Revista Ciência Agronômica, v. 50, n. 2, p. 216-222, abr-jun, 2019
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Water and physiological relationships of lettuce cultivated in hydroponics with brackish waters[1]

Relações hídricas e fisiológicas da alface cultivada em hidroponia com águas salobras

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ABSTRACT - Rationalization of brackish water management in hydroponic crops is one of the ways to expand and manage water supply in shortage areas. Thus, this work was carried out to evaluate the water and physiological relationships of Iceberg lettuce (cv. Tainá) in plants exposed to strategies of replacement of the evapotranspired volume of saline nutrient solutions. Two experiments were conducted in NFT hydroponic system, in which increasing levels of water salinity (0.2, 1.2, 2.2, 3.2, 4.2 and 5.2 dS m^{-1}) were used to prepare the nutrient solutions. In the first experiment, the evapotranspired volume was replaced with the respective brackish water and, in the second one, with public-supply water (0.2 dS m^{-1}). Both experiments were set up in a randomized block design, with six treatments and four replicates, totaling 24 experimental plots. It was concluded that using brackish water to prepare the nutrient solution, regardless of whether the evapotranspired volume was replaced with brackish or public-supply water, affected lettuce water and physiological relationships. However, although it caused a reduction in size, the use of brackish water did not cause visual damages that would compromise the commercial appeal of the plants. It was also found that, when water of up to 5.2 dS m^{-1} was used to prepare the solution, the replacement of the evapotranspired volume with public-supply water increased water use efficiency by up to five times.

Key words: *Lactuca sativa*. Water management. Salinity.

RESUMO - As necessidades da racionalização do manejo de águas salobras em cultivos hidropônicos constituem-se formas de ampliar e gerir a oferta hídrica em regiões de escassez. Neste sentido, este trabalho foi realizado com o objetivo de avaliar as relações hídricas e fisiológicas da alface americana (cv. Tainá) em plantas expostas a estratégias de reposição da lâmina evapotranspirada de soluções nutritivas salinas. Para tal, realizaram-se dois experimentos em sistema hidropônico NFT, nos quais utilizaram-se níveis crescentes de salinidade da água (0,2; 1,2; 2,2; 3,2; 4,2 e 5,2 dS m^{-1}) no preparo das soluções nutritivas. No primeiro experimento, a reposição do volume evapotranspirado foi feita com a respectiva água salobra e no segundo, com água de abastecimento (0,2 dS m^{-1}). Adotou-se delineamento experimental em blocos ao acaso com seis tratamentos e quatro repetições totalizando 24 parcelas experimentais. Concluiu-se que o uso de água salobra no preparo da solução nutritiva, independentemente de a reposição da lâmina evapotranspirada ser efetuada com água salobra ou de abastecimento, afetou as relações hídricas e fisiológicas da alface, no entanto, embora tenha ocasionado redução no tamanho, não proporcionou danos visuais que inviabilizassem o apelo comercial das plantas. Verificou-se também que se usando água de até 5,2 dS m^{-1} no preparo da solução, a reposição da lâmina evapotranspirada com água de abastecimento aumentou em até cinco vezes a eficiência do uso da água.

Palavras-chave: *Lactuca sativa*. Gestão dos recursos hídricos. Salinidade.

DOI: 10.5935/1806-6690.20190025
*Author for correspondence
Received for publication on 16/09/2015; approved on 12/06/2018
[1]Parte da Dissertação de Mestrado do primeiro autor apresentada no programa de Pós-Graduação em Engenharia Agrícola da Universidade Federal Rural de Pernambuco/UFRPE; Pesquisa financiada pelo CNPq e pelo INCTsal
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INTRODUCTION

Limited availability and increased demand for water make the planning and management of water resources in semi-arid regions a challenging task (MOURSI; KIM; KALUARACHCHI, 2017). In this context, using the “alternative waters” available and cultivation techniques compatible with the local reality is fundamental to make food production viable (PAULUS *et al*., 2010).

However, the main obstacle in the use of these “alternative waters”, especially brackish waters (GENHUA; RAUL, 2010), is their deleterious effects on crop yield (SUN; LU; WANG, 2016). Thus, hydroponics has been mentioned as a way to allow these waters to be used (SANTOS JÚNIOR *et al*., 2015) and, among the reasons, it has been cited that the energy relationship established by the minimization of matric potential favors the absorption of water and nutrients, at the same saline level, compared with cultivation in soil (SANTOS JÚNIOR *et al*., 2013).

Even under hydroponic conditions, the use of saline nutrient solutions coupled to the replacement with good-quality water must have an effect on the yields of hydroponic crops (ALVES *et al*., 2011), in comparison to the replacement with brackish water, in this case due to the successive supply of salts. Several studies related to the use of brackish waters in hydroponic crops, especially for lettuce, have already been conducted (DIAS *et al*., 2011a, 2011b; PAULUS *et al*., 2010), but the analysis on the water and physiological relationships of this crop under salt stress, despite being fundamental (SILVA *et al*., 2013; TRAVASSOS *et al*., 2012), is still incipient.

It is worth highlighting that plants exposed to salt stress reduce water consumption, as observed by Paulus *et al*. (2012) for lettuce (cv. Verônica), in which salt stress compromised water use efficiency and its relative content. In addition, for restricting the growth of the photosynthetically active area of the plant, it minimizes carbon fixation and consequently biomass production (NEGRÃO; SCHMÖCKEL; TESTER, 2016), thus leading to disadvantages in water and physiological relationships of plants.

Given the above, this study aimed to evaluate the water and physiological relationships of Iceberg lettuce (cv. Tainá) in plants exposed to strategies of replacement of the evapotranspired volume of saline nutrient solutions.

MATERIAL AND METHODS

The study was carried out at the Department of Agricultural Engineering of the Federal Rural University of Pernambuco, in a greenhouse, whose structure is located at geographic coordinates 8°01’05” S and 34°5’48” W, with mean altitude of 6.5 m.

The crop used was Iceberg lettuce (cv. Tainá), grown in hydroponic system in which increasing levels of water salinity (0.2, 1.2, 2.2, 3.2, 4.2 and 5.2 dS m^{-1}) were used to prepare the nutrient solution. These treatments were arranged in a completely randomized design, with four replicates, totaling 24 experimental plots. Two strategies were established to replace the evapotranspired volume: in the first one (Experiment I – February/2013), the volume was replaced using solutions with the respective levels of salinity, according to the treatments; and in the second one (Experiment II - June/2013), the volume was replaced with water from the municipal supply system of Recife-PE.

Regarding the preparation of nutrient solutions, the brackish waters used (ECw = 0.2, 1.2, 2.2, 3.2, 4.2 and 5.2 dS m^{-1}) were obtained by adding NaCl (RICHARDS, 1954) in the public-supply water (EC = 0.2 dS m^{-1}). Then, the quantity of ions proposed by Furlani (1998) specifically for leafy vegetables was solubilized, and the fertilizers used to prepare the nutrient solution were calcium nitrate, potassium nitrate, MAP, magnesium sulfate, copper sulfate, zinc sulfate, manganese sulfate, boric acid, sodium molybdate and EDTA-Fe 13%. After the solution was homogenized, the initial electrical conductivity of the nutrient solution (EC_{sol}), per treatment, was: 1.4, 2.4, 3.0, 4.0, 4.7 and 5.5 dS m^{-1}. During the nursery stage, the nutrient solution was diluted by 50% using water from the municipal supply system.

The type of hydroponic system adopted was the *Nutrient Film Technique* - NFT, whose principle is based on a laminar flow of nutrients. Its structure consisted of 3-m-long, 75-mm-diameter independent trapezoid profiles, which were installed with spacing of 0.25 m between plants and 0.30 m between profiles, at maximum height of 0.85 m in relation to the lower reference plane and 5% slope.

In regard to nutrient solution management, each treatment had one independent tank with volumetric capacity for 50 L and one additional tank, also independent, to replace the evapotranspired volume, with capacity for 15 L. The solution was applied with the aid of an electric pump and an electric timer set to release solution into the system, between 7:00 and 18:00 h, adopting 15-min intervals so that the release of solution lasted 15 minutes as well. At the other times of the day, the timer was set to release solution every 2 hours for 15 minutes.

Sowing was carried out in phenolic foam treated with potassium hydroxide (0.1 N KOH) and, after sowing, the boards were kept in the dark for approximately 24 hours for seed germination. After that, the seedlings were taken to the nursery, where they remained for 15 days. At 15 days after sowing (DAS), they were transplanted to the experimental units and the treatments were established.

The variables analyzed at harvest, at 21 DAT in the first experiment and at 30 DAT in the second experiment, were: water use efficiency in the production of fresh and dry phytomass, which was obtained based on the relationship between fresh or dry matter (measured on commercial scale with two decimal places after drying in the oven at 65 °C until constant weight) and water consumption by the plant (FAGAN *et al*., 2009), according to equation 1:

$$WUE = \left(\frac{\Delta FD}{\Delta CONS} \right) \tag{1}$$

Where: WUE - Water use efficiency (g L^{-1}), ΔFD - Variation of fresh matter obtained at harvest and dry matter obtained after drying in the oven in grams (g), and ΔCONS - Sum of water consumption at the end of the experiment based on readings in liter (L).

Leaf area ratio (LAR), which represents the relationship between total leaf area (LA) and total dry matter (TDM), expressed in square centimeters per gram (BENINCASA, 2003), was also evaluated using equation 2:

$$LAR = \left(\frac{LA}{TDM} \right) \tag{2}$$

In addition, the following parameters were evaluated: water content in the shoots (WCS) and roots (WCR), shoot biomass production index (SBPI), according to the methodology proposed by Benincasa (2003), and root/shoot ratio (R/S), determined using the methodology proposed by Magalhães (1979).

The results of the experiments were subjected to analysis of variance by F test and, when there was significant effect of the treatments (quantitative factor), regression analysis was carried out. All analyses were conducted at 0.05 probability level using the statistical program SISVAR version 5.3 (FERREIRA, 2011).

RESULTS AND DISCUSSION

Regarding nutrient solution electrical conductivity (EC_{sol}), a positive variation of up to 25.4% was observed when evapotranspiration was replaced with brackish water (Figure 1A) and a negative oscillation of 14.2% was observed when public-supply water was used (Figure 1B).

The positive variation of EC_{sol} under replacement with brackish water was due to the successive supply of NaCl, as also observed by Soares *et al*. (2010), who found increased EC_{sol} when brackish water was used to replace the evapotranspired volume. Conversely, under replacement with public-supply water (EC = 0.2 dS m^{-1}), the negative oscillation may be attributed to the removal of nutrients by plants and the consequent reduction of concentration.

Under both replacements of ETc, the pH_{sol} was within the range from 5.5 to 6.5 (Figure 2A and 2B). In sunflower cultivation under salt stress in NFT hydroponic system, Maciel *et al*. (2012) also found a similar trend and, on this subject, Furlani (1999) commented that pH variations within the range from 4.5 to 7.5 do not affect plant development in hydroponic systems.

According to the analysis of variance presented in Table 1, there were significant effects on all variables studied, under both strategies of replacement of evapotranspired volume, except for root/shoot ratio and shoot biomass production index.

Replacement of the evapotranspired volume with either brackish water or public-supply water significantly affected (p>0.01) the WUE-SFM of lettuce plants (Figure 3A).

Figure 1 - Mean values of nutrient solution electrical conductivity (EC_{sol}) under replacement with brackish water (A) and public-supply water (B)

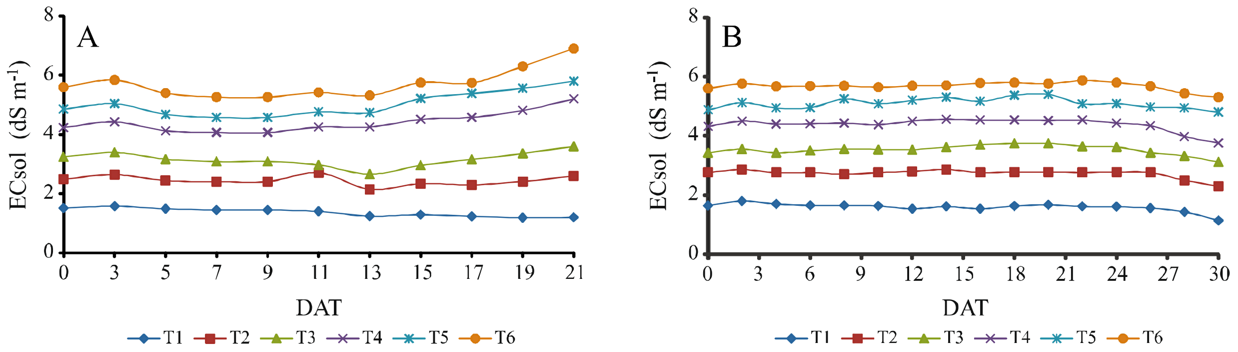


Figure 2 - Mean values of pH in the nutrient solution respectively replaced with brackish water (A) and public-supply water (B)

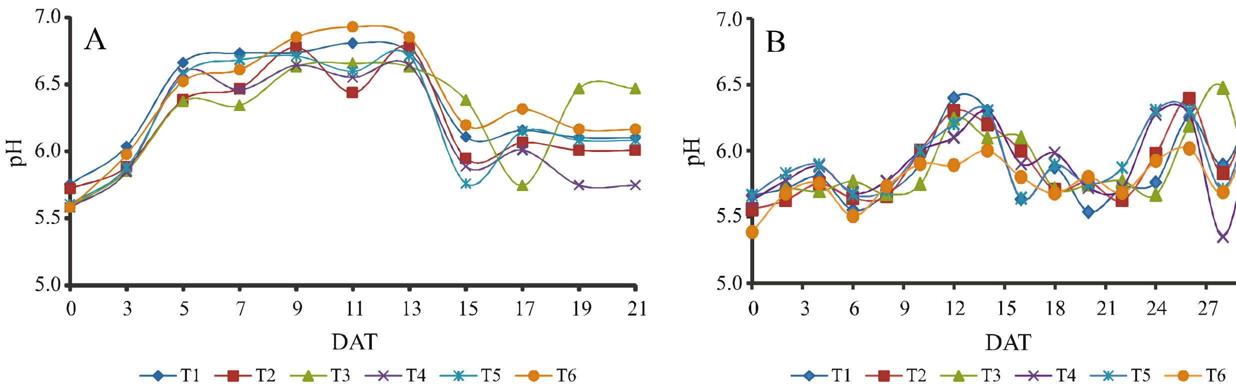


Table 1 - Summary of analysis of variance for water use efficiency in the production of shoot fresh matter (WUE-SFM) and shoot dry matter (WUE-SDM), leaf area ratio (LAR), root/shoot ratio (R/S), shoot biomass production index (SBPI) and water contents in the shoots (WCS) and roots (WCR) of Iceberg lettuce (cv. Tainá) grown in NFT hydroponic system under salt stress as a function of the salinity of the water used to replace the evapotranspired nutrient solution

F Test (Experiment 1 - replacement with brackish water)							
S. V	WUE-SFM	WUE-SDM	LAR	R/S	SBPI	WCS	WCR
ECw	128.7208**	63.2937**	252.7106**	1.3603^{ns}	1.9399^{ns}	64.8341**	6.5890**
Linear Reg.	77.7565**	212.8781**	1153.0422**	0.2274^{ns}	4.1411^{ns}	204.2009**	0.4647^{ns}
Quadratic Reg.	453.6208**	11.0730**	0.0059^{ns}	0.5599^{ns}	1.5778^{ns}	97.6261**	27.5115**
Residual	5.69553	0.00417	173.94444	0.00141	0.00421	4.19316	0.00376
CV (%)	6.59	3.35	2.11	13.81	8.05	2.36	7.08
F Test (Experiment 2 - replacement with public-supply water)							
S. V	WUE-SFM	WUE-SDM	LAR	R/S	SBPI	WCS	WCR
ECw	8.6074**	975.8611**	48.8617**	1.8738^{ns}	1.6577^{ns}	79.1094**	6.5065**
Linear Reg.	4.7262*	4520.0213**	23.9440**	0.0583^{ns}	3.2482^{ns}	322.5352**	1.3808^{ns}
Quadratic Reg.	30.6332**	825.3357**	234.0721**	0.1018^{ns}	2.0610^{ns}	57.0355**	24.0472**
Residual	161.6660	0.00283	224.58333	0.00122	0.00042	3.95265	0.00034
CV (%)	11.32	2.09	3.21	14.22	2.64	2.25	2.08

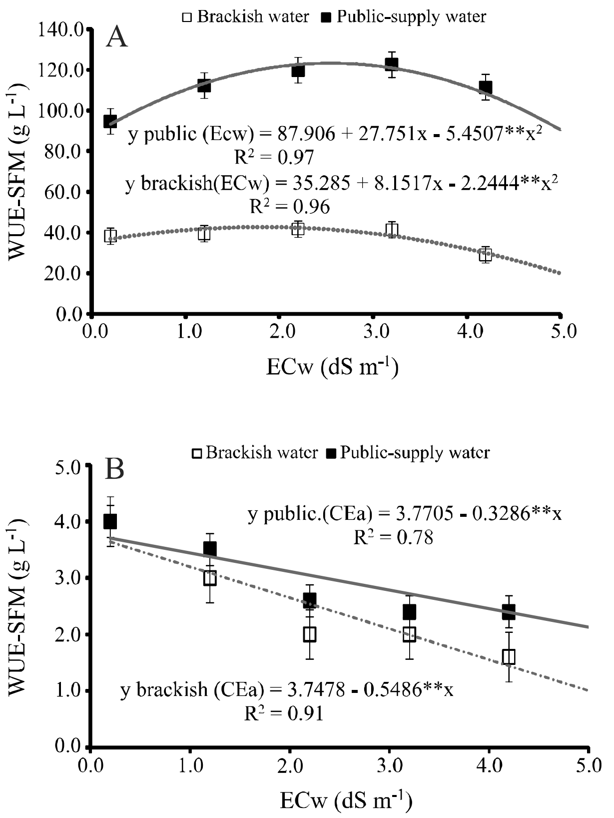
** and * = significant at 0.01 and 0.05 probability levels, respectively. WUE-SFM - Water use efficiency in the production of shoot fresh matter, WUE-SDM - Water use efficiency in the production of shoot dry matter, LAR - Leaf area ratio, R/S - Root/shoot ratio, SBPI - Shoot biomass production index, WCS - Water content in the shoots and WCR - Water content in the roots, ns - not significant

In both cases, the values of efficiency fitted best to a quadratic model so that maximum estimated efficiency in shoot fresh matter production (42.6 g L^{-1}) was obtained at ECw of 1.81 dS m^{-1} when brackish water was used in the replacement and at ECw of 2.54 dS m^{-1} when public-supply water was used.

Taking as reference the highest salinity level tested (5.2 dS m^{-1}), when public-supply water was used in the replacement, the WUE-SFM increased by up to five times in comparison to the replacement with brackish water, i.e., plants under replacement with public-supply water were more efficient in water use.

Regarding water use efficiency in shoot dry matter production (WUE-SDM), at the point represented by 0.2 dS m^{-1} the efficiency is equivalent for both replacement strategies, differentiating from this level on, i.e., for ECw of 5.2 dS m^{-1}, the estimated efficiency was 0.89 g L^{-1} in the replacement with brackish water and 2.061 g L^{-1} in the replacement with public-supply water. This indicates that, for every liter of water consumed, plants under replacement with public-supply water produced 2.93 times more dry matter than those subjected to replacement with brackish water (Figure 3B).

Figure 3 - Water use efficiency in the production of shoot fresh matter (A) (WUE-SFM) and shoot dry matter (B) (WUE-SDM) of Iceberg lettuce (cv. Tainá) grown in hydroponic system as a function of the salinity of the water used to replace the evapotranspired volume of nutrient solution

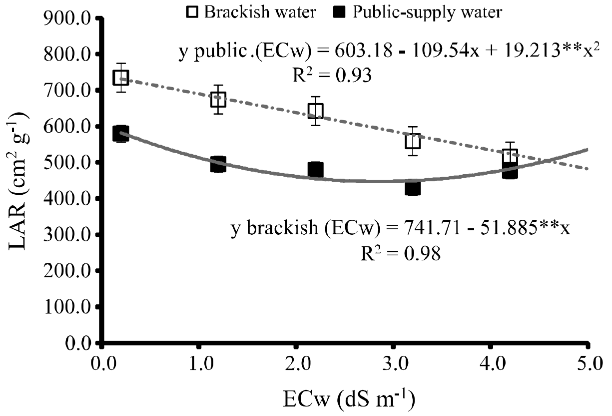


The use of brackish water to replace the evapotranspired volume caused linear reduction of 7.0% per unit increase in EC in leaf area ratio (LAR); however, under replacement with public-supply water, there was a maximum variation of 4.9% in LAR among the ECw levels studied (Figure 4).

Under the effect of salinity, the proportion of leaf area in relation to total dry matter decreased linearly, leading to a reduction in the interface of air and water exchange with the environment to minimize water loss by evapotranspiration, but energy capture for photosynthesis also begins to be compromised.

There is scarce information on LAR behavior in plants under salt stress in hydroponic cultivation.

Figure 4 - Leaf area ratio of Iceberg lettuce (cv. Tainá) grown in NFT hydroponic system under salt stress, as a function of the salinity of the water used to replace the evapotranspired volume of nutrient solution 4.98 8.43



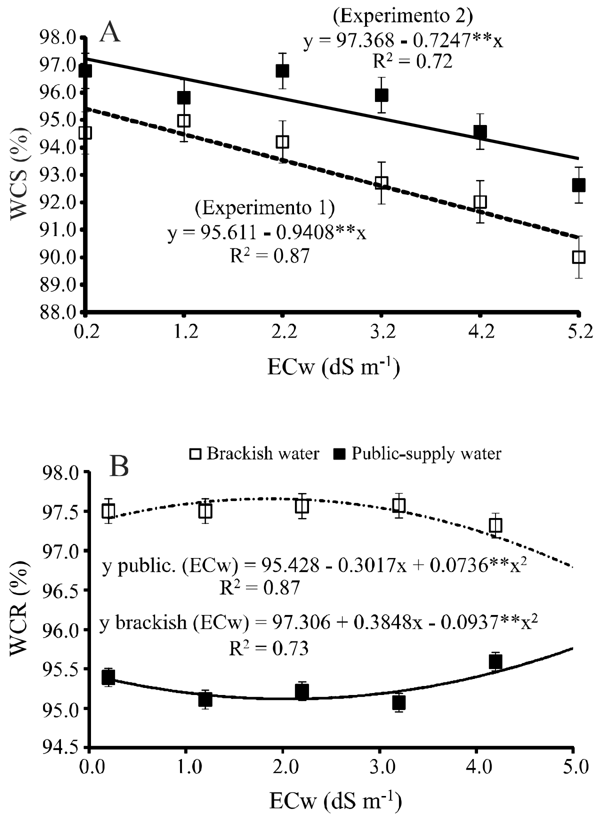
However, Oliveira *et al*. (2012) also observed a reduction (15.8%) in the LAR of cotton grown under saline conditions. Garcia *et al*. (2010), evaluating the responses of bean genotypes to salinity, also noted a reduction (40.4%) in LAR due to the increase in soil saturation extract salinity from 2.50 to 10 dS m^{-1}.

Replacement of the evapotranspired volume with either brackish water or public-supply water significantly affected (p>0.01) the water contents in shoots and roots of Iceberg lettuce (Figure 5).

The water content in the shoots of Iceberg lettuce (cv. Tainá) decreased linearly by 4.93% per unit increase in ECw for the replacement with brackish water and by 3.73% for the replacement with public-supply water (Figure 5A). These results may be attributed to the relationship between the higher salt concentration caused by the replacement with brackish water and the consequent demand for more energy for osmotic homeostasis, which probably led to greater loss in shoot water content.

The results obtained here corroborate those reported by Alves *et al*. (2011), who analyzed strategies of use of brackish water in lettuce production in NFT hydroponic system and observed that increasing levels of salinity in the nutrient solution from 1.45 to 7.5 dS m^{-1} caused greater linear reductions (2.28%) in the water content of 'Verônica' curly lettuce shoots when brackish water was used to prepare the nutrient solution and replace the evapotranspired volume; likewise, when public-supply water was used to replace the losses by evapotranspiration, lower linear reduction was obtained (1.34%).

Figure 5 - Water contents in the shoots (A) and roots (B) of Iceberg lettuce (cv. Tainá) grown in NFT hydroponic system under salt stress, as a function of the salinity of the water used to replace the evapotranspired volume of nutrient solution



In a general analysis on WCS, it can be inferred that plants subjected to the lowest ECw levels evapotranspired more and kept higher water content in the shoots, i.e., the metabolism related to water and nutrients was higher along the entire cycle. The shoots of plants subjected to more saline treatments tend to have tissues that are thicker and richer in organic and inorganic substances per leaf area unit, with lower water content, as part of the strategy of the plant to reduce water losses, since the reduction of osmotic potential requires greater energy expenditure to absorb water and nutrients necessary for its development.

In relation to water content in the roots, the data fitted to a quadratic model (p>0.01). Under replacement with brackish water, plants reached maximum water content in the roots (97.70%) at 2.0533 dS m^{-1} and a reduction occurred from this point on. On the other hand, under replacement with public-supply water, a minimum water content (95.11%) was estimated at 2.0495 dS m^{-1} with a subsequent trend of increase (Figure 5B). Although higher water content in the roots was observed under replacement with brackish water, which may be attributed to the greater need for osmotic adjustment due to the higher salt concentration, the WCR under both strategies of nutrient solution replacement were higher than 95%.

Iceberg lettuce production was possible using brackish water to prepare the nutrient solution, since no visual characteristics such as burn or other damages were observed, but there was a reduction in plant size. Thus, it can be considered as a viable alternative for the production in hydroponic system and freshwater saving, especially in regions where this type of water prevails.

CONCLUSIONS

1. The use of brackish water to prepare the nutrient solution, regardless of whether the evapotranspired volume was replaced with brackish or public-supply water, affected the water and physiological relationships of Iceberg lettuce in hydroponic cultivation;
2. When water of up to 5.2 dS m^{-1} was used to prepare the nutrient solution, the replacement of the evapotranspired volume with public-supply water increased by up to five times the water use efficiency of Iceberg lettuce (cv. Tainá);
3. Although there was a reduction in the size of lettuce plants, the use of brackish water to prepare the nutrient solution under replacement with either brackish or public-supply water did not lead to visual damages and, therefore, did not compromise the commercial appeal of the plants.

ACKNOWLEDGMENTS

The authors thank the Pernambuco Research Support Foundation (FAPECE), CNPq, and CAPES for the scholarships and INCTSal/CNPq for the support to conduct the study.

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