were 213.75 and 455.80 g $^{plant-1}$ for 'Gloriosa' lettuce and 195.12 and 368.57 g $^{plant-1}$ for 'Tainá' lettuce, respectively (Table 3).

Table 3. Average values of plant height (AP), number of leaves (NF), aerial part diameter (DPA), fresh matter (MFPA) and dry matter (MSPA) of the aerial part of the lettuce 'Robusta', 'Gloriosa' and 'Tainá' were grown in two different hydroponic systems (SHs) and subjected to two levels of water electrical conductivity (ECa in dS m $^{-1}$).

	Days after transplant (DAT)									
	21	**28**	**21**	**28**	**21**	**28**	**21**	**28**	**21**	**28**
	AP (cm)		**NF**		**DPA (cm)**		**MFPA (g)**		**MSPA (g)**	
CEa	cv. 'Robusta'									
0.3	25.8a		21.9a		40.6a		189.3a		8.5a	
5.3	19, 5b		18.1b		31.3b		105.0b		5.7b	
S H										
NFT	22.6a		19.7a		36.5a		155.6a		7.0a	
DFT	22.5a		20.3a		35.4a		138.8a		7.2a	
CEa	cv. 'Gloriosa'									
0.3	26.8a	32.2a	17.0a	26.1a	40.6a	46.8a	213.8a	455.8a	10.5a	15.7a
5.3	20.7b	27.2b	13.4b	20.6b	30.9b	35.8b	114.9b	243.7b	6.2b	9.8b
S H										
NFT	24.0a	30.1a	15.2a	24.1a	36.5a	42.0a	171.0a	355.3a	8.2a	12.9a
DFT	23.5a	29.3a	15.2a	22.6a	35.0a	40.6a	157.6a	344.3a	8.5a	12.6a
CEa	cv. 'Taina'									
0.3	23.7a	30.2a	13.2a	21.3a	38.1a	45.0a	169.1a	368.6a	7.9a	13.2a
5.3	17.7b	21.6b	9.6b	15.0b	27.7b	30.7b	67.0b	165.1b	4.3b	8.8b
S H										
NFT	20.9a	26.1a	12.0a	19.1a	33.6a	38.4a	129.2a	285.7a	6.4a	10.8a
DFT	20.5a	25.7a	10.7b	17.1b	32.3a	37.3a	106.9b	247.9a	5.8a	11.2a

In the columns, means with the same letters do not differ statistically by the Tukey test at 0.05 probability.

F or Experiment II (Table 4), at 21 and 28 DAT, the average MFPA values were, respectively, 209.92 and 452.54 g plant–1 for 'Gloriosa' lettuce and 141.74 and 318.43 g plant–1 for 'Tainá' lettuce. In the study by Ludke et al. (2009), with lettuce grown in soil (with the application of organic compost as a topdressing) and plants harvested at 76 DAS (days after sowing), a production of 426.9 g plant–1 was recorded for 'Gloriosa' lettuce; for 'Tainá' lettuce, the production was 430 g plant–1, which was more than 100 g greater than that observed in the present work for Experiment II (Table 4). This difference may be related to the lower adaptation of 'Tainá' lettuce to local climatic conditions during the present experiment. However, the difference in plant age must also be considered in this comparison. 'Tainá' lettuce showed greater development at the end of the experiment, and its early harvest, at 28 DAT or 50 DAS, may have compromised its completion. 'Tainá' lettuce is suitable for summer and has an average cycle of 75 DAS (SAKATA, 2019). The harvest period for iceberg lettuce in this study was defined on the basis of 'Gloriosa' lettuce, which has already reached commercial standards at 50 DAS.

Table 4. Average values of plant height (AP), number of leaves (NF), aerial part diameter (DPA) and fresh matter (MFPA) and dry matter mass of aerial part (MSPA) of 'Robusta', 'Gloriosa' and 'Tainá' lettuce subjected to two levels of water electrical conductivity (ECa in dS m $^{-1}$) and different nutrient solution recirculation intervals (IRSNs in h) in the DFT hydroponic system.

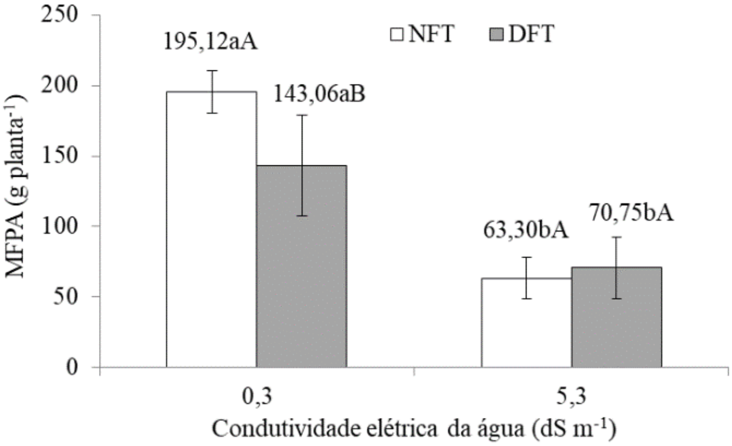
	Days after transplant (DAT)									
	21	**28**	**21**	**28**	**21**	**28**	**21**	**28**	**21**	**28**
	AP (cm)		**NF**		**DC (cm)**		**MFPA (g)**		**MSPA (g)**	
CEa	cv. 'Robusta'									
0.3	25th		21st		38.3a		158.2a		8.5a	
5.3	19b		17b		29.8b		81.1b		4.9b	
IRSN										
0.25	23rd		20th		35.4a		138.8a		7.2a	
2	22nd		19th		33.6a		112.3ab		6.4a	
4	21st		18th		33.2a		107.8b		6.6a	
Cea	cv. 'Gloriosa'									
0.3	26th	32.6a	18th	26.9a	39.1a	45.8a	209.9a	452.5a	10.7a	15.4a
5.3	20b	24.1b	13b	19.7b	29.1b	33.5b	100.3b	198.8b	5.8b	9.3b
IRSN										
0.25	24th	29.3a	15th	24.1a	35.0a	40.6a	157.6a	344.3a	8.5a	12.6a
2	24th	28.2a	15th	23.2a	34.1a	39.6a	158.9a	326.2a	8.4a	12.3a
4	23rd	27.4a	15th	22.7a	33.4a	38.7a	148.9a	306.5a	7.9a	12.2a
CEa	cv. 'Taina'									
0.3	23rd	28.9a	12th	18.9a	36.4a	42.0a	141.7a	318.4a	7.1a	12.3a
5.3	18b	20.7b	9b	14.6b	28.0b	29.7b	63.9b	142.1b	3.8b	8.1b
IRSN										
0.25	21st	25.7a	11th	17.1a	32.3a	37.3a	106.9a	247.9a	5.8a	11.2a
2	21st	24.8a	11th	17.0a	33.2a	36.0ab	111.4a	239.9a	5.7a	10.1ab
4	20th	23.9a	10th	16.1a	31.1a	34.3b	90.2a	203.0a	4.9a	9.3b

In the columns, means with the same letters do not differ statistically by the Tukey test at 0.05 probability.

Under hydroponic conditions in the NFT system, Soares et al. (2015) recorded MFPA production of 'Tainá' lettuce on the order of 383.35 g $^{plant-1}$ at 21 DAT under control treatment (CEa 0.2 dS $^{m-1}$) during the winter season. For this same lettuce cultivar, Maia (2019) reported commercial MFPA production on the order of 280.83 g $^{plant-1}$ at 33 DAT (50 DAS). These results reinforce that variations in the production of cultivars of the same plant species from one location to another are highly dependent on climatic conditions, as well as on management and/or nutrient solution formulation.

In Experiment I, when the individual effects of the hydroponic systems were evaluated only for the NF of 'Tainá' lettuce, the highest averages were obtained in the NFT system, which were on the order of 12.00 and 19.14 leaves at 21 and 28 DAT, respectively (Table 3). In the DFT system, the average values were approximately 11% lower than those in the NFT system. This higher NF obtained in the NFT system at 21 DAT also resulted in greater production of MFPA under cultivation conditions with fresh water (ECw 0.3 dS $^{m-1}$), with MFPA values on the order of 195.12 g plant–1, than 143.06 g $^{plant-1}$ in the DFT system (Figure 7). These results show that in this cultivation phase (21 DAT), 'Tainá' lettuce was more sensitive to the constant flooding of the roots in the nutrient solution; subsequently, the plants maintained a superior growth pattern to those produced in the NFT system, which made the difference between the hydroponic systems insignificant at 28 DAT.

Figure 7. Interaction between the electrical conductivity of water (ECa) and that of the hydroponic system (Experiment I) on the basis of the fresh matter mass of the aerial part of 'Tainá' lettuce at 21 days after transplanting.



Lowercase letters compare the means of the ECa levels within each hydroponic system, and uppercase letters compare the means of the hydroponic systems within each ECa level via Tukey's test at 0.05 probability. The vertical bars indicate the standard deviations of the means.

The lack of significant differences for most of the variables evaluated for the three lettuce cultivars according to the hydroponic systems demonstrates that growing this vegetable in the DFT system adapted to tubes is technically feasible. As an advantage of this system, Silva et al. (2016b) and Silva et al. (2018a) reported that plant roots remain continuously immersed in nutrient solution. Therefore, from this perspective, the DFT system may be attractive and recommended, since in situations of mechanical failure or temporary power outages, the chance of production loss due to water stress is lower than that in the NFT system, in which the slope of the channels drains the nutrient solution naturally into the reservoir.

In other studies, the DFT system in tubes has been shown to be viable for the cultivation of several plant species, such as coriander (SANTOS JÚNIOR et al., 2015; SILVA et al., 2016ab; SILVA et al., 2018a; SILVA et al., 2020b), basil (GONDIM FILHO et al., 2018; ALVES et al., 2019a; SANTOS et al., 2019; SILVA et al., 2019), arugula (CAMPOS JÚNIOR et al., 2018), chicory (ALVES et al., 2019b; SILVA et al., 2020a), parsley (MARTINS et al., 2019) and chives (SILVA JÚNIOR et al., 2019a, 2019b; SOUZA et al., 2020).

The results of this study become even more relevant when only lettuce cultivation in the DFT system is evaluated (Experiment II). In this case, there was no significant effect of the nutrient solution recirculation interval on the variable of greatest economic or marketable interest (MFPA) for 'Gloriosa' and 'Tainá' lettuce. The average MFPA yields were 155.12 and 325.66 g $^{plant–1}$ (cv. 'Gloriosa') and 102.83 and 230.26 g $^{plant–1}$ (cv. 'Tainá') at 21 and 28 DAT, respectively (Table 4). These results are of great economic importance, as they can allow the farmer to extend the intervals between nutrient solution recirculation events, with the advantages of lower electricity consumption and a lower risk of loss or reduced plant growth due to power outages for periods of up to 4 h.

For 'Robusta' lettuce, the intervals between recirculations had a significant effect on MFPA at 21 DAT, with a maximum production of 138.79 g $^{plant-1}$ under the 0.25 h interval, whereas under the longest interval between recirculations (every 4 h), MFPA was lower (107.84 g $^{plant-1}$), which corresponded to a percentage reduction of approximately 22.30% (Table 4). This detrimental effect of the longer interval between recirculations may be due to the absence or low availability of dissolved oxygen caused by the increased root volume in the cultivation channel and/or increased temperature between 11 am and 6 pm (Figure 2D). On the basis of these results, 'Robusta' lettuce was more sensitive to the increase in the intervals between recirculations of the nutrient solutions.

For 'Tainá' lettuce at 28 DAT, the highest mean values of DC (37.31 cm) and MSPA (11.22 g $^{plant-1}$) were also recorded under a shorter interval between recirculations (0.25 h). Under a longer interval between recirculations of 4 h, the values of DC and MSPA were lower by 8.12 and 16.85%, respectively, than those obtained under an interval of 0.25 h (Table 4).

In the study by Tesi; Lenzi and Lombardi (2003b), with lettuce in a DFT hydroponic system and different recirculation frequencies, it was observed that oxygen deficiency (nonaerated nutrient solution) caused a significant reduction in the fresh mass of the head and roots, dry mass of the head and head diameter. According to Tesi, Lenzi and Lombardi (2003a), the dissolved oxygen content tends to decrease with increasing water temperature.

Hypoxia is a concern in the DFT system because, according to Navarro (2013), plants growing in this system may experience problems due to a lack or insufficient amount of dissolved oxygen needed for their development. This is due to the gradual consumption of dissolved oxygen in the nutrient solution. He also reported that a lack of oxygen reduces root permeability to water and that toxin accumulation may occur; consequently, under stress conditions, nutrient salts (ions) cannot be absorbed in sufficient quantities. Tesi et al. (2003b) reported that a lack of oxygen reduces plant absorption of water and minerals, with repercussions on aerial and root growth, leading to a decrease in final yield.

In soil or substrate, the crop's oxygen demand is met in the pore space, provided that the substrate is moist and has adequate drainage (DHUNGEL; BHATTARAI; MIDMORE, 2012). On the other hand, in circulating systems, oxygen is partially supplied by the simple movement of the nutrient solution. Notably, without an adequate amount of oxygen available to the root system, the plant will not grow (LEE et al., 2014; BLOK et al., 2017), and if insufficient levels are present, premature death of root tissues and/or plant death may occur.

Currently, simple recirculation does not guarantee oxygenation of the nutrient solution. In other words, flowing the solution through the hydraulic system and cultivation gutters and even creating its eventual aeration as it falls into the reservoir can result in insufficient oxygenation. The lack of an effect of recirculation frequency on dissolved oxygen in this study should be taken with caution, as only a single measurement was taken between 9 and 10 AM, a period when the solution temperature was not yet very high.

In similar previous studies, which used a DFT system in tubes, Silva et al. (2016 b) and Silva et al. (2018a) did not observe a significant difference in coriander production when the nutrient mixture was recirculated every 8 and 2 h in the cultivation channels compared with recirculations every 0.25 h. The increase in the intervals between recirculations is highly dependent on the time of year due to temperature variations.

For example, Silva Júnior et al. (2019b) reported reductions in chive production of approximately 17% and 4% in summer and autumn, respectively, when recirculations were performed every 12 h, compared with every 8 h, under cultivation conditions under a CEsol of 1.5 dS $^{m–1}$.

At 21 DAT, when the three lettuce cultivars were compared, in general, under saline stress conditions, the percentage reductions in AP were similar. For NF and DPA, the reductions were similar to those obtained for AP, mainly for 'Gloriosa' (Experiment I) and 'Tainá' (Experiments I and II) lettuce. The smallest reductions in NF were observed for 'Robusta' lettuce. At 28 DAT, the reductions in NF and DPA for 'Gloriosa' lettuce (Experiments I and II) remained at the same level as those obtained seven days earlier (at 21 DAT), whereas for 'Tainá' lettuce, there was an increase, mainly in DPA.

The results of the present study show that lettuce cultivars respond differently to salinity stress. As reported in the literature, plant responses to saline stress vary among species/cultivars, different organs and growth stages, durations of exposure to salts (DIAS et al., 2011; ABBAS et al., 2015; KALHOR et al., 2018), the types and concentrations of salts to which the plants are subjected (AHMADI; SOURI, 2018), and environmental factors such as temperature, relative humidity, and light intensity (HASANUZZAMAN; NAHAR; FUJITA, 2013).

In general, the greatest reduction under saline stress occurred in MFPA, a variable of greatest commercial interest, which corroborates other studies (FERNANDES et al., 2018; SILVA et al., 2018b; GUIMARÃES et al., 2020). In this case, in addition to the reduction in the emission of new leaves, smaller leaf areas (not measured) were observed than those obtained under conditions without salinity stress.

Compared with other studies with salinities close to those used in the present work, there was no difference in MFPA when the nutrient solution was prepared without (0 mM) and with (50 mM) NaCl, in NFT hydroponics for a period of 50 DAT of 'Paris Islands Cos' lettuce cultivation (AL-MASKRI et al., 2010), and under CEsol of 5.4 dS m $^{–1}$ in relation to the control (CEsol 2.5 dS m $^{–1}$), in the cultivation of 'Lollo' lettuce Rossa' in DFT hydroponics (BORGHESI et al., 2013).

Even with the reduction in lettuce MFPA production, hydroponics has favored the use of brackish water (largely owing to its precocity), as the effect of salts becomes less harmful to plants, as pointed out by several studies for the crop under study (SAKAMOTO; KOGI; YANAGISAWA, 2014; BARTHA et al., 2015; SOARES et al., 2015; GUIMARÃES et al., 2017; NIU et al., 2018; SILVA et al., 2018a).

When only brackish water with an ECw of up to 5.3 dS m–1 $^{\text{is available}}$ for cultivation, it may be strategic to harvest the plants later. For example, considering the yields of the cultivars 'Gloriosa' and 'Tainá', for which two harvests were possible, the MFPAs obtained under salt stress at 28 DAT were similar to the yields obtained seven days earlier (at 21 DAT) under conditions without salt stress (ECw 0.3 dS $^{m–1}$). Therefore, it is possible to use this water in production as an alternative for producers with freshwater constraints, even those with reduced productivity, leaving good-quality water for other, more demanding purposes.

6 CONCLUSIONS

The temperature of the nutrient solution increased as the interval between recirculations of the nutrient solutions in the DFT system, adapted to PVC pipes, increased.

Increasing the temperature of the nutrient solution increased the electrical conductivity of the nutrient solution between 1 pm and 4 pm.

The use of fresh water with an electrical conductivity (ECa) of 0.3 dS m–1 promoted greater growth and production of the three lettuce cultivars ('Gloriosa', 'Robusta' and 'Tainá'). Despite the reduction in plant size when brackish water (ECa 5.3 dS m^{-1}) was used, there was no decrease in the visual quality of the product for commercialization.

On the basis of the fresh mass of the aerial part (a variable of commercial interest) of lettuce, it was technically feasible to adopt an interval between recirculations of the nutrient solution of up to 4 h in a DFT hydroponic system in tubes for the cultivars of the American group ('Gloriosa' and 'Tainá'). For lettuce in the curly group ('Robusta'), it was technically feasible to use intervals of up to 2 h for recirculating the nutrient solution.

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