ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.27, n.9, p.736-745, 2023
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v27n9p736-745

Hydroponic coriander grown under nutritional solutions prepared with brackish water of different cation prevalence[1]

Coentro hidropônico cultivado sob soluções nutritivas preparadas em águas salobras com diferentes prevalências catiônicas

Franz E. C. Navarro[2], Ivis A. C. e Silva[2*], José A. Santos Júnior[2], Tarcísio F. de Oliveira[2], Gerônimo F. da Silva[2] & Ênio F. de F. e Silva[2]

[1] Research developed at Universidade Federal Rural de Pernambuco, Programa de Pós-Graduação em Engenharia Agrícola, Recife, PE, Brazil
[2] Universidade Federal Rural de Pernambuco/Programa de Pós-Graduação em Engenharia Agrícola, Recife, PE, Brazil

HIGHLIGHTS:
The cationic nature has no effect on the water consumption of coriander grown under nutrient solution with high salinity.
The use of waters with prevalence of Mg^{2+} result in greater leaf area in coriander.
The production and water relations of coriander decrease when grown on brackish water.

ABSTRACT: The use of brackish water for preparation of nutrient solutions has several impacts on crop performance, depending on the water concentration and cation prevalence. Therefore, this study was conducted to evaluate production and water relations of coriander grown on nutrient solutions prepared with brackish waters with different cationic natures under hydroponic conditions. A randomized block experimental design with four replicates was used, in a 4 × 3 factorial arrangement. The treatments consisted of four electrical conductivities of the nutrient solution (1.6, 3.2, 4.8, and 6.4 dS m^{-1}) which were prepared in waters with different salts (NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$). Salinity negatively affected the production and water relations of coriander grown in hydroponic system; plants grown on nutritive solutions with predominance of Na^+ had higher total dry weight and shoot dry weights, as well as higher stomatal conductance. The largest leaf area was found when using the nutrient solution with predominance of Mg^{2+}.

Key words: *Coriandrum sativum* L., soilless cultivation, salinity

RESUMO: O uso de águas salobras no preparo de soluções nutritivas tem diferentes impactos no desempenho das culturas, dependendo da concentração e prevalência catiônica da água. Portanto, este estudo foi realizado com o objetivo de avaliar a produção e as relações hídricas do coentro cultivado em soluções nutritivas preparadas com águas salobras de diferentes naturezas catiônicas em condições hidropônicas. O delineamento experimental adotado foi de blocos ao acaso, analisado em esquema fatorial 4 × 3, com quatro repetições. Os tratamentos consistiram de quatro níveis de condutividade elétrica da solução nutritiva (1,6; 3,2; 4,8 e 6,4 dS m^{-1}) que foram preparadas em águas salinizadas com diferentes sais (NaCl; $CaCl_2.2H_2O$ e $MgCl_2.6H_2O$). A salinidade afetou negativamente a produção e as relações hídricas do coentro cultivado em sistema hidropônico; verificou-se que as plantas submetidas às soluções nutritivas com predominância de Na^+ tiveram maior produção de massa seca total e massa seca da parte aérea, bem como maior gs; assim como a maior área foliar foi obtida utilizando solução nutritiva com predominância de Mg^{2+}.

Palavras-chave: *Coriandrum sativum* L., cultivo sem solo, salinidade

• Ref. 269981 – Received 28 Nov, 2022
* Corresponding author - E-mail: ivisandrei@gmail.com
• Accepted 03 Jun, 2023 • Published 11 Jun, 2023
Editors: Ítalo Herbet Lucena Cavalcante & Walter Esfrain Pereira

Introduction

The transition from conventional cultivation systems in soils to soilless cultivation (hydroponics) has been an alternative for arid and semi-arid regions, mainly for the growth of leafy vegetables (Santos Júnior et al., 2015a; Batista et al., 2021).

In hydroponics, the use of waters with high electrical conductivities has been possible (Silva et al., 2018; Silva et al., 2022). These results have been partly attributed to the minimization of the matrix potential in this form of cultivation, which favors the use of waters with higher concentrations; however, studies have highlighted the impact of the cation prevalence in these waters (Santos Júnior et al., 2015b; Muchecua et al., 2022).

Some cations (Na^+, Ca^{2+} and Mg^{2+}) and anions (Cl^-, CO_3^{2-}, HCO_3^- and SO_4^{2-}) are prevalent in waters of the Brazilian Semiarid region (Rodrigues et al., 2019). Studies have reported successful use of preparation of nutrient solutions for the growth of several leafy vegetables, such as coriander (Silva et al., 2016) and rocket (Campos Júnior et al., 2018a). However, improper management in preparing nutrient solutions may lead to several problems and limit water and nutrient absorption (Carvalho et al., 2018; Dias et al., 2020).

In this sense, studies have evaluated impacts of different cation prevalence on the use efficiency of macronutrients in the context of concentrations in brackish water when preparing nutrient solutions (Muchecua et al., 2022), water relations (Navarro et al., 2022), and production variables (Martins et al., 2019a) for leafy vegetables.

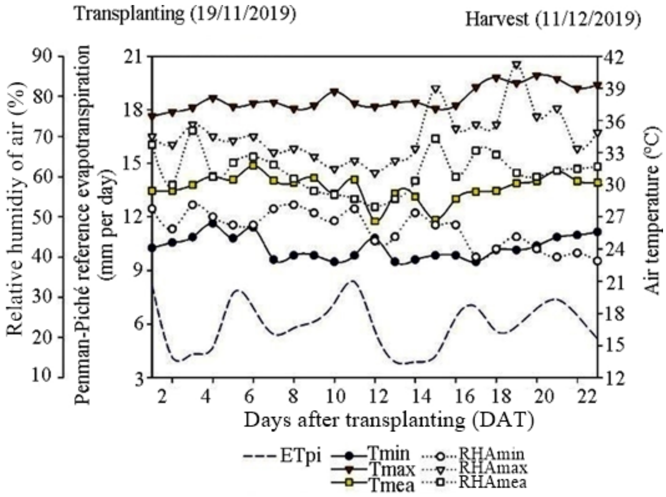
Therefore, this study was carried out to evaluate production and water relations of coriander grown in nutrient solutions prepared with brackish waters of different cationic natures under hydroponic conditions.

Material and Methods

The experiment was conducted in November and December 2019, in a greenhouse at the Laboratório de Fertirrigação e Salinidade of the Departamento de Engenharia Agrícola of the Universidade Federal Rural de Pernambuco (UFRPE), in Recife, PE, Brazil (8°1'7"S, 34°56'53"W, and altitude of 6.5 m).

The environmental conditions of the greenhouse were assessed through data on temperature and relative humidity (Figure 1), using a portable weather station (Digitech model XC0348) installed within the protected environment that records means every 10 minutes. The mean temperature and relative humidity were 30.12 ± 1.34 °C and 62.16 ± 5.90% during the study period. Reference evapotranspiration was also monitored, using the Penman-Piché method (Figure 1).

A randomized block experimental design with four replications was used, in a 4 × 3 factorial arrangement. The coriander plants were grown under four electrical conductivities of the nutrient solution (1.6, 3.2, 4.8, and 6.4 dS m^{-1}), which were prepared with brackish waters of three different cationic natures (Na^+, Ca^{2+}, and Mg^{2+}, obtained by solubilizing the salts NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$, respectively).



Tmin - Minimum air temperature; Tmax - Maximum air temperature; Tmea - Mean air temperature; RHAmin - Minimum relative air humidity; RHAmax - Maximum relative air humidity; RHAmea - Mean relative air humidity

Figure 1. Daily mean reference evapotranspiration, relative air humidity, and air temperature inside the greenhouse, during the experimental period

The coriander plants were grown in hydroponics; each experimental block comprised a 2×1.40 m pyramid-shaped wooden structure with capacity for twelve PVC tubes (Santos Júnior et al., 2016). Each tube (2-m-long and 100-mm-diameter) represented an experimental unit. Circular holes of 60 mm diameter were drilled in the tubes with spacing of 0.14 m between holes, considering the central axis of each hole. The tubes were installed with zero slope, maintaining a nutrient solution depth of 0.04 m (corresponding to a volume of approximately 8 L).

Coriander seeds of the cultivar Verdão (Feltrin® Sementes, Farroupilha, Brazil) were sown in November 2019, in 180 mL plastic cups with small holes at the bottom and on all sides, filled with coconut fiber as substrate (Golden Mix, type 47). Fifteen seeds were sown per cup. Moisture was maintained by spraying 100 mL of public water (electrical conductivity ECw of 0.12 dS m^{-1}) twice a day until transplanting to the hydroponic system.

The brackish waters were prepared using the amount of the respective salts of each treatment, which was estimated by [(mg L^{-1}) ≅ 640 × ECw (dS m^{-1})] Richards (1954). The salts were dissolved in 20 L of public water (ECw = 0.12 dS m^{-1}). The treatments based on NaCl, $CaCl_2.2H_2O$, and $MgCl_2.6H_2O$ had concentrations of 0, 20.3, 40.6, and 60.90; 0, 9.23, 18.45, and 27.68; and 0, 10.75, 21.51, and 32.26 mmol$_c$ L^{-1}, respectively, corresponding to electrical conductivities of the brackish waters of 0.12, 1.72, 3.32, and 4.92 dS m^{-1} for the three cationic nature tested.

Subsequently, fertilizer salts were added to the respective waters, according to the formulation by Furlani et al. (1999), using the following quantities for 20 L: 15.0 g of calcium nitrate (15.5% N and 18.0% Ca), 10.0 g of potassium nitrate (12.0% N and 45.0% K), and 3.0 g of monoammonium phosphate (12.0% N and 51% P). Magnesium sulfate (11.0% and 9.0% Mg) and micronutrients (0.5% B, 0.5% Cu, 2.5% Fe, 2% Mn, 0.2% Mo, and 1.5% Zn) were provided by applying 8.0 g of the KSC Mix (Timac Agro/Vitas Portugal Lda., Lisboa, Portugal).

After adding the nutrients, the electrical conductivities of the nutrient solutions (ECns) evaluated in the present study were established.

Seven days after sowing (DAS), the coriander was transplanted to the hydroponic channels previously filled with 8 L of nutrient solution. Twelve bunches of coriander seedlings were transplanted per channel, with spacing of 0.14 m. The nutrient solutions were recirculated in the hydroponic channels twice a day (8:00 a.m. and 4:00 p.m.) during the experiment. The solutions were applied manually to the channels until the level of 0.04 m was exceeded. The excess solution in relation to the level inside the channel returned to the reservoir through a flexible hose.

The ECns, pH, concentration of dissolved oxygen (mg L^{-1}), and temperature (°C) of the nutrient solutions were measured daily. Electrical conductivity and pH were measured in the hydroponic channels using a conductivity meter (AK51) with precision of 0.01 mS cm^{-1} and a conductivity meter (AK90) with precision of 0.1, both with automatic temperature compensation (Akso, Sao Leopoldo, Brazil).

Dissolved oxygen concentrations of the nutrient solution were measured in the hydroponic channels using a oximeter (DO Eco) with precision of 0.01 mg L^{-1} with automatic temperature compensation (Akso, Sao Leopoldo, Brazil). The temperature of the nutrient solutions was simultaneously measured using the same equipment.

The level of the stock reservoir of nutrient solution was replaced with their respective brackish water every seven days, as the water consumption of the plants increased and the volume of solution in the reservoir decreased.

The harvest was performed at 23 days of cultivation in the hydroponic system (30 days after sowing - DAS). Four bunches of plants (formed by 15 plants each) were harvested and evaluated for total fresh weight (TFW, g per bunch) by weighing all plants in the cultivation unit (cup), including the roots, which were then separated from the aerial part, carefully removed from the cups, and washed to remove the substrate.

The plants were separated into shoot and roots and the shoot fresh weight (SFW, g per bunch) and root fresh weight (RFW, g per bunch) were determined on a precision scale.

The fresh material (shoot and roots) was separately placed in labeled Kraft paper bags and dried in a forced air-circulation oven at 60 °C until constant weight, to quantify the shoot dry weight (SDW, g per bunch) and root dry weight (RDW, g per bunch). The total dry weight (TDW, g per bunch) was obtained by summing SDW and RDW.

Leaf areas (LA) were obtained by the leaf disc method. All fresh leaves of four plants per bunch were weighed and counted. The disks were detached and immediately individually weighed on an analytical balance. A plant awl with a known area (1.78 cm^2) was used. One disk per leaf was removed from the basal portion, in a region with fine veins.

The leaf area was estimated according to the methodology of Benincasa (2003) using Eq. 1:

$$LA = \frac{DA \times (DW + LM)}{DW} \quad (1)$$

where:

LA - leaf area (cm^2);
DA - disk area (cm^2);
DW - disk weight (g); and,
LM - leaf weight (g).

On the same day of harvest, gas exchange was evaluated through stomatal conductance (g_s, mol H_2O m^{-2} s^{-1}), transpiration (E, mmol H_2O m^{-2} s^{-1}), and CO_2 assimilation rate (A, μmol H_2O m^{-2} s^{-1}) were evaluated using a portable infrared gas analyzer (LI-6400; LI-COR Biosciences, Lincoln, USA).

The intrinsic water-use efficiency (A/gs - (μmol m^{-2} s^{-1})/(mol H_2O m^{-2} s^{-1})) and instantaneous water-use efficiency (A/E - (μmol m^{-2} s^{-1})/(mmol H_2O m^{-2} s^{-1})) were estimated after data collection. Measurements were carried out between 8:30 - 9:30 a.m., in the photosynthetically active radiation range of 1500 μmol photons m^{-2} s^{-1} and airflow of 200 mL min^{-1}.

Water content (WC) was calculated based on the fresh (FW) and dry (DW) weights of shoots (SWC) and roots (RWC) through to the methodology of Benincasa, (2003), using Eq. 2:

$$WC(\%) = \left[\frac{(SFW - SDW)}{FW}\right] \times 100 \quad (2)$$

Water use efficiency (WUE) was calculated based on the ratio between the SFW (g) and the accumulated water consumption (WC, L) per bunch of plants in 23 days, according to Eq. 3:

$$WUE_{SFW}\left(g\ L^{-1}\right) = \frac{SFM(g)}{WC(L)} \quad (3)$$

WC was calculated according to the water consumed from the reservoir containing the nutrient solution and the number of plants in the hydroponic cultivation channels.

The data obtained were subjected to analysis of variance by the F-test ($p \leq 0.05$) using the statistical package SISVAR 5.7 (Ferreira, 2019). The electrical conductivities of the nutrient solution were analyzed through regression analysis, and the cationic nature of the water were compared by the Tukey's test ($p \leq 0.05$).

Results and Discussion

The electrical conductivity of all nutrient solutions increased during the experimental period, in all cationic predominance tested, mainly for initial electrical conductivities higher than 3.2 dS m^{-1}. The solution with predominance of NaCl at ECns of 3.2 dS m^{-1} presented the highest increase (14.8%) in relation to the initial ECns (Figures 2 A, B, and C, respectively).

These increases in ECns can be attributed to the input of salts, as the replacement of the evapotranspiration volume was carried out using the respective brackish water. Similar results were found in other works (Martins et al., 2019b; Soares et al., 2020; Cruz et al., 2021) in which this nutrient solution management strategy was also used.

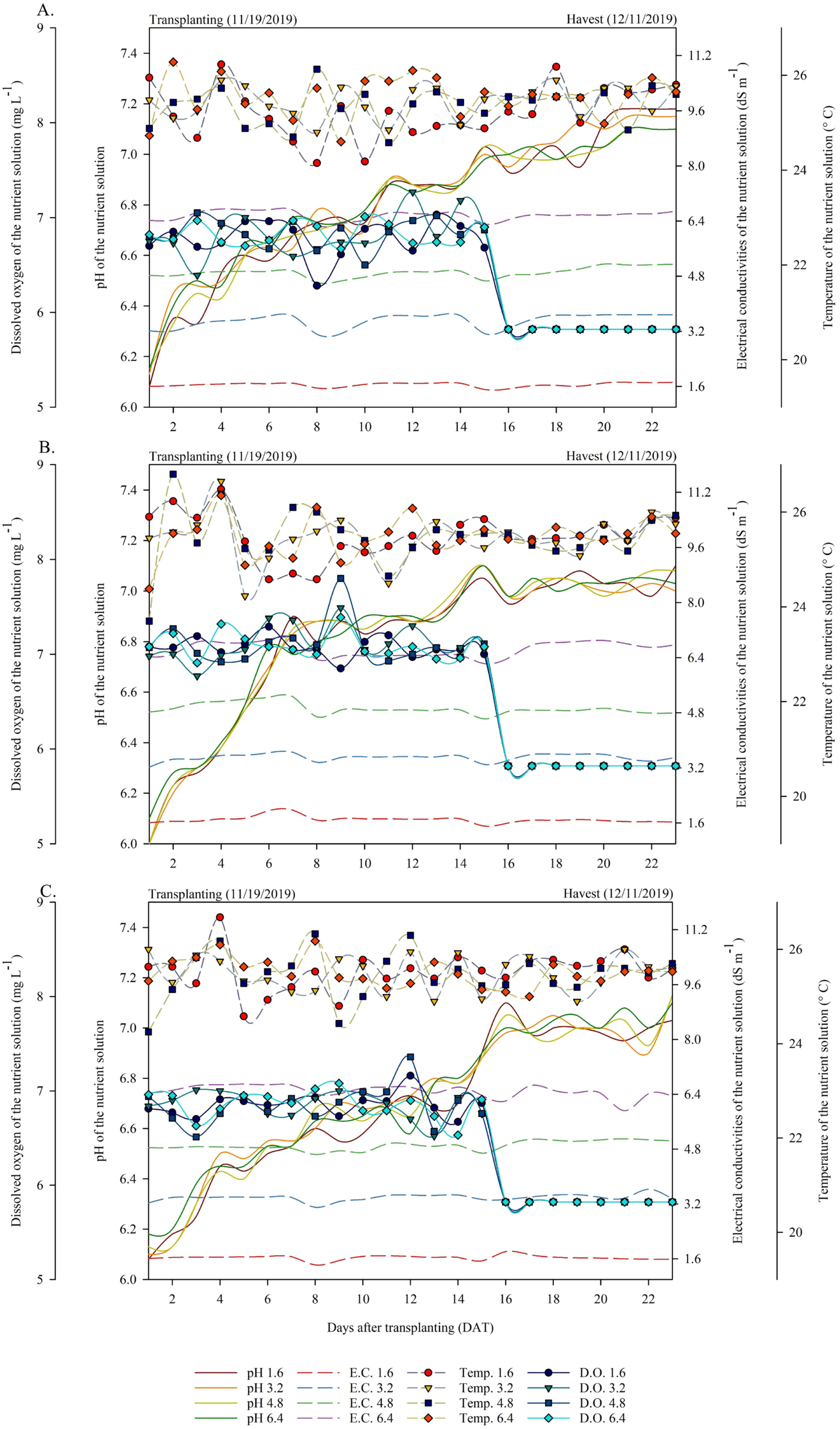


Figure 2. Mean electrical conductivity, pH, temperature, and dissolved oxygen of the nutrient solution with cation prevalence of NaCl (A), $CaCl_2$ (B), and $MgCl_2$ (C) for coriander plants grown in a hydroponic system

The pH remained in the range between 6.0 and 7.2 in all treatments (Figure 2 A, B, and C, respectively), remaining within the recommended range by Furlani (1995) for most crops grown in hydroponic systems, which is 4.5 to 7.5.

Similar dynamic was found for the temperature of the nutrient solution for all ionic predominance and concentrations tested, with mean, maximum, and minimum temperatures of 32.3, 33.7, and 29.2 °C respectively, during the experimental period (Figure 2 A, B, and C, respectively). In general, nutrient solution temperatures in the range between 20 and 30 °C are adequate for plant growth (He et al., 2019).

Dissolved oxygen varied between 6.2 and 7.0 ppm in all treatments until 16 days after transplanting (DAT), and remained constant, at 6.3 ppm, until the end of the experimental cycle (Figure 2 A, B, and C, respectively). This decrease is explained by the increase in volume of roots, and consequently, in oxygen demand (Silva et al., 2020).

Significant interactions ($p \leq 0.01$) were found between the electrical conductivity and cationic nature of the solutions for total fresh weight (TFW), shoot fresh weight (SFW), shoot water content (SWC), and root water content (RWC) (Table 1). The isolate factors had significant effect ($p \leq 0.01$) on the total dry weight (TDW), and shoot dry weight (SDW) (Table 1). Only ECns significantly affected ($p < 0.01$) the root fresh (RFW) and dry (RDW) weights (Table 1).

The follow-up analysis of the TFW interaction (Figure 3A) showed that the use of solutions with predominance of NaCl and $MgCl_2$ resulted in the highest TFW, 45.31 and 42.31 g bunch^{-1} at the ECns of 1.6 and 3.03 dS m^{-1}, respectively. Solutions prepared with $CaCl_2$, resulted in linear decreases in TFW, with a decrease of 9.64% per ECns unit increased.

TDW (Figure 3B) showed a quadratic response to increases in ECns; the highest TDW was 4.88 g bunch^{-1} at the estimated ECns of 2.27 dS m^{-1}. Regarding the cation sources used, plants grown on the solution with predominance of NaCl showed higher TDW (4.40 g bunch^{-1}) compared to those grown on the solution with predominance of $CaCl_2$ (3.31 g bunch^{-1}) and $MgCl_2$ (3.46 g bunch^{-1}). The solutions with the predominance of $CaCl_2$ and $MgCl_2$ did not differ from each other (Figure 3B).

Similar to TFW (Figure 3A), SFW data fit to a quadratic model for NaCl and $MgCl_2$. As for $CaCl_2$, the data fit to linear models, with decreases in SFW as the ECns was increased (Figure 3C); the highest SFW were found for the ECns of 1.6 dS m^{-1}. The highest SFW for NaCl and $MgCl_2$ (39.37 and 35.77 g bunch^{-1}, respectively) were found for the ECns 3.01 dS m^{-1}. In solutions with predominance of $CaCl_2$, increases in ECns resulted in a maximum decrease of 54.97%, corresponding to a decrease of 10.29% per ECns unit increased.

The treatment with predominance of NaCl resulted in higher SFW (41.23 and 28.97 g bunch^{-1}) between ECns of 3.2 and 4.8 dS m^{-1}, differing ($p \leq 0.05$) from CaCl and $MgCl_2$. In the initial and final ECns (1.6 and 6.4 dS m^{-1}), no differences ($p \leq 0.05$) were found between cationic natures.

Similar SFW was found treatments with $CaCl_2$ and $MgCl_2$ (34.14 and 15.61 g bunch^{-1}) at the estimated ECns of 2.09 and 6.23 dS m^{-1}, respectively. The intersection of the curves occurred at the estimated ECns of 3.35 and 5.38 dS m^{-1}, for NaCl and $MgCl_2$, corresponding to SFW of 35.45 and 24.88 g bunch^{-1}, respectively.

The highest SDW (4.28 g per bunch) was found for the estimated ECns of 2.24 dS m^{-1} (Figure 3D). Regarding the different cation sources used, solutions with predominance of NaCl resulted in higher SDW (3.83 g) than those with predominance of $CaCl_2$ (2.80 g) and $MgCl_2$ (2.94 g). However, solutions with predominance of $CaCl_2$ and $MgCl_2$ did not differ in SDW from each other (Figure 3D).

The increase in ECns resulted in different effects on RFW and RDW (Figures 3E and F). RFW decreased 5.08% per ECns unit increased (Figure 3E); the highest RDW (Figure 3F) was found for the ECns of 2.65 dS m^{-1}, corresponding to 0.6 g bunch^{-1}.

Considering the cationic natures within the ECns, the lowest SWC were 85.74% (solution with predominance of NaCl), 87.65% ($CaCl_2$), and 87.28% ($MgCl_2$), at the estimated ECns of 3.73, 3.61, and 1.79 dS m^{-1}, respectively (Figure 3G). The highest SWC found were 89.72, 91.29, and 95.3%, obtained at the highest ECns level (6.4 dS m^{-1}) for solutions with predominance of NaCl, $CaCl_2$, and $MgCl_2$, respectively.

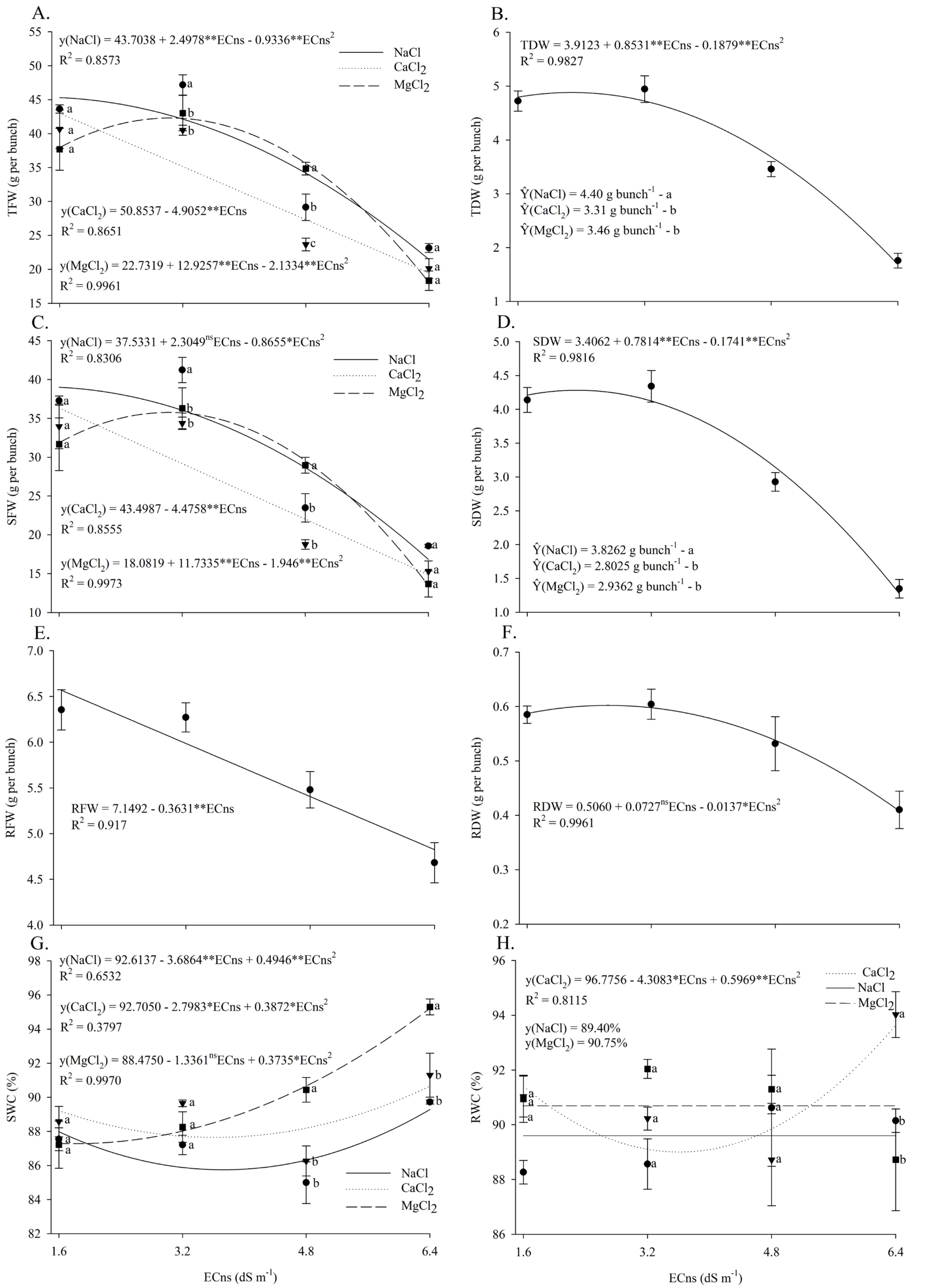
The SWC found for the cationic natures presented no difference ($p \geq 0.05$) at the ECns of 1.6 and 3.2 dS m^{-1}; however, the nutrient solution with predominance of $MgCl_2$ resulted in higher SWC than those with predominance of NaCl and $CaCl_2$ at the ECns of 4.8 and 6.4.

Considering the ECns range studied, the lowest RWC (89%) was found for the estimated ECns of 3.61 dS m^{-1}, notably, when Ca^{2+} is prevalent in the water (Figure 3H). However, the highest RWC was found for the highest ECns, corresponding to 94% for the solution with prevalence of $CaCl_2$. The RWC of plants

Table 1. Analysis of variance of total fresh weight (TFW), total dry weight (TDW), shoot fresh weight (SFW), shoot dry weight (SDW), root fresh weight (RFW), root dry weight (RDW), shoot water content (SWC), and root water content (RWC) of coriander plants grown under four electrical conductivities of the nutrient solutions (ECns) prepared with salts of different cationic natures

SV	DF	Mean square							
		TFW	TDW	SFW	SDW	RFW	RDW	SWC	RWC
ECns	3	1357.7**	25.7**	1168.3**	22.8**	7.36**	0.09**	58.4**	1.88ns
Linear regression	1	3354.0**	64.7**	2853.1**	57.5**	20.2**	0.21**	84.3**	4.01ns
Quadratic regression	1	403.7**	11.1**	355.4**	9.54**	1.54ns	0.06*	55.1**	0.93ns
CN	2	82.3**	5.57**	82.7**	4.95**	0.18ns	0.02ns	34.6**	11.9ns
Block	3	29.8ns	0.18ns	29.3ns	0.10ns	0.42ns	0.02ns	5.73ns	8.34ns
ECns x CN	6	49.1**	0.26ns	42.8**	0.32ns	0.69ns	0.02ns	13.0**	15.8**
Error	33	10.9	0.14	11.8	0.14	0.48	0.01	2.76	4.57
CV (%)		9.89	10.06	12.35	11.64	12.15	20.39	1.87	2.37

SV = source of variation; CN = cationic nature; CV = coefficient of variation; DF = degrees of freedom; ns, * and ** = not significant, and significant at $p \leq 0.05$ and $p \leq 0.01$ by the F test, respectively



Vertical bars represent the standard error of the mean (n = 4). Different letters indicate significant differences between cationic natures of salts by the Tukey's test (p ≤ 0.05)

Figure 3. Total fresh weight - TFW (A), total dry weight - TDW (B), shoot fresh weight - SFW (C), shoot dry weight - SDW (D), root fresh weight - RFW (E), root dry weight - RDW (F), shoot water content - SWC (G), and root water content- RWC (H) of coriander plants in function of electrical conductivities of the nutrient solutions (ECns) prepared with salts of different cationic natures

grown on solutions with predominance of NaCl and $MgCl_2$ did not show significant differences, presenting means of 89.40 and 90.75%, respectively.

Reductions in coriander production in hydroponic cultivation due to saline stress have been described in the literature. Silva et al. (2018) found decreases of 6.08% and 3.32% in SFW and SDW of coriander, per ECns unit increased. Martins et al. (2019b) reported losses in TFW, TDW, RFW, and RDW of coriander plants grown on brackish nutrient solutions prepared with waters of different cationic natures. It confirms that high salinity can cause disturbances in plant metabolism, restricting growth and causing yield loss (Silveira et al., 2016).

Significant interactions were found between ECns and cationic nature for water consumption (WC) and water use efficiency (WUE) (Table 2).

The effect ($p < 0.01$) of the isolated factors was significant for stomatal conductance (g_s), intrinsic water-use efficiency (A/g_s), and leaf area (LA) (Table 2). Only the ECns significantly affected ($p < 0.01$) transpiration (E), and instantaneous water-use efficiency (A/E) (Table 2).

Stomatal conductance (g_s) decreased linearly as the ECns was increased, varying 44.8% from the lowest to the highest ECns, corresponding to a decrease of 5.84% per ECns unit increased (Figure 4A). The cationic natures differed ($p \leq 0.05$) in g_s from each other; plants grown on solutions with predominance of NaCl in the nutrient solution presented higher g_s, followed by the solutions with $CaCl_2$ and $MgCl_2$; which is probably because NaCl is a monovalent cation.

The highest E was found for the estimated ECns of 2.66 dS m^{-1}, corresponding to 2.72 mmol H_2O m^{-2} s^{-1} (Figure 4B). Considering the cationic natures within the ECns (Figure 4C), the WC decreased 4.53% per ECns unit increased in the solution with the predominance of NaCl, and 3.14% in the solution with $MgCl_2$. The solution with predominance of $CaCl^2$ presented the highest WC (0.72 L $bunch^{-1}$) for the estimated ECns of 1.6 dS m^{-1}.

The highest means were found for plants grown on solutions with predominance of NaCl and MgCl, 0.67 and 0.62 L $bunch^{-1}$ at the ECns of 3.2 and 4.8 dS m^{-1}, respectively, differing ($p \leq 0.05$) from plants grown on solutions with predominance of $CaCl_2$ and $MgCl_2$, however, at the ECns of 1.6 and 6.4 dS m^{-1}, no significant difference was found among WC means. At the estimated ECns of 2.4 and 4.9 dS m^{-1}, the WC of plants grown on solutions with the predominance of $CaCl_2$ and $MgCl_2$ and; NaCl and $MgCl_2$ were equivalent, corresponding to WC of 0.67 and 0.61 L $bunch^{-1}$.

Solutions with predominance of NaCl and $MgCl_2$ presented the highest WUE, 54.03 and 55.16 g L^{-1}, for the estimated ECns of 2.14 and 3.28 dS m^{-1} (Figure 4D). The increase in ECns caused a linear decrease in WUE of coriander plants when using the solution with predominance of $CaCl_2$, which was 41.69% from the lowest to the highest ECns. a significant difference in WUE was found only in the ECns of 4.8 dS m^{-1}; plants grown on solutions with predominance of $MgCl_2$ presented higher WUE (46.69 g L^{-1}), differing ($p \leq 0.05$) from the other cation sources, which did not differ from each other.

The WUE in plants grown on solutions with predominance of $CaCl_2$ and $MgCl_2$ were similar for the estimated ECns of 2.03 and 5.98 dS m^{-1}, with 50.09 and 31.31 g L^{-1}, respectively. Solutions with the predominance of NaCl and $MgCl_2$ presented similar WUE for the estimated ECns of 2.62 and 5.39 dS m^{-1}, representing a WUE of 53.75 and 40.59 g L^{-1}, respectively.

A/gs was negatively affected by the increases in ECns (Figure 4E), fitting to a quadratic regression; the highest A/gs found was 97.60 μmol $m^{-2}s^{-1}$/mmol H_2O $m^{-2}s^{-1}$, for the estimated ECns of 3.43 dS m^{-1}. Considering only the cationic natures, solutions with predominance of $MgCl_2$ had higher A/gs (83.9 μmol $m^{-2}s^{-1}$/mmol H_2O $m^{-2}s^{-1}$), differing ($p \leq 0.05$) from solutions with predominance of NaCl and $CaCl_2$, which did not differ ($p > 0.05$) from each other.

The increases in ECns affected the A/E (Figure 4F), which fit to a quadratic regression model. The highest A/E found was 3.96 μmol (CO_2)/mmol (H_2O), for the estimated ECns of 3.19 dS m^{-1} (Figure 4F).

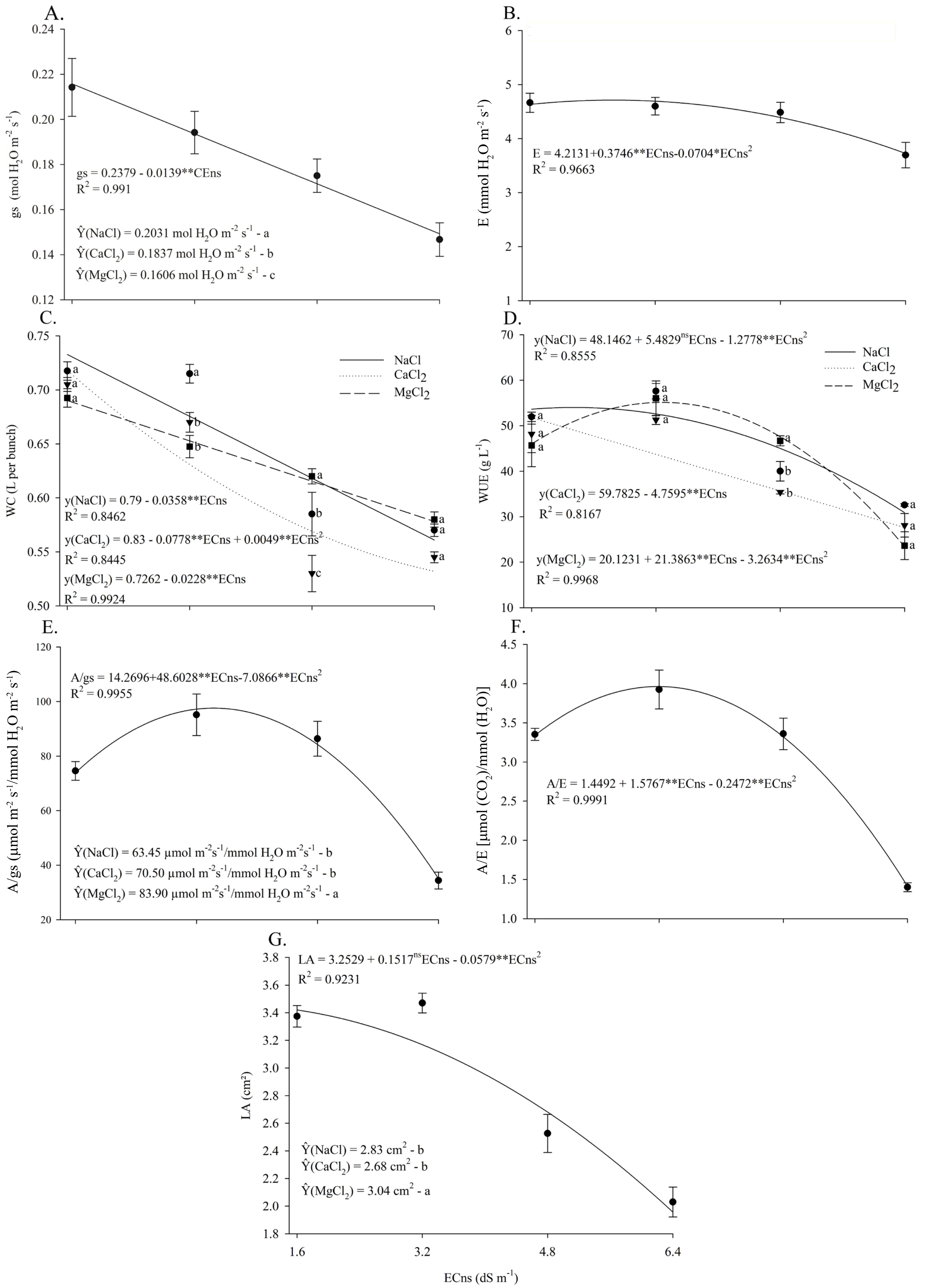
LA was affected by the increases in ECns (Figure 4G), fitting to a quadratic regression model, the highest LA found was 3.35 cm^2, for the estimated ECns of 1.6 dS m^{-1}. Considering only the cationic natures, the solution with predominance of $MgCl_2$ had higher LA (3.04 cm^2), statistically differing from the NaCl and $CaCl_2$ solutions, which did not statistically differ from each other.

Stomatal closure is one of the first defense mechanisms of plants against saline stress. Low g_s were found under high ECns, which triggered limitations in transpiration and A/gs, as also found in other studies (Freire et al., 2014; Campos Júnior et al., 2018b).

Table 2. Analysis of variance of stomatal conductance (g_s), transpiration (E), water consumption (WC), water use efficiency (WUE), intrinsic water-use efficiency (A/gs), instantaneous water-use efficiency (A/E), and leaf area (LA) of coriander plants grown under four electrical conductivities of the nutrient solutions (ECns) prepared with salts of different cationic natures

SV	DF	Mean square						
		gs	E	WC	WUE	A/gs	A/E	LA
ECns	3	0.0099**	2.42**	0.0591**	1609.9**	8655.3**	14.7**	5.75**
Linear regression	1	0.0295**	5.46**	0.1617**	3451.2**	10052.6**	24.7**	14.9**
Quadratic regression	1	0.0002ns	1.56*	0.0006ns	1079.4**	15797.8**	19.2**	1.05*
CN	2	0.0072**	0.44ns	0.0049**	92.2*	1727.3**	0.32ns	0.54**
Block	3	0.0020*	2.56**	0.0004ns	74.5*	569.1ns	1.27**	0.23*
ECns x CN	6	0.0012ns	0.22ns	0.0033**	66.7*	299.0ns	0.64ns	0.19ns
Error	33	0.0006	0.29	0.0004	22.3	270.8	0.28	0.08
CV (%)		13.54	12.41	3.29	10.97	22.66	17.65	9.86

SV = source of variation; CN = cationic natures; CV = coefficient of variation; DF = degrees of freedom; ns, * and ** respectively not significant and significant at $p \leq 0.05$ and $p \leq 0.01$ by the F test



Vertical bars represent the standard error of the mean (n = 4). Different letters indicate significant differences between cationic natures of the salts by the Tukey's test ($p \leq 0.05$)

Figure 4. Stomatal conductance - g_s (A), transpiration - E (B), water consumption - WC (C), water use efficiency - WUE (D), intrinsic water-use efficiency - A/gs (E), instantaneous water-use efficiency - A/E (F), and leaf area - LA (G) of coriander plants in function of electrical conductivities of the nutrient solutions (ECns) prepared with salts of different cationic natures

The results found for WC, g_s, and biomass production were more expressive for plants grown on solutions with prevalence of Na, compared to those grown on solutions with prevalence of Ca and Mg. It can be attributed to several factors connected to the effect of the cation prevalence on the nutrient solution: (i) the different ion exchange selectivity of the cations; (ii) the different absorption energy levels of the cations; (iii) the greater susceptibility of calcium to precipitation. These factors affected the intensity of osmotic and ionic components, which result in different levels of response in plants.

Silva et al. (2018) found decreases in WC of 5.26 and 5.85% per ECns unit increased in coriander plants. Guimarães et al. (2019) evaluated crisp lettuce cultivars in a hydroponic system and reported decreases in E and WUE of 32.2 and 46.2% for ECns ranging from 1.6 to 7.6 dS m^{-1}, respectively. Cavalcante et al. (2019) evaluated gas exchange and photochemical efficiency of hydroponic pepper grown on a solution with high salinity and found decreases in g_s, E, and A/E as the ECns was increased from 1.7 to 11.7 dS m^{-1}. Rebouças et al. (2013) found decreases in LA of coriander plants grown in a hydroponic system due to increases in ECns.

Conclusions

1. The shoot and root biomass productions and water consumption of coriander decreased with increasing electrical conductivity of the nutrient solution.

2. The growth of coriander in nutrient solutions with predominance of Na^+ presented higher total dry weight and shoot dry weight, as well as higher stomatal conductance.

3. The cationic nature of the water used in the preparation of the nutrient solution did not affect the instantaneous water-use efficiency.

Literature Cited

Batista, M. C.; Nascimento, R. do; Maia Júnior, S. O. de; Nascimento, E. C. S.; Bezerra, C. V. de C.; Lima, R. F. de. Physiology and production of cherry tomato cultivars in a hidroponic system using brackish water. Revista Brasileira de Engenharia Agrícola e Ambiental, v.25, p.219-227, 2021. https://doi.org/10.1590/1807-1929/agriambi.v25n4p219-227

Benincasa, M. M. P. Análise de crescimento de plantas: noções básicas. Jaboticabal: FUNEP, 2003. 42p.

Campos Júnior, J. E.; Santos Júnior, J. A.; Martins, J. B.; Silva, E. F. de F. e; Almeida, C. D. G. C de. Rocket production in a low cost hydroponic system using brackish water. Revista Caatinga, v.31, p.1008-1016, 2018a. https://doi.org/10.1590/1983-21252018v31n424rc

Campos Júnior, J. E.; Santos Júnior, J. A.; Silva, E. F. de F. e; Martins, J. B.; Rolim, M. M. Consumption, efficiency and water content of arugula under different management of brackish nutritional solutions. Engenharia Agrícola, v.38, p.885-892, 2018b. https://doi.org/10.1590/1809-4430-Eng.Agric.v38n6p885-892/2018

Carvalho, R. S. C.; Bastos, R. G.; Souza, C. F. Influence of the use of water on nutrient absorption and production of lettuce grown in a hydroponic system. Agricultural Water Management, v.203, p.311-321, 2018. https://doi.org/10.1016/j.agwat.2018.03.028

Cavalcante, A. R.; Santos Júnior, J. A; Furtado, G. F.; Chaves, L. H. G. Gas exchanges and photochemical efficiency of hydroponic bell pepper under salinity and plant density. Revista Brasileira de Engenharia Agrícola e Ambiental, v.23, p.3-8, 2019. https://doi.org/10.1590/1807-1929/agriambi.v23n1p3-8

Cruz, R. I. F.; Silva, G. F. da; Silva, E. F. de F. e; Soares, H. R. e; Santos Junior, J. A.; Santos, H. R. B. Water yield and consumption of cauliflower plants grown in a hydroponic system using brackish waters and different flow rates. Revista Brasileira de Engenharia Agrícola e Ambiental, v.25, p.422-428, 2021. https://doi.org/10.1590/1807-1929/agriambi.v25n6p422-428

Dias, N. da S.; Fernandes, C. dos S.; Sousa Neto, O. N. de; Silva, C. R. da; Ferreira, J. F. da S.; Sá, F. V. da S.; Cosme, C. R.; Souza, A. C. M.; Oliveira, A. M. de; Batista, C. N. de O. Potential agricultural use of reject brine from desalination plants in family farming areas. In: Saline and Alkaline Soils in Latin America. Cham: Springer International Publishing, 2020. Chap.2, p.101-118.

Ferreira, D. F. Sisvar: a computer analysis system to fixed effects split plot type designs. Revista Brasileira de Biometria, v.37, p.529-535, 2019. https://doi.org/10.28951/rbb.v37i4.450

Freire, J. L. de O.; Dias, T. J.; Cavalcante, L. F.; Fernandes, P. D.; Lima Neto, A. J. de. Rendimento quântico e trocas gasosas em maracujazeiro amarelo sob salinidade hídrica, biofertilização e cobertura morta. Revista Ciência Agronômica, v.45, p.82-91, 2014. https://doi.org/10.1590/S1806-66902014000100011

Furlani, P. R. Cultivo de alface pela técnica de hidroponia - NFT. Campinas: Instituto Agronômico, 1995. 18p. Documentos IAC, 55

Furlani, P. R.; Silveira, L. C. P.; Bolonhezi, D.; Faquin, V. Cultivo hidronpônico de pantas. Campinas: Instituto Agronômico de Campinas, 1999, 52p. Boletim Técnico

Guimarães, R. F. B.; Maia Júnior, S. de O.; Nascimento, R. do; Melo, D. F. de; Ramos, J. G; Andrade, J. R. de. Trocas gasosas em cultivares de alface crespa em cultivo hidropônico com água salina. Revista Brasileira de Agricultura Irrigada, v.13, p.3599-3609, 2019.

He, F.; Thiele, B.; Watt, M.; Kraska, T.; Ulbrich, A.; Kuhn, A. J. Effects of root cooling on plant growth and fruit quality of cocktail tomato during two consecutive seasons. Journal of Food Quality, v.2019, p.1-15, 2019. https://doi.org/10.1155/2019/3598172

Martins, J. B.; Santos Júnior, J. A.; Silva Júnior, F. J. da; Silva, G. F. da; Medeiros, S. de S. Production of parsley in hydroponic conditions under isosmotic brackish nutrient solutions. Ciência e Agrotecnologia, v.43, p.1-10, 2019a. https://doi.org/10.1590/1413-7054201943023418

Martins, J. B.; Santos Júnior, J. A.; Bartusch, V. P.; Gheyi, H. R.; Bezerra Neto, E.; Silva, M. M. da. Water relations in parsley plants cultivated in brackish nutrient solutions of different cationic natures. Revista Brasileira de Engenharia Agricola e Ambiental, v.23, p.662-668, 2019b. https://doi.org/10.1590/1807-1929/agriambi.v23n9p662-668

Muchecua, S. M. H.; Santos Júnior, J. A.; Menezes, S. M. de; Silva, G. F. da; Chaves, L. H. G.; Cruz, R. I. F. Ionic relationships between macronutrients and sodium in parsley under nutrient solutions prepared with brackish water. Revista Brasileira de Engenharia Agrícola e Ambiental, v.26, p.11-20, 2022. https://doi.org/10.1590/1807-1929/agriambi.v26n1p11-20

Navarro, F. E. C.; Santos Júnior, J. A.; Martins, J. B.; Cruz, R. I. F.; Silva, M. M. da; Medeiros, S. de S. Physiological aspects and production of corander using nutrient solutions prepared in different brackish waters. Revista Brasileira de Engenharia Agrícola, v.26, p.831-839, 2022. https://doi.org/10.1590/1807-1929/agriambi.v26n11p831-839

Rebouças, J. R. L.; Ferreira Neto, M.; Dias, N. da S.; Souza Neto, O. N. de; Diniz, A. A.; Lira, R. B. de. Cultivo hidropônico de coentro com uso de rejeito salino. Irriga, v.18, p.624-634, 2013. https://doi.org/10.15809/irriga.2013v18n4p624

Richards, L. A. Diagnosis and improvement of saline and alkali soils. Washington: USDA - Department of Agriculture, 1954. 160p. Agriculture Handbook, 60

Rodrigues, L. L. L. S.; Silva, E. F. S.; Farias, M. L.; Pinheiro, A. M.; Lima, R. B.; Morais, F. M. S.; Santos, E. P. S.; Campêlo, M. C. S.; Silva, L. F.; Freitas, D. F.; Oliveira, F. O. Water quality of underground wells in Limoeiro do Norte, Brazilian Northeast. Journal of Agricultural Science, v.11, p.251-259, 2019. https://doi.org/10.5539/jas.v11n17p251

Santos Júnior, J. A.; Gheyi, H. R.; Cavalcante, A. R.; Dias, N. da S.; Medeiros, S. de S. Produção e pós-colheita de flores de girassóis sob estresse salino em hidroponia de baixo custo. Engenharia Agrícola, v.36, p.420-432, 2016. https://doi.org/10.1590/1809-4430-Eng.Agric.v36n3p420-432/2016

Santos Júnior, J. A.; Gheyi, H. R.; Cavalcante, A. R.; Medeiros, S. de S.; Dias, N. da S.; Santos, D. B. dos. Water use efficiency of coriander produced in a low-cost hydroponic system. Revista Brasileira de Engenharia Agrícola e Ambiental, v.19, p.1152-1158, 2015a. https://doi.org/10.1590/1807-1929/agriambi.v19n12p1152-1158

Santos Júnior, J. A.; Gheyi, H, R.; Dias, N. da S.; Guedes Filho, D. H. Crescimento do girassol em sistema hidropônico sob estresse salino e densidades de plantio. Irriga, v.20, p.233-247, 2015b. https://doi.org/10.15809/irriga.2015v20n2p233

Silva, M. G. da; Oliveira, I. de S.; Soares, T. M.; Gheyi, H. R.; Santana, G. de O.; Pinho, J. de S. Growth, production and water consumption of coriander in hydroponic system using brackish waters. Revista Brasileira de Engenharia Agrícola e Ambiental, v.22, p.547-552, 2018. https://doi.org/10.1590/1807-1929/agriambi.v22n8p547-552

Silva, M. G. da; Soares, T. M.; Gheyi, H. R.; Costa, I. P.; Vasconcelos, R. S. Growth, production and water consumption of coriander grown under different recirculation intervals and nutrient solution depths in hydroponic channels. Emirates Journal of Food and Agriculture, v.32, p.281-294, 2020. https://doi.org/10.9755/ejfa.2020.v32.i4.2094

Silva, M. G. da; Soares, T. M.; Gheyi, H. R.; Santos, C. C. dos; Oliveira, M. G. B. de. Hydroponic cultivation of coriander intercropped with rocket subjected to saline and thermal stress in the root-zone. Revista Ceres, v.69, p.148-157, 2022. https://doi.org/10.1590/0034-737X202269020004

Silva, M. G. da; Soares, T. M.; Gheyi, H. R.; Oliveira, I. de S.; Silva Filho, J. A. da; Carmo, F. F. do. Frequency of recirculation of nutrient solution in hydroponic cultivation of coriander with brackish water. Revista Brasileira de Engenharia Agrícola e Ambiental, v.20, p.447-454, 2016. https://doi.org/10.1590/1807-1929/agriambi.v20n5p447-454

Silveira, J. A. G.; Silva, S. L. F.; Silva, E. N.; Viégas, R. A. Mecanismos biomoleculares envolvidos com a resistência ao estresse salino em plantas. In: Gheyi, H. R.; Dias, N. S.; Lacerda, C. F. (eds.). Manejo da salinidade na agricultura: estudos básicos e aplicados. 2.ed. Fortaleza: INCTSal, 2016. Cap.13, p.181-196.

Soares, H. R. e; Silva, E. F. de F. e; Silva, G. F. da; Cruz, A. F. da S.; Santos Júnior, J. A.; Rolim, M. M. Salinity and flow rates of nutrient solution on cauliflower biometrics in NFT hydroponic system. Revista Brasileira de Engenharia Agrícola e Ambiental, v.24, p.258-265, 2020. https://doi.org/10.1590/1807-1929/agriambi.v24n4p258-265