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CONSUMPTION, EFFICIENCY AND WATER CONTENT OF ARUGULA UNDER DIFFERENT MANAGEMENT OF BRACKISH NUTRITIONAL SOLUTIONS

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KEYWORDS

Eruca sativa, cultivation without soil, salinity.

ABSTRACT

The need to use strategies for using brackish water in agriculture, especially in semi-arid conditions, is evident. Based on this information, this study was developed with the aim of evaluating the consumption, efficiency and water content, as well as the dry mass of the arugula plants (cv. Broad Leaf) exposed to brackish nutrient solutions as a function of replacement strategies and circulation frequencies. The treatments consisted of six salinity levels of the nutrient solution (1.5, 3.0, 4.5, 6.0, 7.5 and 9.0 dS m-1) and two circulation frequencies (twice a day 8 a.m. and 4 p.m., and three times a day at 8 a.m., 12 p.m. and 5 p.m.). In Experiment I, the evapotranspiration line was replaced with the respective brackish water used in the preparation of the solution, and in Experiment II, the water supply was used. In both treatments, the experimental design was completely randomized, in a 6 x 2 factorial scheme, with five replications. The conclusion is that it is technically feasible to circulate the nutrient solution twice a day and there were lower losses in the water relations, in the biomass production of the shoot and in the partition of photoassimilates when the replacement with water supply was adopted.

INTRODUCTION

In the context of the Brazilian semi-arid region, the low availability of surface water with compatible quality for irrigation constitutes one of the obstacles for the development of the agricultural sector, triggering socioeconomic losses, mainly in the context of family farming (Alves et al., 2011).

The lack of water is even more damaging when contextualized to the insufficiency of technical assistance and inputs, making indispensable the use of technologies developed and/or adapted to the hydrological, climatic, edaphic, land, infrastructure, and other characteristics of the semi-arid region. In this way, several researches (Alves et al., 2011, Maciel et al., 2012, Santos, et al., 2010) highlight the technical viability of the hydroponic crop for this region of Brazil and suggest its improvement aiming at the use of brackish water in the production of vegetables and flowers as an alternative to generate the income in diffuse communities (Santos Júnior et al., 2016).

While the elevation of salinity in the root environment impairs the nutrient absorption and reduces the plant evapotranspiration, it also negatively affects the crop production (Silva et al., 2012). In the hydroponic crops, this energy ordering is reorganized, because the matrix potential tends to be zero, which makes the energy balance mainly function of the osmotic potential, that is, at the same saline level, there is less damage to the hydroponic plants than in soil conditions (Santos Júnior et al., 2016).

In the case of leafy vegetables, whose socioeconomic role is relevant in the context of small farmers who use family labor, several studies evaluate the feasibility of using brackish water under hydroponic conditions (Paulus et al., 2012; Nunes et al., 2013; Rebouças et al., 2013; Bione et al., 2014; Santos Júnior et al., 2014).

In addition, in the case of arugula, when salinity tolerance is considered moderately sensitive, already developed studies (Oliveira et al., 2013, Souza Neta et al., 2013, Silva et al., 2013) also prove the feasibility of using brackish water in their cultivation under hydroponic conditions, yet there are still insipient studies that recommend other strategies for the use of these waters and the management of brackish nutrient solutions, related to the water relations bias in the scope of consumption and water use efficiency, justified by the qualitative scarcity but

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also quantitative of water resources in the semi-arid environment.

Based on this information, this study was developed with the aim of evaluating the consumption, efficiency and water content, as well as the dry mass of the arugula plants (cv. Broad Leaf) exposed to brackish nutrient solutions as a function of replacement strategies and circulation frequencies.

MATERIAL AND METHODS

The experiments were carried out between September and December 2016, under greenhouse conditions, linked to the Department of Agricultural Engineering of the Federal Rural University of Pernambuco - DEAGRI/UFRPE, in Recife-PE, (8º 01’ 05” south latitude and 35º 56’ 48” west longitude, and average elevation of 6 m). The climate of the place was classified as As, according to Köppen classification, tropical megathermal, with annual average rainfall of 1,501 mm, average temperature of 26ºC and average relative humidity of 76% (Brasil, 1992).

In the experimental environment, the temperature and relative humidity were monitored daily, with a maximum average temperature of 37.4ºC and a minimum of 32.2ºC, as well as an average RH of 61.4% and a minimum of 44.5%.

The experimental design was completely randomized, in a 6 x 2 factorial scheme, with five replications, totaling 60 experimental units. The treatments consisted of six salinity levels of the nutrient solution (1.5, 3.0, 4.5, 6.0, 7.5 and 9.0 dS m^{-1}) and two circulation frequencies (twice at 8 a.m. and 4 p.m., and 3 times a day at 8 a.m.,12 p.m. and 5 p.m.). These treatments were replicated in two experiments carried out in sequence; in the first one, the replacement of the evapotranspiration line was performed with the respective brackish water used in the preparation of the nutrient solution and, in the second experiment, with the water supply (0.12 dS m^{-1}).

The hydroponic system used consisted of a wooden support waterproofed with oil paint, with dimensions of 6.00 x 1.40 m, designed with capacity for 12 PVC pipes with 6 m of length and 100 mm of diameter, in level. In the tubes, circular ‘cells’ of 60 mm diameter were drilled, equally spaced every 20 cm, considering the central axis of each cell.

At the end of the tubes, elbows were coupled, and a tap was added to one of the elbows for water outlet, inducing the permanence of a level of 4 cm throughout the length of the tube, aiming at the equitable and uniform distribution of the solution to the plants (Santos Júnior et al., 2016).

The crop adopted was the arugula (*Eruca sativa*), cv. Broad leaf. The sowing was carried out in 180 ml disposable plastic cups drilled on the sides and bottom, which were filled with coconut fiber substrate; after the sowing, the daily watering (0.12 dS m^{-1}) was applied in the morning and in the afternoon with water supply until 15 days after sowing (DAS), when the transplanting was performed. The germination cups, with seedlings and substrate, were then inserted into the tubes according to previously established treatments.

In relation to the preparation of the nutrient solution, initially twelve different reservoirs were filled with 90 L of water supply (EC 0.12 dS m^{-1}) and then, based on the empirical equation of Richards (1954), the NaCl quantitative for the establishment of saline levels was calculated and solubilized, and after, the same amount of fertilizers proposed by Furlani et al. (1999) in all treatments was solubilized.

Regarding the management of the nutrient solution, with the specific frequency of each treatment, it was applied daily and manually twice the capacity of each tube, in order to homogenize and aerate the solution. The replacement of the evapotranspiration nutrient solution line was carried out every seven days, and the electrical conductivity (EC_{ns}) and the pH_{ns} of the nutrient solution were monitored daily.

It was evaluated at the end of the culture cycle (45 DAS): (*i*) water consumption (HC), based on the sum of weekly replenishments; (*ii*) the efficiency of water use in the production of fresh (EWU-FPS) and dry (EWU-DPS) phytomass of the shoot, through the relation between the fresh and dry mass produced in the shoot and the water consumption by plant; (*iii*) the water content in the plant (WCP), in the shoot (WCS) and the root (WCR), according to Benincasa (2003); (*iv*) the shoot biomass production index (SBPI), according to Benincasa (2003); and (*v*) the root shoot relation, according to Magalhães (1979). At the end of the cycle, the photo assimilate partition was also evaluated in the shoot and in the root according to Magalhães (1979).

The results were submitted to the normality test and the analysis of variance through the F test. When the significance of the interaction between the treatments was observed, the statistical analysis was performed and its discussion was prioritized. In the other cases, the salinity levels of the nutrient solution were compared by regression analysis and the nutrient solution circulation frequencies using the Tukey test. All analyzes were carried out using the statistical software Sisvar (Ferreira et al., 2011) at significance level of 0.05 probability.

RESULTS AND DISCUSSION

Under the replacement of the evapotranspirated level with brackish water, there was an increase of EC_{ns} at all saline levels tested, with a maximum variation of 14 and 13.32%, when two and three circulations of the nutrient solution were adopted daily, respectively, under the initial EC_{ns} of 9 dS m^{-1}; however this EC_{ns} represented the highest osmotic potential tested and, consequently, the lower rate of water and nutrient absorption by the plants, similarly, it also corresponded to the higher contribution and accumulation of salts from the brackish water used in the replacement. In this tonic, the pH variation did not exceed 15% of the initial values, independent of the EC_{ns} or the circulation frequency of the nutrient solution.

The water supply replenishment (EC = 0.12 dS m^{-1}) implied a reduction in the concentration of salts and a decrease in the initial EC_{ns} in the respective treatments, naturally under EC_{ns} of 1.5 dS m^{-1}, a higher absorption rate of water and nutrients occurred, and the highest decreases were observed - 15.6 and 14.4%, when two and three circulations of the nutrient solution per day were adopted, respectively. This removal/dilution of the bases, evidently, caused a tendency of decrease in the pH of the nutrient solution, being verified a maximum decrease of 20%. In general analysis, the variation of EC_{ns} and pH_{ns} were within the predicted for each treatment proposed.

The osmotic potential, corresponding to the respective electrical conductivity of the nutrient solution (EC_{ns}) tested, naturally influenced the water consumption (WC). In empirical analysis, the accumulation of salts resulting from the replacement by brackish water (Figure 1A) resulted in lower water consumption, while the dilution of the salts verified by replenishment with water supply (Figure 1B) enabled higher average water consumption by plants.

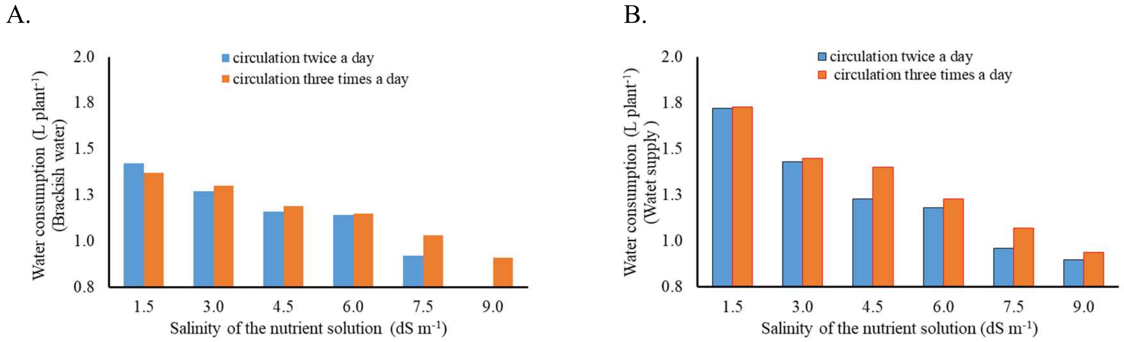

FIGURE 1. Average water consumption of arugula plants (cv. Broad leaf) under replacement of the evapotranspirated level (A) with brackish water and (B) with water supply. Average results for plants exposed to brackish nutrient solutions under replacement strategies and circulation frequencies.

Empirically, there was a tendency of greater water consumption with the increase of the circulation frequency of the nutrient solution, under both strategies adopted, due to among other aspects, to the higher oxygenation and lower average saline concentration of the nutrient solution obtained by the most frequent homogenization. When comparing the effect of the circulation frequencies, the greatest difference in average water consumption was observed in the EC_{ns} of 4.5 dS m^{-1} (17.58%) under replacement with brackish water and in the EC_{ns} of 9.0 dS m^{-1} (12.14%) under water supply.

Under the replacement of the evapotranspirated level with brackish water, the EC_{ns} influenced ($p < 0.01$) the variables EWU-FPS, EWU-DPS, WCP, WCS and WCR, and there was no influence ($p > 0.05$) isolated of the circulation frequency, however, there was a significant effect ($p < 0.05$) of the interaction between the treatments for the EWU-DPS. Under replenishment with water supply, the EC_{ns} had a significant effect on EWU-FPS, EWU-DPS and WCS, as well as the frequency of circulation and interaction between treatments under ($p < 0.05$) EWU-FPS (Table 1).

TABLE 1. F Test for the efficiency of water use in the production of fresh and dry phytomass of shoot, water content in the plant, in the shoot and in the root of arugula plants (cv. Broad leaf) exposed to salty nutritive solutions under replacement strategies and circulation frequencies.

Source of variation	DF	F test									
		EWU – FPS		EWU - DPS		WCP		WCS		WCR	
		BW	WS	BW	WS	BW	WS	BW	WS	BW	WS
Salinity (S)	5	**	**	**	**	**	ns	**	**	**	ns
Linear Regression	1	**	**	**	**	**	ns	**	**	**	ns
Quadratic Regression	1	ns	**	ns	**	*	ns	*	*	*	ns
Frequency (F)	1	ns	**	ns	ns	ns	ns	ns	ns	ns	ns
Interaction S x F	5	ns	**	**	ns	ns	ns	ns	ns	ns	ns
Residue	48	48	48	48	48	48	48	48	48	48	48
CV	%	11.51	8.07	10.98	9.12	3.40	3.72	3.96	3.37	3.93	4.16

DF = degree of freedom; CV = coefficient of variation; ** = significant at 0.01 probability; * = significant at 0.05 probability; ns = not significant. EWU - FPS and EWU - DPS = efficiency of water use in fresh and dry phytomass production of shoot, respectively; WCP, WCS and WCR = water content in the plant, in the aerial part and in the root, respectively. BW = replacement with the respective brackish water and WS = replacement with water supply. Transformation in $(X + 0.5)^{0.5}$.

In relation to EWU-FPS, under replacement with brackish water, there was a linear decrease at the ratio of 1.261 g L^{-1} with the unit increment of EC_{ns}; in this scenario of water use efficiency reduction, a loss of up to 74.95% was observed in the saline range studied (Figure 2A). Silva et al. (2012), working with arugula cultivar in the NFT system, verified more pronounced reductions for each dS m^{-1} increased in relation to these results, probably due to different climatic and experimental conditions.

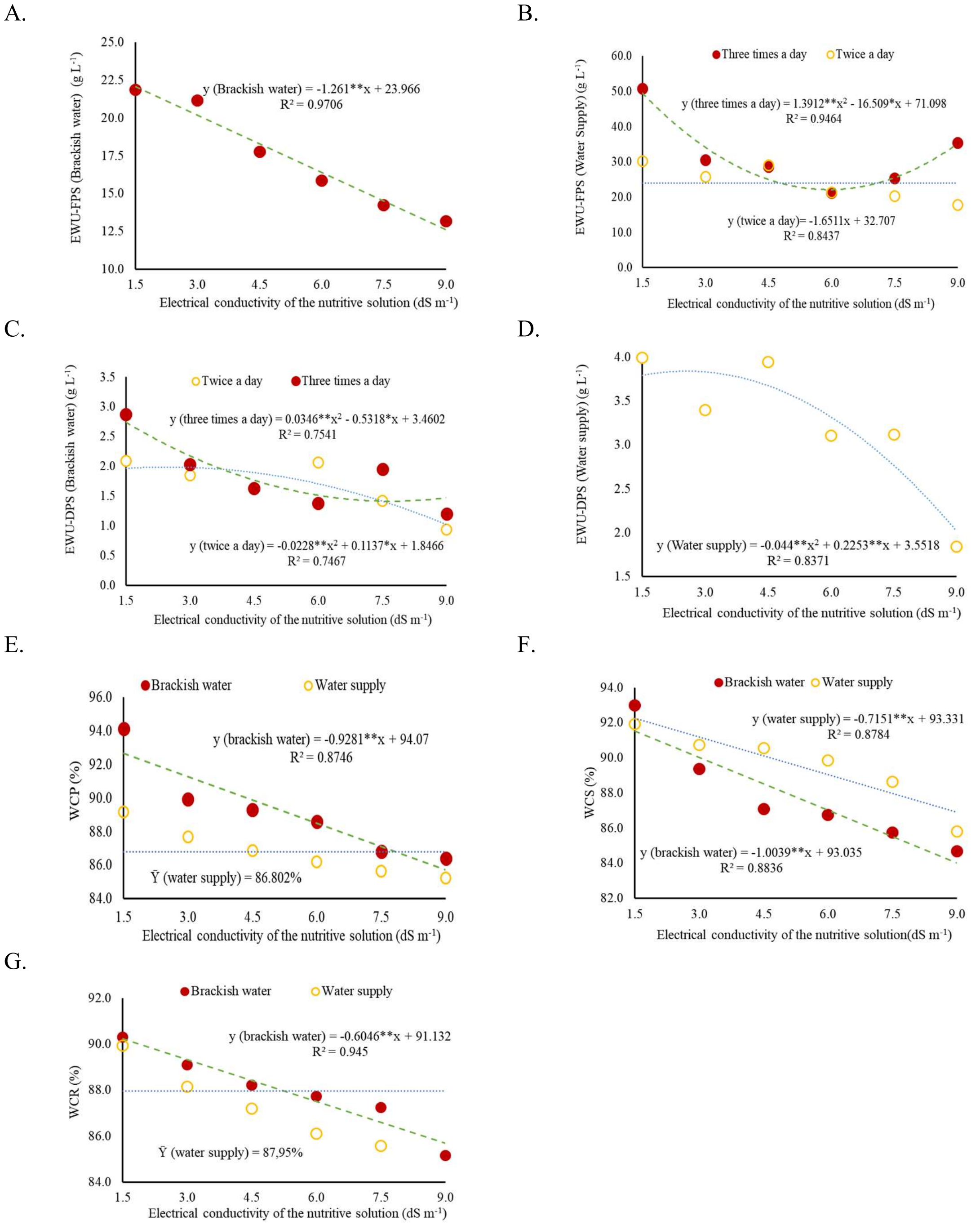

FIGURE 2. Efficiency of water use for fresh and dry phytomass (A and B) (C and D); (E) water content in the plant, (F) in the shoot and (G) in the root. Results for arugula plants (cv. Broad leaf) exposed to brackish nutrient solutions under replacement strategies and circulation frequencies.

Under replenishment with water supply, after analysis of the interaction between treatments, no significant effect (p>0.05) was observed when the solution was circulated twice daily with an average of 24.038 g L^{-1}; under 3 circulations per day, the EWU-FPS was adjusted to the quadratic model, being estimated maximum (49.46 g L^{-1}) and minimum (22.12 g L^{-1}) point under 1.5 and 5.93 dS m^{-1}, respectively (Figure 2B). It is likely that the increase of EWU verified from 6 dS m^{-1} may be a result of the combination between the maintenance of the biomass produced in previous phases of the cycle and the reduction of water consumption due to the increase in the osmotic potential.

When adopting two circulations per day, the EWU-DPS was maximum (1.9883 g L^{-1}) for the EC_{ns} estimated at 2.49 dS m^{-1} and minimum (1.0231 g L^{-1}) for 9.0 dS m^{-1}; as well as for three circulations per day, the values of maximum (2.74 g L^{-1}) and minimum (1.41 g L^{-1}) were estimated in the EC_{ns} of 1.5 and 7.68 dS m^{-1}, respectively (Figure 2C). In research with cilantro under salt stress in hydroponics, using brackish water in the replacement of the evapotranspirated level, Silva (2014), when increased the circulation frequency, also observed an increase in EWU-DPS (3.44 and 3.35 g L^{-1}); naturally that the absolute EWU-DPS values of arugula are lower than those of cilantro for reasons of physiological order.

Under replenishment with water supply, the EWU-DPS results were adjusted to the quadratic model ($p < 0.01$), so that the maximum efficiency (3.8402 g L-1) was estimated for ECns of 2.56 dS m^{-1}, successively lower values were verified until the EC_{ns} of 9.0 dS m^{-1}, in which the minimum EWU-DPS (2.5518 g L^{-1}) was estimated (Figure 2D). Silva (2014), found that the use of brackish water and water supply (EC = 0.32 dS m^{-1}) in cilantro crop, both for the preparation of the nutrient solution and for the replacement of the volume consumed, resulted in a reduction in EWU- DPS in 19.19% and 13.13%, respectively, that is, values lower than those of this study.

The WCP, under replacement with brackish water, decreased ($p < 0.01$) by up to 8.12% when considering the salt interval from 1.5 to 9.0 dS m^{-1} (Figure 2E). Studying the hydrous consumption of arugula in hydroponic NFT cultivation using waste from a desalter in Ibimirim-PE, Silva et al. (2012) estimated the WCP in 85.36% for the water EC of 3.2 dS m^{-1}, which is lower than the WCP observed in the plants under 9.0 dS m^{-1} in this study. This reduction can be attributed to the reduction of water consumption and to the successive physiological and biochemical processes required for the osmotic adjustment inside the plant (Soares et al., 2010).

As for WCS, under replacement with brackish water, there was a reduction ($p<0.01$) of 8.96% in the studied range and a decrease of 1.0039% with a unit increase of the EC_{ns} (Figure 2F). When the replenishment was adopted with water supply, the total loss was estimated at 6.17%. In another analysis, Paulus et al. (2010) also verified a decrease in water content in lettuce tissues (cv. Pira Roxa and Verônica) in hydroponics, using brackish water in the replacement of the evapotranspiration line, as well as Silva et al. (2013), studying the hydroponic cultivation of arugula (cv. Broad leaf) under saline nutrient solution up to 10.5 dS m^{-1}, estimated a decrease of 1.88% in each dS m^{-1} increased to the water used in the preparation of the solution nutritious.

In relation to the WCR, when the brackish water was used, there was a unit decrease of 0.8587%, totaling a variation of 7.72% in the proposed saline range (Figure 2G).

In general terms, under the replacement with brackish water, there was variation of up to 8.12; 8.96 and 7.72% in WCP, WCS and WCR, respectively, while under the replacement with water supply, the average values were 86.802% for the WCP, there was a decrease in the proposed salt interval of 8.96% for WCS and an average of 87.95% for WCR. Probably, the successive accumulation of soluble salts in the organs of the plant reduced the efficiency of the osmotic adjustment, reducing the water content in the various parts of the plant (Nascimento et al., 2015).

Regardless of the strategy of the replacement of the evapotranspirated level, the behavior of SBPI, the r R/S, PPS and PPR were influenced ($p<0.01$) by the salinity of the nutrient solution, while the circulating frequencies of the solution and the interaction between the treatments did not cause the same (Table 2).

TABLE 2. F Test for the biomass index of the shoot, root and shoot relation, photoassimilate partition in the shoot and in the root of arugula plants (cv. Broad leaf) exposed to brackish nutritive solutions under strategies of replacement and frequency of circulation.

Source of variation	DF	F test							
		SBPI		r R/S		PPS		PPR	
		BW	WS	BW	WS	BW	WS	BW	WS
Salinity (S)	5	**	**	**	**	**	**	**	**
Linear Regression	1	**	**	**	**	ns	**	**	**
Quadratic Regression	1	ns	ns	ns	ns	ns	ns	ns	ns
Frequency (F)	1	ns	ns	ns	ns	ns	ns	**	ns
Interaction S x F	5	ns	ns	ns	ns	ns	ns	**	ns
Residue	48	48	48	48	48	48	48	48	48
CV	%	7.55	8.18	3.63	6.28	6.60	5.80	7.97	5.87

DF = degree of freedom; CV = coefficient of variation; ** = significant at 0.01 probability; * = significant at 0.05 probability; ns = not significant. BW = replacement with the respective brackish water and WS = replacement with water supply. SBPI = shoot biomass production index; r R/S = Root/shoot ratio; PPS = Photoassimilates Partition of shoot; PPR = Photosimilates Partition in the root; BW = replacement with the respective brackish water and WS = replacement with water supply. Transformation in $(X + 0.5)^{0.5}$.

As for the SBPI, under replacement with brackish water, values of up to 0.9122 were estimated in plants under initial EC_{ns} of 1.5 dS m^{-1} ($p < 0.01$). In the proposed salt interval, the losses totaled 37.23%, so that the estimated reduction per unit increase of the EC_{ns} was 0.033. Under replacement with supply water ($p < 0.01$), a decrease of 0.0431 per unit increment of EC_{ns} and total losses in the studied range of 48.10% were estimated (Figure 3A).

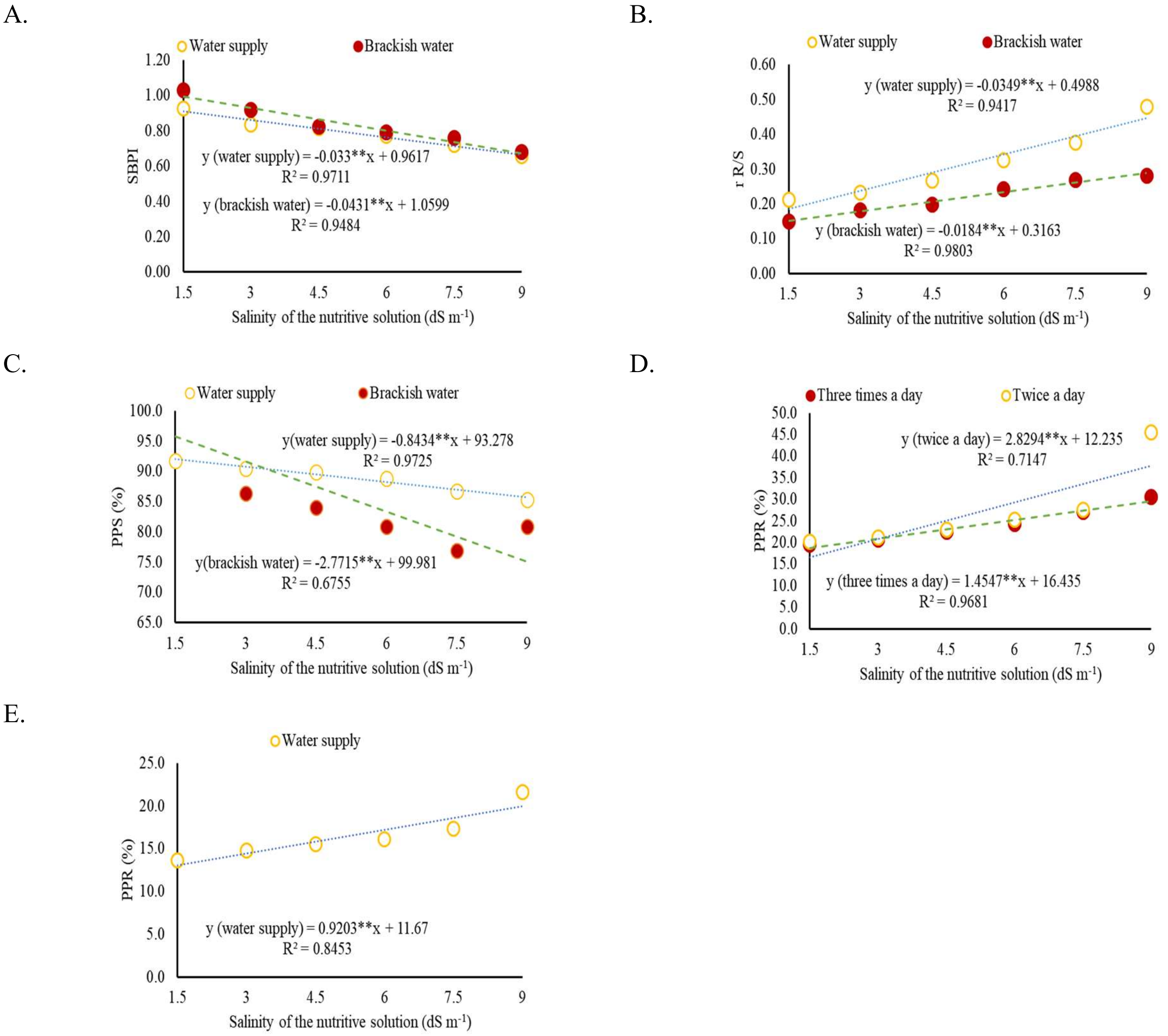

FIGURE 3. (A) Shoot biomass production index, (B) root/shoot ratio, (C) photoassimilates partition of shoot and (D and E) of the root. Results for arugula plants (cv. Broad leaf) exposed to brackish nutrient solutions under replacement strategies and circulation frequencies.

In relation to r R/S, when the replacement with brackish water was adopted, the variation of the EC_{ns} had a significant effect ($p < 0.01$) with a growth estimate of 47.80% within the proposed saline range, and an increase of 0.0184 was estimated per unit increase of the EC_{ns}. Under replenishment with water supply ($p < 0.01$), the estimated increment per unit increment of EC_{ns} was 0.0349 (Figure 3B). This result can be caused by the maintenance of the root mass and reduction of the mass of the shoot imposed by the osmotic effect (Sá et al., 2013), including Silva et al. (2013), studying the use of saline nutrient solution in hydroponic cultivation of the arugula (cv. Broad Leaf), prepared in water supply, also verified linear growth in the root/shoot relation, varying 0.003 for each unit increase in salinity.

Regarding the PPS, when compared to brackish water replacement ($p < 0.01$), losses of up to 27.70% were estimated in the comparison between plants under the highest and lowest EC_{ns} used in this study, with losses of 2.77% per unit increase of the EC_{ns}. Under replenishment with water supply ($p < 0.01$), a reduction of 12.10% in PPS was estimated when considering the plants under EC_{ns} of 1.5 and 9 dS m^{-1}, with losses of 1.32% through increase in salinity unit (Figure 3C). Possibly, the changes in the percentage distribution of the dry mass of the shoot were provoked by the saline stress, which is consistent with the fact that the increase of the salinity in the solution, besides reducing the biomass production, can also change the dry mass partition between different parts of the plants (Silva et al., 2003).

In the PPR analysis, under replacement with brackish water, after analysis of the interaction between the treatments, there was an increase of 43.71%, when two circulations of the solution per day were adopted, and an increase of 63.05% with three circulations per day, under the same EC_{ns} (Figure 3D). In the conditions, the prioritization of the photoassimilates distribution to the roots is evident, which is probably due to the need of the development of the root system in search of nutrients in a stress environment (Taiz & Zeiger, 2013).

When the replenishment was performed with water supply ($p < 0.01$), there were PPR values estimated at 14.09; 14.22; 14.97; 16.35; 18.36 and 20.99% in plants under EC_{ns} of 1.5; 3.0; 4.5; 6.0; 7.5 and 9.0 dS m^{-1}, respectively; that is, an increase of up to 32.86% in the PPR of the arugula due to the variation of the salinity (Figure 3E).

In studies with arugula (cv. Broad leaf) under salt stress, with solution prepared and replenished with water supply in NFT system, Silva et al. (2013) estimated that it is possible to obtain yields without loss of relative yield using saline waters in hydroponic cultivation of arugula up to 2.75 dS m^{-1} salinity. In general analysis, in this study, when water of 3.0 dS m^{-1} was used in the preparation of the nutrient solution (EC_{ns} of 4.5 dS m^{-1}), even under replacement with brackish water, there were losses but the results were still satisfactory.

CONCLUSIONS

1. There were lower losses in the consumption, efficiency and water content and in the production of biomass of the shoot in the arugula, when the replenishment with water supply was adopted;
2. The consumption and the efficiency of water use were reduced by the saline increment, independently of the strategy of replacement of the evapotranspirated level;
3. The saline stress caused a greater accumulation of dry mass in the root to the detriment of the aerial part;
4. Technically, it is feasible to recirculate the nutrient solution twice a day.

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