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Lettuce growth and water consumption in NFT hydroponic system using brackish water

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Key words:
Lactuca sativa L.
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A B S T R A C T
The qualitative aspects of water, such as the preparation or replenishment of the nutrient solution, are critical to the success of hydroponic crops. Therefore, the aim of this study was to evaluate the behavior of “Americana” lettuce (cv. Tainá) under increasing levels of saline stress (0.2 - control, 1.2, 2.2, 3.2, 4.2 and 5.2 dS m^{-1}), replenishing the evapotranspiration with brackish water in Experiment I and supply water (0.2 dS m^{-1}) in Experiment II, both used in the preparation of the nutrient solution. In both experiments, the treatments were arranged in a randomized block design, with six treatments and four replicates. Shoot fresh matter, shoot dry matter and leaf area in Experiment I suffered reductions of 15.22, 12.67 and 15.6% per unit increase of EC, respectively. In Experiment II, reductions of 8.01, 6.90 and 8.14% were observed for the same variables, respectively. In Experiments I and II, linear decrease in water consumption due to the increase in salinity was observed, with reductions of 8.83 and 5.63% for each unit increase of electrical conductivity of water when the evapotranspiration was replenished using brackish and supply water, respectively.

Palavras-chave:
Lactuca sativa L.
hidroponia
salinidade

Crescimento e consumo hídrico de alface americana cultivada com águas salobras em sistema hidropônico

R E S U M O
Os aspectos qualitativos da água quanto ao preparo ou reposição da solução nutritiva são fundamentais para o sucesso de cultivos hidropônicos. Portanto, o objetivo do presente trabalho foi avaliar o comportamento da alface americana (cv. Tainá) sob níveis crescentes de estresse salino (0,2 - testemunha, 1,2, 2,2, 3,2, 4,2 e 5,2 dS m^{-1}) com reposição da lâmina evapotranspirada usando a água salobra utilizada no preparo da solução no Experimento I ou com água de abastecimento (0,2 dS m^{-1}) no Experimento II. Em ambos os experimentos os tratamentos foram distribuídos em um delineamento experimental em blocos ao acaso com seis tratamentos e com quatro repetições. As massas fresca e seca da parte aérea e a área foliar no Experimento I sofreram reduções de 15,22, 12,67 e 15,6%, por incremento unitário da condutividade elétrica, respectivamente. No Experimento II foram constatadas reduções de 8,01, 6,90 e 8,14%, para as massas fresca e seca da parte aérea e área foliar, respectivamente. Verificou-se, nos Experimentos I e II, diminuição linear do consumo hídrico em função do aumento da salinidade, com reduções percentuais de 8,83 e 5,63% por incremento unitário da condutividade elétrica da água utilizada no preparo da solução nutritiva, nas resposição com águas salobra e doce, respectivamente.

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Introduction

Water is a natural resource used for the most diverse purposes, but the availability of good quality water has decreased progressively in the world. On the other hand, water demand has increased due to the population growth. Semiarid regions, in general, do not have superficial water, like rivers and lakes, so the use of underground brackish water becomes an alternative (Sachit & Veenstra, 2014).

The need to find new technologies for the use of brackish water is permanent, with its best use in plant production, in order to decrease the environmental impacts (Santos et al., 2010). Soares et al. (2007) state that hydroponics is the alternative that agrees with the reality of the semiarid region of the Northeast, for providing higher water availability to plants and due to the higher tolerance to salinity by plants in hydroponic cultivation, when compared with conventional systems of cultivation in soil.

Lettuce is cultivated in all the regions in Brazil, especially where there is family farming. However, given the changes in food habits and the growth of "fast food" networks, the market for "Americana" lettuce has increased notoriously (Sala & Costa, 2012). According to Silva et al. (2013), this plant is globally cultivated for fresh consumption in salads.

Studying the performance of lettuce cultivars subjected to different salinity levels of the irrigation water, Oliveira et al. (2011) observed that growth parameters decreased linearly with the increase in salinity, which was also found by Soares et al. (2010), Santos et al. (2011) and Alves et al. (2011).

The use of brackish water in NFT (Nutrient Film Technique) hydroponic systems for the production of "Americana" lettuce can represent an alternative of income for those farmers who have this type of water on their farms. Therefore, studies using brackish water in the preparation of nutrient solution and in the replenishment of evapotranspiration in lettuce cultivation are extremely important, especially in the semiarid region of Brazil.

This study aimed to evaluate the behavior of "Americana" lettuce (cv. Tainá) under increasing levels of saline stress (0.2 - control, 1.2, 2.2, 3.2, 4.2 and 5.2 dS m^{-1}), with the replenishment of evapotranspiration using brackish water in Experiment I and supply water (0.2 dS m^{-1}) in Experiment II, both used in the preparation of the nutrient solution.

Material and Methods

Two experiments with hydroponic "Americana" lettuce aiming to study the effect of salinity on its growth and water consumption were carried out at the Department of Agricultural Engineering of the Federal Rural University of Pernambuco (DEAGRI/UFRPE), Recife (8° 01' 05" S; 34° 5' 48" W; 6.5 m) in the protected environment of a greenhouse (24 x 7 m), with ceiling height of 3 m at the lowest part and 4.5 m at the highest part. The experiments were conducted in different periods, Experiment I in February and Experiment II in June 2013.

The crop used in the experiments, "Americana" lettuce cv. Tainá, was planted in phenolic foam boards, treated with potassium hydroxide (KOH, 0.01N). After planting, the boards were kept in a dark environment for approximately 24 h for seed germination. Then, in both experiments, the seedlings were taken to the nursery, where they remained for 15 days, receiving nutrient solution (Furlani, 1998) diluted in the supply water (0.2 dS m^{-1}) in the proportion of 50%. At 15 days after seeding, also for both experiments, the seedlings were transplanted to the experimental units, where they received full strength nutrient solution (Furlani, 1998) according to the treatments. Both experiments were set in a randomized block design, with six treatments and four replicates, totaling 24 experimental plots.

In Experiment I, the evapotranspiration was replenished using brackish water. In this case, the simplest use of brackish water by farmers was simulated, not requiring any type of special management, just the usual procedure for hydroponics using good quality water.

In Experiment II, the evapotranspiration was replenished using supply water (0.2 dS m^{-1}), and the treatments were maintained at constant salinity levels throughout the crop cycle, simulating situations where more qualified farmers are able to control the electrical conductivity of the solution (ECsol) through the use of low EC water. In order to replenish the consumed water, automatic water-supply systems were installed in both experiments, with an individual graduated ruler for each plot. The systems were built using continuous sections of PVC tubes with diameter of 150 mm, allowing the automatic outflow of water to the nutrient solution reservoir using a float valve, as well as daily readings to determine the evapotranspiration volume (V_{ETc}) during the cultivation, according to Eq. 1:

$$V_{ETc} = \frac{(FR - IR) \times \pi \times D^2}{4 \times n \times \Delta t} \times 10^5 \qquad (1)$$

where:

V_{ETc} - evapotranspiration volume, in mL $plant^{-1}$ d^{-1};

FR - final reading of the water level in the reservoir of the supply system, cm;

IR - initial reading of the water level in the reservoir of the supply system, cm;

D - internal diameter of the reservoir of the supply system, m;

ΔT - time interval between readings, days; and

n - number of plants in the hydroponic bed during the time interval ΔT.

The adopted hydroponic system was NFT (nutrient film technique). An independent hydroponic system was used in each plot, composed of a 3-m long trapezoidal gully channel, with diameter of 75 mm. The experimental spacing was 0.25 m between plants and 0.30 m between gully channels. The hydroponic gully channels were installed at an average height of 0.85 m from the soil surface, with four supporting points, at an inclination of 5%.

Each plot had a circulating electric pump (35 W, 220 V), a 50-L reservoir for the nutrient solution and a 15-L reservoir, which replenished constantly and automatically the water consumed in the evapotranspiration (Soares et al., 2009).

For the Experiments I and II, the treatments were prepared by adding NaCl to the water, obtaining the following salinity levels: T1 - 0.2; T2 - 1.2; T3 - 2.2; T4 - 3.2; T5 - 4.2 and T6 - 5.2 dS m^{-1}. Then macro and micronutrients were added to prepare the nutrient solution, according to Furlani (1998). After homogenizing the solution, pH and ECsol were observed for each treatment. The ECsol readings were: 1.4, 2.4, 3.0, 4.0, 4.7 and 5.5 dS m^{-1}.

The fertilizers used in the preparation of the nutrient solution in both experiments were calcium nitrate, potassium nitrate, monoammonium phosphate (MAP), magnesium sulfate, copper sulfate, zinc sulfate, manganese sulfate, boric acid, sodium molybdate and Fe-EDTA (13% Fe). Complete replenishment of nutrient solution was performed 14 days after transplanting (DAT), in both experiments, since the EC of the nutrient solution for the treatment T1 (0.2 dS m^{-1}) was below 1 dS m^{-1}.

The variables ECsol and pH were monitored in different periods in both experiments, and water consumption was determined based on the daily readings of the automatic supply systems.

In the Experiment I, the lettuce was harvested at 21 DAT and the following variables were evaluated: shoot fresh matter (SFM), shoot dry matter (SDM), leaf area (LA) and absolute (AGR-SFM) and relative (RGR-SFM) growth rate of shoot fresh matter. In the Experiment II, the lettuce was harvested at 30 DAT, and SFM, SDM and LA were evaluated.

In order to determine AGR-SFM and RGR-SFM, three samplings were performed (at 7, 14 and 21 DAT), in which the plant material was weighed using analytical scale and the respective rates calculated by the equations of Hunt (1990). After weighing, the plant material was dried in a forced-air oven at 70 °C for 96 h, for later determination of shoot dry matter, also through weighing. Leaf area was determined using the disc method according to Pereira & Machado (1987).

The data were subjected to analysis of variance using F test and to analysis of polynomial regression, when there was significant effect of the treatments.

Results and Discussion

Values of ECsol and pH of the nutrient solution of the treatments are presented in Figure 1.

In the Experiment I, the initial EC value (1.4 dS m^{-1}) increased by 8.3, 20, 30, 23.4 and 25.4% for the treatments T2, T3, T4, T5 and T6, respectively, due to the accumulation

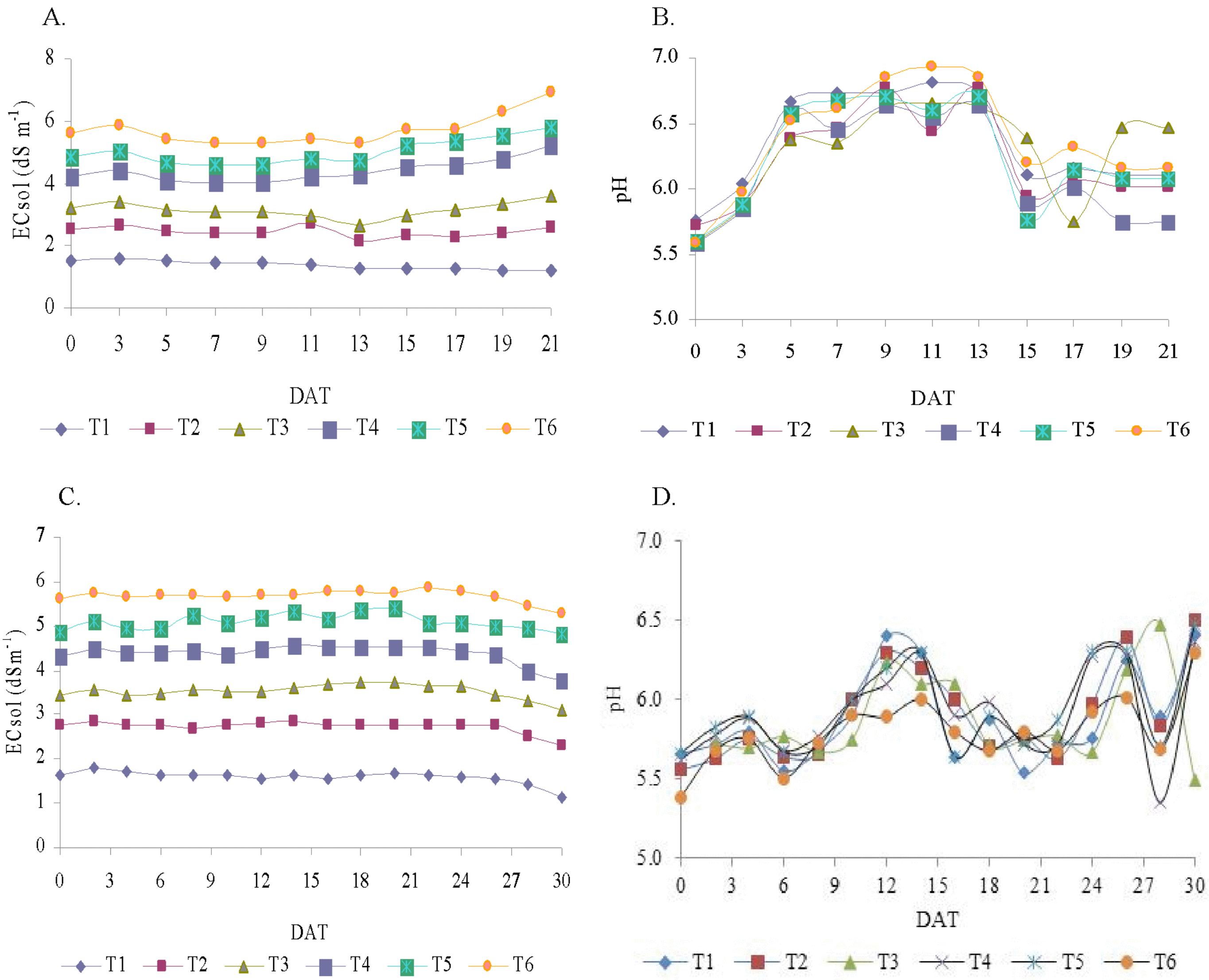

Figure 1. Mean values of electrical conductivity (ECsol) and pH (pH) of the nutrient solution, in the Experiment I (A and B) and in the Experiment II (C and D), in function of the days after transplanting (DAT)

of salts from the increment in the salinity levels of the water used to prepare the nutrient solution and to the lower nutrient absorption in these treatments.

Since the evapotranspiration in the Experiment I was replenished using brackish water, there was an increment of up to 25.4% in the EC of the most saline solution. However, in the treatment using supply water (0.2 dS m^{-1}) to prepare the nutrient solution, there was a decrease of 14.2%, comparing initial and final ECsol values (Figure 1A). This can be attributed to the ETc replenishment using low EC water, i.e., as the plants consumued the nutrients necessary for the development, the salinity level decreased and, consequently, the electrical conductivity also decreased.

These results agree with those found by Soares et al. (2010), who also observed increase in the EC of the nutrient solution when using brackish water to replenish the evapotranspiration, for the production of lettuce cv. Verônica in NFT hydroponic system.

The EC of the nutrient solution in the Experiment II, for all treatments, remained virtually constant during the crop cycle, with a reduction of up to 30.9% from 26 to 30 DAT (end of the cycle), compared with the initial EC (Figure 1C).

In general, the pH of the nutrient solution ranged from 5.5 to 6.5 (Figure 1B and 1D), i.e., these values are within the range where plants are not negatively influenced by pH. According to Furlani (1999), pH values from 4.5 to 7.5 do not affect plant development in hydroponic systems. The pH values of the nutrient solution observed in this study agree with those found by Maciel et al. (2012), who studied ornamental sunflower production in NFT hydroponic system under different salinity levels.

The mean values of the absolute (AGR-SFM) and relative (RGR-SFM) growth rates of the shoot fresh matter as a function of the electrical conductivity of water (ECw) are shown in Figure 2A and 2B, respectively.

AGR-SFM decreased in all evaluation periods with the increase in water salinity levels (Figure 2A). From 0 to 7 DAT, the values decreased and adjusted to the quadratic model, with maximum of 1.31 g d^{-1}, for the control treatment (0.2 dS m^{-1} water), and minimum of 0.30 g d^{-1}, for plants subjected to nutrient solution prepared using 3.9 dS m^{-1} water.

Likewise, for the period of 8-14 DAT, AGR-SFM values decreased and adjusted to the quadratic model, with maximum of 3.76 g d^{-1} for the control treatment and minimum of 2.48 g d^{-1} for the treatment with nutrient solution prepared using 4.29 dS m^{-1} water (Figure 2A).

For the period of 15-21 DAT, AGR-SFM values decreased and adjusted to the linear model, with a reduction of 17.5% per unit increase of ECw, i.e., the high levels of ECw caused a sharp reduction of the AGR-SFM in this period, which reached 91% (1.8 g d^{-1}) for the treatment using 5.2 dS m^{-1} water, compared with the control (19.7 g d^{-1}).

The results for AGR-SFM observed in this study corroborate those obtained by Viana et al. (2004), who also observed a reduction of AGR-SFM with the increase in the water salinity level for all evaluation periods (0-10, 10-20 and 20-30 DAT), when evaluating the effect of five water EC levels (0.3, 1.0, 1.7, 2.4 and 3.1 dS m^{-1}) on the morphophysiological production parameters of lettuce.

The different salinity levels of the water used to prepare the nutrient solution reduced RGR-SFM quadratically in the period of 0-7 DAT (Figure 2B), with a minimum growth of 0.53 g d^{-1} for the salinity level of 3.8 dS m^{-1}. For the period of 8-14 DAT, and salinity level of 0.97 dS m^{-1} (maximum physical efficiency) (Figure 2B), RGR-SFM increased by 0.30 g d^{-1}, while for 15-21 DAT and the salinity level of 2.92 dS m^{-1} (maximum physical efficiency), a maximum growth of 0.26 g d^{-1} was observed for RGR-SFM.

Although RGR-SFM decreased from the EC of 2.92 dS m^{-1} on (15-21 DAT), plants subjected to the highest salinity level (5.2 dS m^{-1}), compared with the control, showed higher RGR-SFM during the evaluation period (Figure 2B), i.e., these plants were more efficient at accumulating dry matter per unit of preexisting material over time.

The results for RGR-SFM obtained in this study confirm those found by Viana et al. (2004), studying lettuce, and by

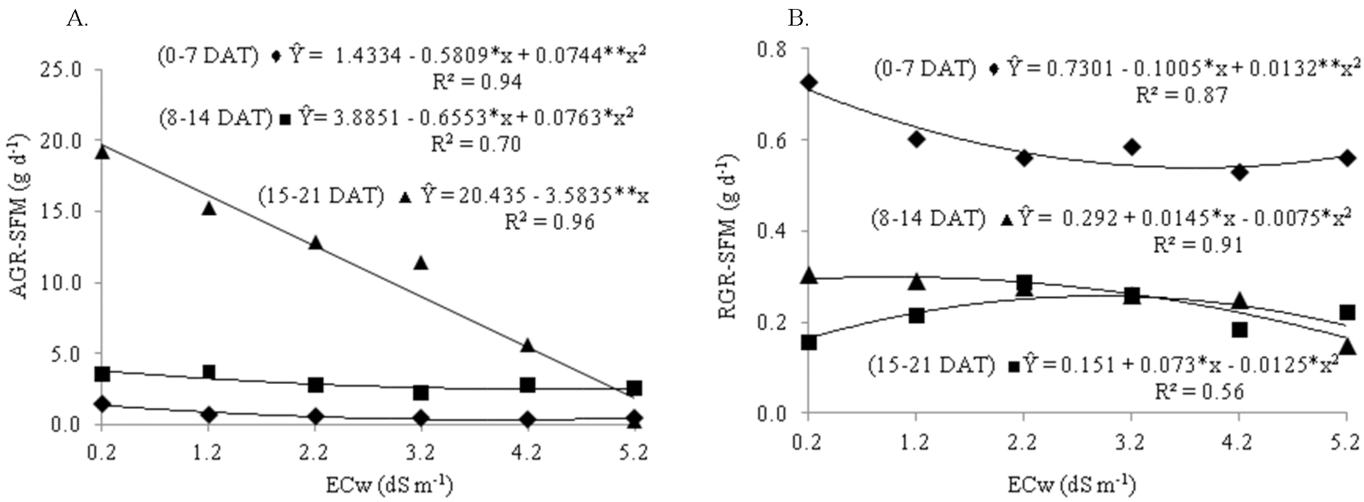

Figure 2. Absolute growth rate (AGR-SFM) (A) and relative growth rate (RGR-SFM) (B) of the shoot fresh matter of "Americana" lettuce, as a function of the electrical conductivity (ECw) of the water used to prepare the nutrient solution in three evaluation periods 0-7, 8-14 and 15-21 days after transplanting (DAT)

Santos et al. (2013), who found influence of water salinity on the relative growth rate of castor bean plants.

According to the analysis of variance (Table 1), there was significant effect for all studied variables in both experiments.

The regression analysis for SFM and SDM of lettuce plants in the Experiments I and II are shown in Figure 3.

In the Experiment I, when the evapotranspiration was replenished using brackish water, there was a linear reduction of 15.23% in SFM (Figure 3A) per unit increase of the EC of the water used to prepare the nutrient solution. Studying the production of lettuce cv. Verônica in a hydroponic system using saline water, Paulus et al. (2010) found SFM decrease of 7.80%. Similarly, Santos et al. (2010) observed reduction of about 17.06% per unit increase in dS m^{-1} for the lettuce cv. Vera, but using underground brackish water.

In the Experiment II, where the evapotranspiration was replenished using 0.2 dS m^{-1} supply water, there was a linear decrease of 8% for SFM (Figure 3A) per unit increase of the EC of the water used to prepare the nutrient solution. Still according to Figure 3A, for the salinity level of 5.2 dS m^{-1}, a SFM value of 227.18 g was estimated when supply water was used to replenish the evapotranspiration losses.

The highest SFM values observed in the Experiment II, compared with the Experiment I, are due to the lower accumulation of salts in the nutrient solution of this experiment, since the evapotranspiration was replenished using supply water (0.2 dS m^{-1}), and, consequently, to the higher absorption of nutrients by the plants in this experiment.

The differences in SFM values observed between the Experiments I and II, as a consequence of the management to replenish the evapotranspiration, corroborate the results found by Alves et al. (2011), who found that the use of brackish water to prepare nutrient solution and fresh water to replenish the evapotranspiration reduced lettuce yield (SFM) by 4.99% with per unit increase of dS m^{-1}. On the other hand, lettuce yield was reduced by 7% with per unit increase of dS m^{-1} when brackish water was used both to prepare the nutrient solution and to replenish the evapotranspiration.

According to the regression equation adjusted to the SDM data (Figure 3B), there were reductions of 12.7 and 6.9% per unit increase of the EC of brackish water (Experiment I) and supply water (Experiment II), used to replenish the evapotranspiration, respectively. These results corroborate those found by Soares et al. (2010), Paulus et al. (2010) and Santos et al. (2010), who reported linear reduction of SDM of hydroponic lettuce as a function of the increase in water salinity.

Table 1. Values of F test and coefficient of variation for the variables shoot fresh matter (SFM), shoot dry matter (SDM) and leaf area (LA) of "Americana" lettuce, in a function of the electrical conductivity of the water used to prepare the nutrient solution of the Experiments I and II

Variables	F Test	CV (%)
	Experiment I	
SFM	61.2801 **	12.42
SDM	21.8706 **	15.54
LA	38.3749 **	16.58
	Experiment II	
SFM	21.4776 **	8.87
SDM	20.7879 **	7.17
LA	173.9171 **	3.26

** Significant at 0.01 probability level; CV – Coefficient of variation

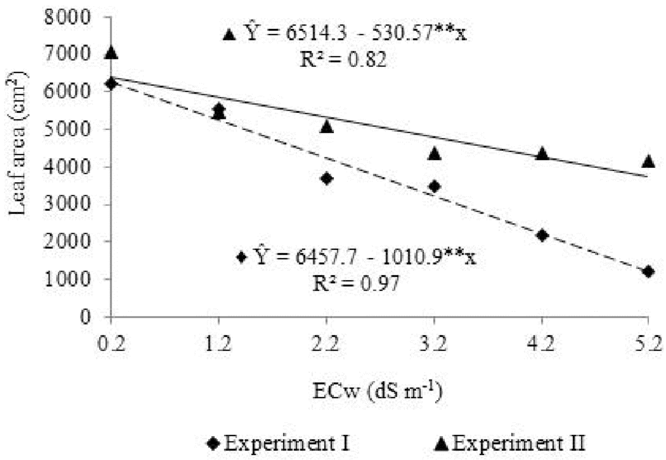

Figure 4. Leaf area of "Americana" lettuce (cv. Tainá) as a function of the electrical conductivity (ECw) of the water used to prepare the nutrient solution

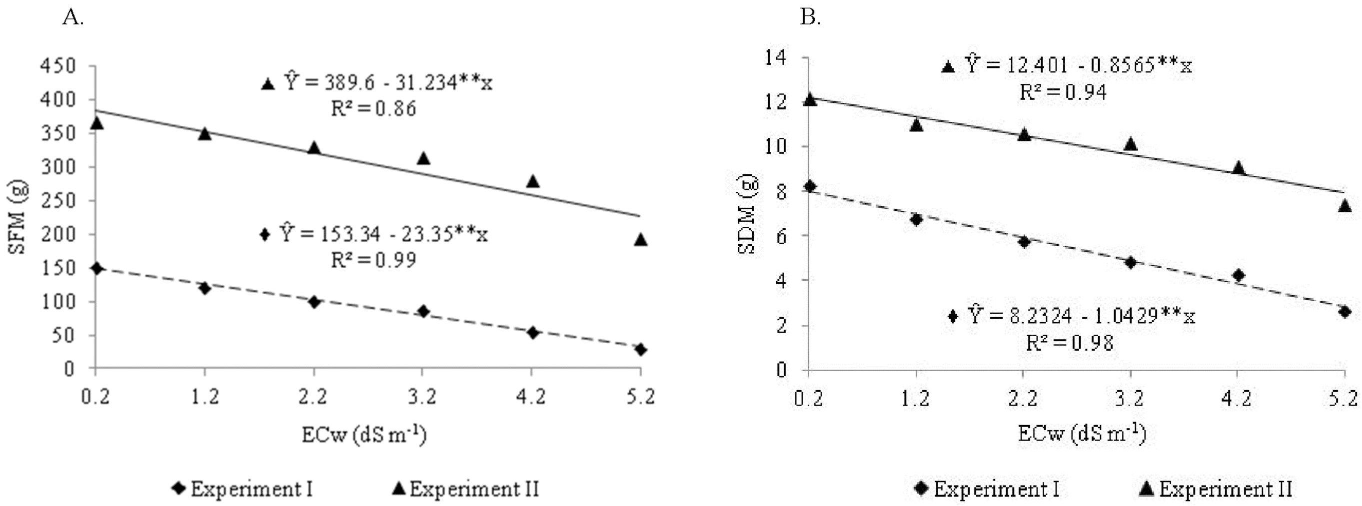

Figure 3. Shoot fresh matter (SFM) (A) and shoot dry matter (SDM) (B) of "Americana" lettuce (cv. Tainá), as a function of the electrical conductivity (ECw) of the water used to prepare the nutrient solution

For leaf area, there were reductions of 15.65 and 8.14% with per unit increase of the salinity levels (Figure 4), in the Experiments I and II, respectively. These results have certainly contributed to the reduction of shoot fresh and dry matter.

The reduction in leaf area is due to the decrease in the volume of plant cells. According to Mittova et al. (2002) and Sultana et al. (2002), the reductions of photosynthesis and leaf area contribute to the adaptation of the crop to saline conditions, so that this reduction in leaf area due to salinity can be a survival mechanism, allowing the plant to save water because of the smaller transpiration area.

Other authors have also observed reduction in leaf area of lettuce as a function of the increase in the salinity of the nutrient solution (Dias et al., 2011; Moraes et al., 2014). Studies on other crops have also shown adverse effects of saline stress on leaf area as a function of increase in saline levels; for instance, Dias et al. (2010) in muskmelon (*Cucumis melo*) and Souza et al. (2010) in physic nut (*Jatropha curcas* L.).

The increase in the salinity level of the nutrient solution caused linear reductions on the water consumption of both experiments, with decreases of 8.8 and 5.6% per dS m^{-1}, in the Experiments I and II, respectively (Figure 5). Soares et al. (2007) reported a linear reduction of water consumption as a function of the increase in the salinity level of the water used in replenishment. The authors observed a decrease of 17.5% in water consumption for a salinity level of 7.46 dS m^{-1}. Reduction in water consumption for lettuce plants with the increase in salinity level was also observed by Viana et al. (2004).

At the end of the cycle, the total water consumption of the plots using supply water (EC_w = 0.2 dS m^{-1}) in the Experiment I was 3.77 L and, for plants subjected to the highest salinity level, this value was reduced to 2.07 L (Figure 5). In the Experiment II, the plots using supply water (EC_w = 0.2 dS m^{-1}) showed total water consumption of 3.84 L and, for plants subjected to the highest salinity level, this value decreased to 2.75 L.

The decrease of water consumption, for the evapotranspiration replenishment using both brackish and supply water, can be explained by the water deficit due to reduction of the osmotic potential under saline conditions, i.e., the absorption of water, which is essential to cell growth, is inhibited by the low water potential around the roots.

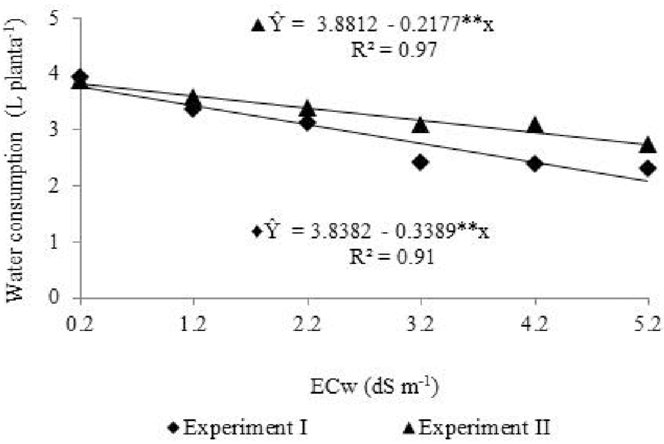

Figure 5. Total water consumption of "Americana" lettuce (cv. Tainá), as a function of the electrical conductivity (ECw) of the water used to prepare the nutrient solution

Conclusions

1. Using brackish water to prepare the nutrient solution resulted in the reduction of the studied growth variables, shoot fresh matter, shoot dry matter and leaf area, regardless of the quality of the water used to replenish the ETc; smaller reductions were found when supply water was used for the replenishment.

2. The replenishment of ETc using supply water promoted stabilization of the electrical conductivity in the nutrient solutions; however, an increase of up to 25.4% was observed for the highest salinity level water when brackish water was used in the replenishment of ETc.

3. Plants in the treatments with the highest salinity level (5.2 dS m^{-1}) and replenished with supply water (EC_w = 0.2 dS m^{-1}) consumed 32.8% less when the ETc was replenished using brackish water (5.2 dS m^{-1}).

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