

## RESEARCH ARTICLE

# Growth, production and water consumption of coriander grown under different recirculation intervals and nutrient solution depths in hydroponic channels<sup>#</sup>

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## ABSTRACT

Water is an increasingly scarce resource in arid and semiarid regions. The irregular precipitation makes hydroponics a recommended technique for these regions, since it demands less water compared to conventional cropping systems. Two experiments, one from May to June 2016 (autumn) and other from March to April 2017 (summer-autumn), were conducted in a hydroponic system in PVC tubes, using the Deep Flow Technique (DFT). A 2 x 3 x 2 factorial arrangement in split-plot was used, which consisted of two nutrient solution depths (0.02 and 0.03 m) and three recirculation intervals of the nutrient solution (0.25, 12 and 24 h), with two coriander cultivars ('Tabocas' and 'Verdão') in the sub-plots, which were cultivated in the same hydroponic channel. Plant height, shoot fresh and dry matters, water consumption, water use efficiency and visual quality of the coriander plants were evaluated. The coriander cv. 'Verdão' was more tolerant to climatic variations, especially when plants were grown in channels with nutrient solution depth of 0.02 m and recirculation interval of 0.25 h, presenting higher growth and production. The recirculation intervals of 12 and 24 h had a negative effect on the variables evaluated; though, this effect was more significant in the summer-autumn experiment, affecting the quality of the plants harvested, especially those of the cv. 'Tabocas'. It may be concluded that the cultivation of the coriander in the DFT system in PVC tubes is viable, especially in sites with insecure electricity supply.

**Keywords:** *Coriandrum sativum* L.; Hydroponics; Dissolved oxygen; Water resources

## INTRODUCTION

Coriander (*Coriandrum sativum* L.) is one of the spices herbs occupying prominent position worldwide, adding flavor and aroma to several foods (Rashed and Darwesh, 2015). In addition to its use in cooking, coriander is used in food and pharmaceutical industries due to its medicinal properties (Szempliński et al., 2018; Uitterhaegen et al., 2018).

In Brazil, more specifically in the Northeast region, coriander is grown by small and medium farmers, especially for green matter production. The irregular precipitation in this region, according to Brito et al. (2018), is one of the obstacles in the conventional cropping system. Thus, with

low water availability the challenge is to maintain coriander quality and yield without affecting household income.

Approximately 70% of available fresh water is used by the agricultural sector (Mancosu et al., 2015; Doungmanee, 2016). Hence, irrigated agriculture may be impracticable in some arid and semi-arid regions where water is an increasingly scarce resource for this activity. In order to mitigate water scarcity problems, hydroponic cultivation has been identified as a suitable solution under this reality of water scarcity (Silva et al., 2017), since it demands less volume of water (reduction of approximately 80%) in relation to conventional cropping systems (Orsini et al., 2018). When the crop is grown in protected environment, climatic adversities are avoided

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(Story et al., 2010; Murphy et al., 2011), ensuring production quality and regularity year round (Phantong et al., 2018).

One of the main obstacles in the hydroponic cultivation is the high cost of the structure and the dependence on electricity for circulation of nutrient solution in closed systems (Silva et al., 2016a; Alves et al., 2019). In Brazil (Alves et al., 2019) and in several parts of the world (Son et al., 2016), the NFT (Nutrient Film Technique) hydroponic system is the most used commercially. NFT is an active system which requires pumping of nutrient solution usually at 0.25 h intervals (Zanella et al., 2008; Cova et al., 2017). Since it depends on electricity, the expansion of hydroponics using the NFT system may be limited in sites where the infrastructure is inadequate to conduct electricity, which leads to insecurity in its supply (Santos Júnior et al., 2015; Silva et al., 2016a; Roy et al., 2018; Santos et al., 2019).

To overcome this problem of dependency on electricity, some researchers adopted the DFT (Deep Flow Technique) system in PVC tubes, mainly for cultivation of vegetables such as coriander (Santos Júnior et al., 2015; Silva et al., 2016ab; Silva et al., 2018a), lettuce (Cova et al., 2017), endive (Alves et al., 2019), rocket (Campos Júnior et al., 2018ab), parsley (Martins et al., 2019), chives (Silva Júnior et al., 2019ab), in which plant roots remain continuously immersed in the nutrient solution which is recirculated but not as frequently as in NFT system.

In case of short interruptions in electricity supply plants do not undergo water restriction in the DFT system in tubes (Silva et al., 2018a). Due to this advantage, in previous studies it was possible to increase recirculation intervals by up to 8 h (three times a day) (Silva et al., 2016a; Campos Júnior et al., 2018ab; Silva Júnior et al., 2019ab). In these studies the nutrient solution depths in the hydroponic channels varied between 0.04 and 0.045 m. On the other hand, recirculation intervals should not be very long because temperature of nutrient solution may increase as it remains static (Silva et al., 2016a), consequently limiting the dissolved oxygen supply to the roots (López-Pozos et al., 2011; Ikeura et al., 2018).

It is necessary to verify the technical feasibility of this system adapted in PVC tubes for different cultivation seasons, as well as to evaluate the interaction between nutrient solution depths in the hydroponic channels and the correct time interval of recirculation. Therefore, the objective of this study was to evaluate the effect of recirculation intervals and nutrient solution depths on the growth, production, water consumption, water use efficiency and quality of two commonly used coriander cultivars.

## MATERIALS AND METHODS

### Experiment location and environmental conditions

Two experiments with coriander (*Coriandrum sativum* L.) under hydroponic conditions were carried out in a greenhouse (East-West orientation), one from May to June 2016 (autumn) and other from March to April 2017 (summer-autumn). The greenhouse was 7.0 m wide and 24 m long, with ceiling height of 2.8 m, protected on the sides by black shade screen and covered by 150 µm thick polyethylene film (Fig. 1A). The study site is part of the experimental area of the Post Graduate Program in Agricultural Engineering, at the Soil and Water Engineering Nucleus, belonging to the Federal University of Recôncavo of Bahia, located in the municipality of Cruz das Almas, Bahia, Brazil (12° 40' 19" S, 39° 06' 23" W, and at an elevation of 220 m).

During the experiments, inside the greenhouse, the air temperature and relative humidity varied from 18.5 to 35.2 °C, and 40.2 to 95.5%, with mean values of 24.4 °C and 79.3% (autumn experiment); 21.3 to 33.6 °C, and 45.0 to 96.1%, with mean values of 25.8 °C and 80.5% (summer-autumn experiment). The data were monitored using a HMP45C thermo-hygrometer sensor (Vaisala, Inc.; Helsinki, Finland) connected to a CR 1000 model data logger (Campbell Scientific, Inc.; Logan, Utah, USA) and the means were recorded every 30 min. The data were collected during the period 8 to 25 and 5 to 15 days after transplanting (DAT) for the autumn and summer-autumn experiments, respectively.

### Experimental design and treatments

The autumn experiment was carried out in a completely randomized design and the summer-autumn experiment in a randomized block design, with four and five replications, respectively. A 2 x 3 x 2 factorial arrangement in split-plot was used, which consisted of two nutrient solution depths (0.02 and 0.03 m) and three recirculation intervals of the nutrient solution (0.25, 12 and 24 h), with two coriander cultivars ('Tabocas' and 'Verdão') in the sub-plots, which were cultivated in the same hydroponic channel.

The recirculation of nutrient solutions was controlled using an analog timer based on the following planning: at the interval of 0.25 h (control), the system was turned on for 15 min and turned off for 15 min, from 06:00 to 18:00 h; from 18:00 to 06:00 h, the system was turned on for 15 min, every 2 h; at the second and third intervals, recirculation was performed every 12 and 24 h, respectively, and each recirculation event lasted 15 min.

### Experimental structure

A hydroponic system with the Deep Flow Technique (DFT) was used, with 6-m channels made of PVC tubes of

0.075 m in diameter, and 0% slope, containing circular holes with 0.05 m in diameter, spaced 0.25 m apart (Fig. 1A). Caps were attached at the ends of each hydroponic channel, maintaining a mean level of the nutrient solution of 0.02 or 0.03 m (Fig. 1B). A drain was installed in the caps at the inlet end of the solution to control the nutrient solution level, conducting the excess solution through a tube back to the solution tank (Fig. 1C).

Benches with trestles made of PVC tubes of 0.05 m in diameter were used to support the hydroponic channels (1.10 m height from ground); three hydroponic channels were used per bench, with horizontal spacing of 0.30 m (Fig. 1A). One corridor (0.5 m wide) was left between the benches to facilitate transit and operability.

Each plot consisted of an independent hydroponic channel, containing a plastic tank (60-L capacity) to store the nutrient solution, and an electric pump to inject the nutrient solution into the channel (Fig. 1C). The tank had a ballcock valve to maintain a constant volume of 50 L of the solution from the water supply tank, built with PVC tube of 0.15 m in diameter. A transparent tube with a tape ruler was installed vertically on the outside of the supply tank to verify the water level in the tank (Fig. 1C). The solution and supply tanks were connected by a tube; the water output was manually controlled through a ball valve that remained closed. The ball valves of the supply tanks were opened daily at fixed hour to verify the water levels and quantify water consumption.



**Fig 1.** Overall view of the greenhouse and experimental structure (A), visualization of nutrient solution depth in the hydroponic channel (B) and components for distribution and return of solution (C). Vertical bar indicate the standard deviation of the mean of five replications.



### Crop conduction

Seeds of two coriander cultivars ('Tabocas' and 'Verdão') were sown in 80-mL plastic cups containing coconut fiber substrate, on 13 May 2016 (autumn experiment) and 14 March 2017 (summer-autumn experiment). 15 seeds of each coriander cultivar were sown per cup and covered with the substrate up to the cup top. The bottoms of the cups were cut at several places to permit root elongation. The seedlings were manually irrigated until transplanting to the hydroponic channels using public-supply water, which had electrical conductivity (EC<sub>w</sub>) of 0.3 dS m<sup>-1</sup> (autumn experiment) and 0.41 dS m<sup>-1</sup> (summer-autumn experiment).

The seedlings of coriander were transplanted to the hydroponic channels at 10 days after sowing, when the treatments started. Before transplanting, the thinning was carried out, leaving 12 seedlings per recipient (cup), according to recommendations of Silva *et al.* (2016b). Each hydroponic channel had 20 coriander bunches (10 of each cultivar).

### Nutrient solution and management of the experiments

The nutrient solution recommended by Furlani *et al.* (1999) for leafy vegetables was used. Nutrient solution was prepared with the available public-supply water of EC<sub>w</sub> 0.3 dS m<sup>-1</sup> (autumn experiment) and 0.41 dS m<sup>-1</sup> (summer-autumn experiment). After adding the nutrients, the resulting electrical conductivities of the solutions (EC<sub>sol</sub>) were 2.27 and 2.37 dS m<sup>-1</sup> and pH values of 5.7 and 5.8 for the autumn and summer-autumn experiments, respectively.

EC<sub>sol</sub> and pH of the solution in the hydroponic channels were monitored during the experiments using a conductivity meter with precision of 0.01 dS m<sup>-1</sup> and pH meter with precision of 0.01, respectively, with automatic temperature compensation (Hanna Instruments Inc.; Woonsocket, Rhode Island, USA). The pH values oscillated within the range recommended for hydroponic cultivation, 5.4 to 6.5 (autumn experiment) and 5.8 to 6.5 (summer-autumn experiment). At the end of the experiments, the EC<sub>sol</sub> values oscillated between 1.81 to 1.90 dS m<sup>-1</sup> (autumn) and 1.73 to 2.00 dS m<sup>-1</sup> (summer-autumn).

The temperatures of the nutrient solutions in the hydroponic channels were evaluated at two development stages (10 and 15 DAT) of the coriander plants, using type-J iron-constantan thermocouples. One thermocouple was used in the hydroponic channel of each treatment. The thermocouples were connected to a data logger, as described in section 'Experiment location and environmental conditions', with means recorded every 1 h.

The visual aspect of the coriander was monitored periodically to identify symptoms related to mineral deficiency, as well as to verify any damage caused by pest and diseases.

### Variables evaluated

#### *Dissolved oxygen concentrations of the nutrient solution*

The concentrations of dissolved oxygen (DO) of the nutrient solution in the hydroponic channels were evaluated only in the summer-autumn experiment at 6, 11, 14, 17, 19 and 24 DAT, in the mornings (08:00 h) and afternoons (14:00 h), using an oximeter with precision of 0.01 mg L<sup>-1</sup> and with automatic temperature compensation (Hanna Instruments Inc.; Woonsocket, Rhode Island, USA). The DO concentrations were analyzed in a split-plot arrangement, according to the measurement times (mornings and afternoons).

### Growth and production of the coriander

Harvests were performed at 20 and 25 DAT in each experiment. In each plot, five coriander bunches of each cultivar were collected, each one with 12 plants, to determine: plant height and shoot fresh matter (SFM) of the bunch of plants. Immediately after weighing, the material was placed in paper bags and dried in a forced-air oven at 65 °C until constant weight, to quantify shoot dry matter (SDM). Plant height was measured using a tape measure from the substrate level up to the apex of the plants.

### Water use efficiency and consumption of the coriander

The water consumption (WC) was calculated based on the volume consumed in the plot divided by the number of bunches of plants in the plot, for periods of 1-20 and 1-25 DAT, according to equation described by Santos *et al.* (2018). Water use efficiency (WUE) was also determined, based on the relationship between SFM or SDM production and the WC, according to equation described by Soares *et al.* (2019). The WC and the WUE were jointly established for both coriander cultivars.

### Statistical analysis

The data of the experiments were evaluated individually. The data were subjected to analysis of variance by F-test, after testing the normality using the Shapiro-Wilk test. The means obtained as a function of the treatments were compared by the Tukey-test ( $p \leq 0.05$ ).

## RESULTS AND DISCUSSION

### Dissolved oxygen concentration and temperature of the nutrient solution

The DO concentrations only in the summer-autumn experiment were significantly affected by isolated effects

and by the interactions between the factors. The DO concentrations in the mornings (Fig. 2A) were significantly higher due to the lower temperatures of the solution. The oxygen availability decreases in the rhizosphere of plants with increasing temperatures (Qin et al., 2007; Sakamoto et al., 2016).

The DO levels gradually decreased until 19 DAT, both in the mornings (Fig. 2A) and afternoons (Fig. 2B), followed by increase in the measurements carried out at 24 DAT. Such increase in DO levels may be explained by the reduction in the number of bunches of plants in the hydroponic channel (10 bunches were harvested at 20 DAT), thus reducing the number of plants competing for oxygen. This behavior of reduction in DO levels corroborates the results reported by Kiferle et al. (2012) and Niñirola et al. (2014), who also found lowest DO levels at the end of the cycle. This is due to the increase in the volume of active roots, consequently promoting greater demand for oxygen (Mobini et al., 2015).

Based on the isolated effects and by the interactions between the factors, at 6 DAT the highest DO levels were observed under recirculation interval of 0.25 h in the mornings, with mean of approximately 6.5 mg L<sup>-1</sup>. Under the other cultivation conditions, the values were less than 6.0 mg L<sup>-1</sup> (Fig. 2A).

Along the experiment, the highest reductions in DO concentrations occurred under recirculation interval of 0.25 h, being more drastic in the afternoons, regardless of the nutrient solution depths in the channels, with values lower than 4.0 mg L<sup>-1</sup> at 24 DAT (Fig. 2B); these reductions are due to the larger volume of plant roots due to growth of plants. For the other cultivation conditions, higher DO levels are justified by the smaller volume of roots, which consequently led to lower oxygen demand, with values above 6.0 mg L<sup>-1</sup> in the channel with nutrient solution depth of 0.02 m in the mornings (Fig. 2A).

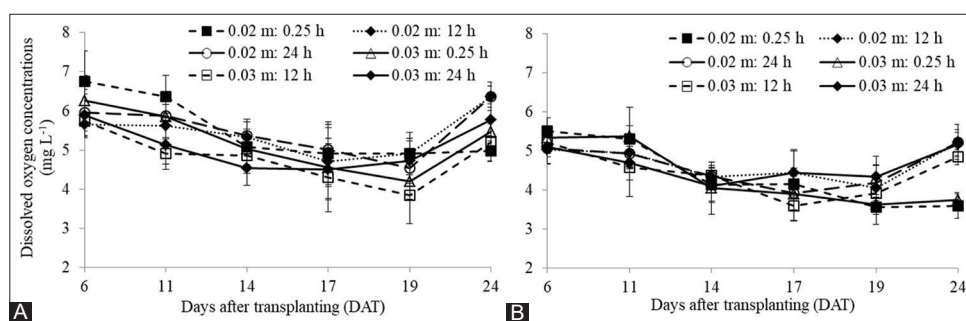
Lack of oxygen reduces the absorption of water and nutrients by roots, which may limit shoot growth and

consequently crop yield (Lenzi et al., 2011). Sensitivity to content of oxygen in the root zone is variable among species and within the same species (Conesa et al., 2015), as well as in the hottest periods of the year, when DO levels decrease and root respiration rates increase (Lenzi et al., 2011). In the study conducted by Lenzi et al. (2011) with spinach in non-aerated solution, at harvest DO levels were 1.92 mg L<sup>-1</sup> in the summer and 2.83 mg L<sup>-1</sup> in the autumn. Despite the low DO levels, yield was not affected because of the short cycle of the crop (22 and 30 days in the summer and autumn experiments).

The temperatures of the nutrient solution in the autumn experiment were approximately equal at 9 h, regardless of solution depths and recirculation intervals (Fig. 3A and 3B). After this time, as air temperature increased, the solution temperatures increased until 14 and 15 h, exceeding 40 °C under the solution depth of 0.02 m and recirculation interval of 0.25 h. In the hydroponic channels under solution depth of 0.03 m and recirculation interval of 0.25 h, the temperatures increased gradually, not exceeding 32 °C.

Between 12 and 13 h, temperatures remained constant under solution depth of 0.03 m and recirculation intervals of 12 and 24 h, because at 12 h the electric pumps of these treatments were turned on, establishing the maximum volume in the hydroponic channel and thereby reducing temperature. At 18 h the temperatures were again approximately equal under the different cultivation conditions, but after this time they decreased more rapidly in the channels with solution depth of 0.02 m. This is due to the specific heat of water, because with solution depth of 0.03 m (larger volume), the solution got heated more slowly and, after heated, its cooling was slower compared to the condition of smaller volume (0.02 m depth).

High temperatures in the channel under solution depth of 0.02 m and recirculation interval of 0.25 h are justified by the heat exchanges between the channel and the nutrient



**Fig 2.** Dissolved oxygen concentrations of the nutrient solution in the hydroponic channels for the coriander grown under different depths and recirculation intervals of nutrient solution, in the mornings (A) and afternoons (B) in the summer-autumn experiment.

solution because, when the system was at rest, the channels got heated rapidly due to the incidence of direct radiation. Therefore, in each recirculation event the solution gained heat when returning to the tank.

In the summer-autumn as air temperature increased the temperatures of the solutions in the different cultivation conditions increased similarly (Fig. 3C and 3D). Until 10 h in the mornings the temperatures were always less than 30 °C, regardless of intervals and solution depths in the cultivation channels. In general, solution temperatures within the range from 20 to 30 °C are considered as adequate for growth of the plants (He et al., 2019). In different studies, solution temperatures above 30 °C have been recorded during the hottest hours of the day (Santos et al., 2010; Santos et al., 2011; Cometti et al., 2013; Silva et al., 2018b).

### Visual symptoms of the coriander plants

Visually, coriander plants were not affected by treatments in the autumn experiment, being considered as of commercial quality. Despite the smaller root volume of plants produced under recirculation intervals of 12 and 24 h compared to the control treatment (interval of 0.25 h), the shoot did not exhibit any type of symptom (Fig. 4A and 4B). These results corroborate those found by Silva et al. (2016ab), who reported that the visual quality of coriander cv. 'Verdão' grown in channels with solution depth of 0.045 m was not affected by recirculation intervals of 8 and 2 h, respectively.

Despite the low fresh matter production of the cv. 'Verdão' when grown in channels under solution depth of 0.03 m and recirculation intervals of 12 and 24 h in the summer-autumn experiment, the quality of the plants was not

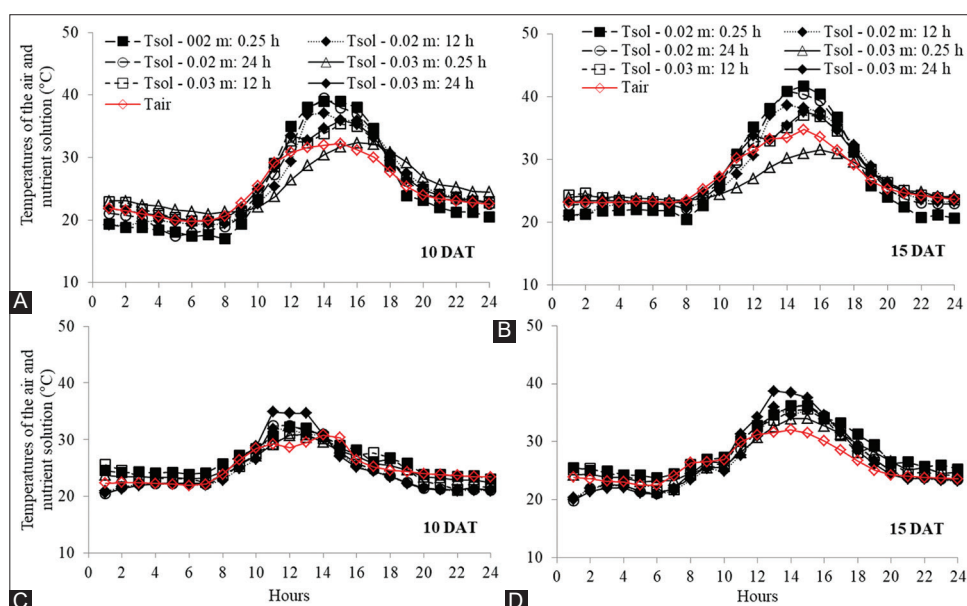
affected (Fig. 4C and 4D). By contrast, the cv. 'Tabocas' when subjected to 12 and 24 h recirculation intervals and grown in channels with solution depths of 0.02 and/or 0.03 m, the plants exhibited compromising characteristics for commercialization of the shoot (yellowish leaves), with poorly developed, dark roots.

### Growth and production of the coriander

According to the F-test of the analysis of variance, for the two evaluated periods (20 and 25 DAT) in both experiments, the plant height, shoot fresh matter (SFM) and shoot dry matter (SDM) of coriander plants were significantly affected by isolated effect of the recirculation intervals of nutrient solution (Table 1). The plant height (25 DAT), SFM (25 DAT) and SDM (20 DAT) were significantly influenced by the nutrient solution depths for the autumn experiment; whereas for the summer-autumn experiment those same variables were influenced in the two periods. In general, significant differences between coriander cultivars were observed for evaluated variables, except for SDM in the autumn experiment at 20 DAT.

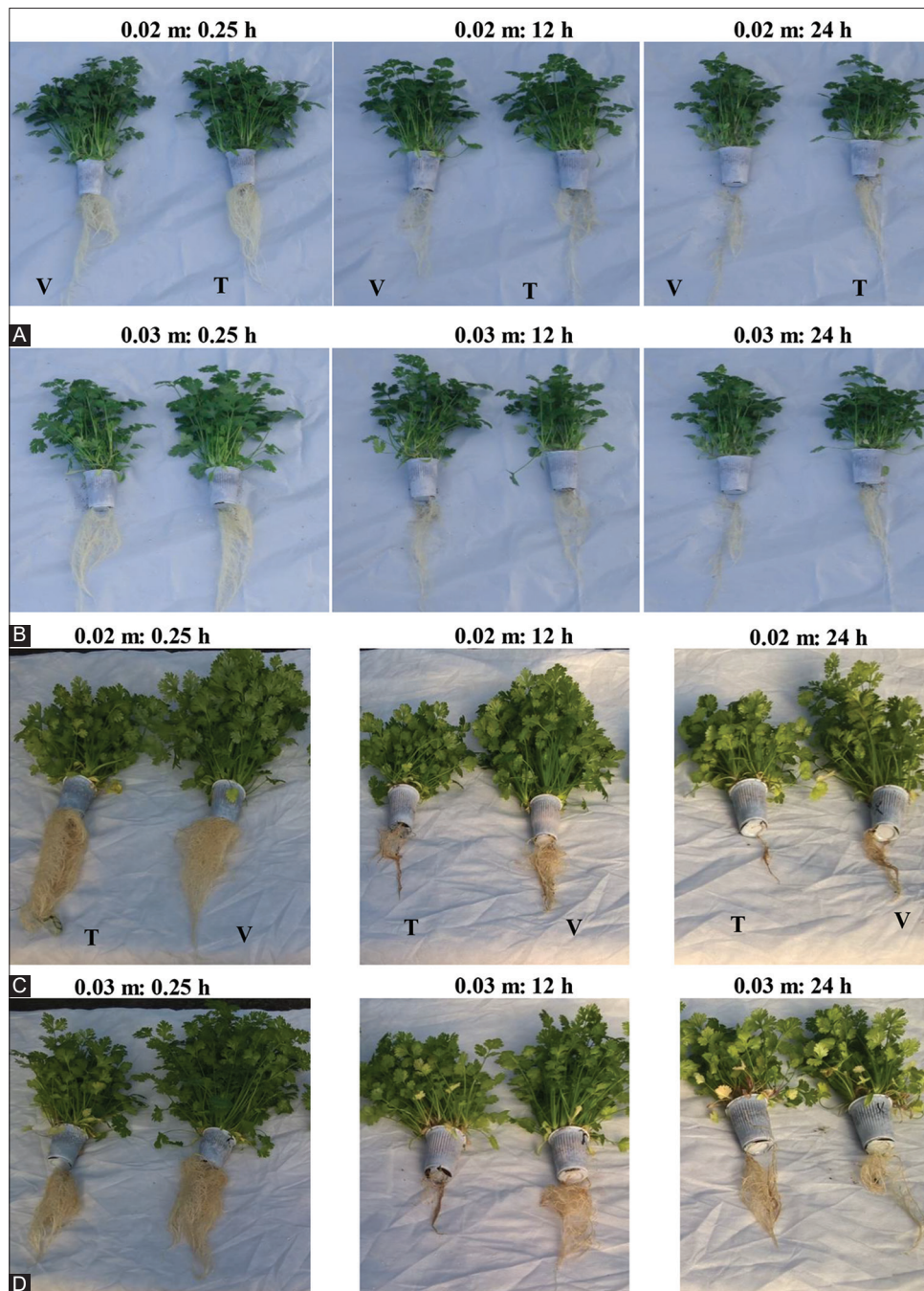
There was significant interaction between recirculation intervals and coriander cultivars for plant height (20 DAT), SFM (20 DAT) and SDM (20 and 25 DAT) in the autumn experiment. Significant interaction between nutrient solution depths and coriander cultivars were observed only on plant height (20 DAT) in the autumn experiment and on SFM (20 and 25 DAT) and SDM (20 DAT) in the summer-autumn experiment (Table 1).

For plant height, the means at 20 DAT were similar in both experiments, slightly more than 20 cm under recirculation



**Fig 3.** Temperature of the air and nutrient solution in the hydroponic channels for the coriander grown under different depths and recirculation intervals of nutrient solution, in the autumn (A and B) and summer-autumn (C and D) experiments.





**Fig 4.** Visual aspect of coriander cv. 'Verdão' (V) and cv. 'Tabocas' (T) grown in hydroponic channels under different depths and recirculation intervals of nutrient solution, in the autumn (A and B) and summer-autumn (C and D) experiments. LSD - least significant difference; vertical bar indicate the standard deviation of the mean; Au - autumn; S-Au - summer-autumn; Figure a - lowercase letters compare the means of the cultivars in each interval (LSD = 0.86) or depth (LSD = 0.71) and uppercase letters compare the means of the intervals (LSD = 1.05) or depths (LSD = 0.71) in each cultivar; in all Figures different letters indicate significant differences at  $p \leq 0.05$  by Tukey-test.

interval of 0.25 h (Fig. 5A and 5B). However, at 25 DAT a higher plant height (30.54 cm) was observed in the experiment carried out in the autumn compared to the summer-autumn experiment (25.42 cm) (Fig. 5B).

The higher plant height (30.54 cm) observed in the present study at 25 DAT for the autumn experiment was similar to that reported by Silva et al. (2015a) in the spring, of the order

of 31.60 cm in the NFT system at 24 DAT. In this study, the bunches of coriander cv. 'Verdão' were spaced at 0.30 m in the hydroponic channels. In contrast to these results, highest values of plant height of coriander cv. 'Verdão' grown in DFT hydroponics in tubes were reported by Silva et al. (2016a) in the summer, by Silva et al. (2016b) in the spring and by Silva et al. (2018a) in the winter, of 39.00, 37.48 and 37.08 cm, respectively. The highest values found in these studies are

**Table 1: Summary of the F-test for plant height, shoot fresh matter (SFM) and shoot dry matter (SDM) of two cultivars of coriander grown under different recirculation intervals (RI) and depths of nutrient solution (DNS) in the hydroponic channels**

Source of variation	Degrees of freedom	F-test					
		Plant height		SFM		SDM	
		Days after transplanting (DAT)					
		20	25	20	25	20	25
		Autumn experiment					
RI	2	**	**	**	**	**	**
DNS	1	ns	**	ns	**	*	ns
RI x DNS	2	ns	ns	ns	ns	ns	ns
Error (1)	18	-	-	-	-	-	-
Cultivars	1	**	**	*	**	ns	**
RI x Cultivars	2	*	ns	**	ns	*	*
DNS x Cultivars	1	*	ns	ns	ns	ns	ns
RI x DNS x Cultivars	2	ns	ns	ns	ns	ns	ns
Error (2)	18	-	-	-	-	-	-
CV1 (%)		7.40	6.90	14.89	14.65	16.19	17.23
CV2 (%)		4.22	7.24	12.24	17.35	9.00	17.62
Summer-autumn experiment							
Blocks	4	ns	ns	ns	ns	ns	ns
RI	2	**	*	**	**	**	**
DNS	1	**	**	**	**	**	**
RI x DNS	2	ns	ns	ns	ns	ns	ns
Error (1)	24	-	-	-	-	-	-
Cultivars	1	**	**	**	**	**	**
RI x Cultivars	2	ns	ns	ns	ns	ns	ns
DNS x Cultivars	1	ns	ns	*	**	*	ns
RI x DNS x Cultivars	2	ns	ns	ns	ns	ns	ns
Error (2)	20	-	-	-	-	-	-
CV1 (%) <sup>a</sup>		10.70	11.80	25.04	28.70	19.73	20.15
CV2 (%) <sup>b</sup>		7.19	8.61	9.62	10.92	9.41	14.44

<sup>a</sup>and <sup>b</sup>-Coefficients of variation of the errors 1 and 2, respectively; \*and \*\*significant respectively at p<0.05 and p<0.01; ns - not significant

justified by the smaller spacing (0.07 m) used between bunches of plants, which intensifies the competition for light.

In general, the highest values of plant height were obtained for the coriander cv. 'Verdão' in comparison to the cv. 'Tabocas' (Fig. 5A and 5C). The superiority in plant height of the coriander cv. 'Verdão' compared to the cv. 'Tabocas' was reported in other studies, such by Bonifacio et al. (2014) in the cultivation in a sand substrate under salt stress and by Soares et al. (2017) in hydroponics NFT.

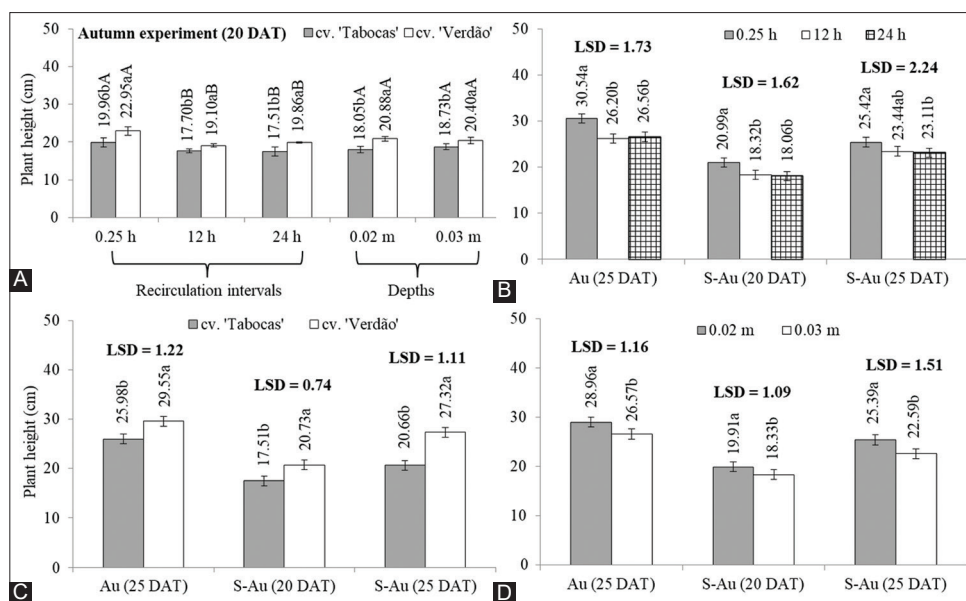
In the follow-up analysis of the interactions for plant height at 20 DAT in the autumn experiment (Fig. 5A), plants of the coriander cv. 'Verdão' grown under the recirculation intervals of 0.25, 12 and 24 h, and under nutrient solution depths of 0.02 and 0.03 m presented highest means in comparison to the cv. 'Tabocas'. When evaluating the cultivars in each recirculation interval, the highest means were obtained under interval of 0.25 h; whereas under the intervals of 12 and 24 h the means did not differ statistically (Fig. 5A); similar behavior was observed at 25 DAT (Fig. 5B).

At 20 DAT in the summer-autumn experiment, similar behavior of plant height in function of recirculation intervals was observed, whereas at 25 DAT when the plants were grown under solution recirculation twice a day (12 h) the means did not differ statistically from the control (0.25 h) (Fig. 5B). In another study in the DFT system in tubes carried out by Silva et al. (2016a), the plant height of coriander was a variable that had no significant changes under solution recirculation three times a day (every 8 h) in relation to the control (0.25 h) at 21 DAT.

For nutrient solution depths, the highest means of plant height were obtained, in general, when the plants were grown under depth of 0.02 m in comparison to the 0.03 m depth (Fig. 5D).

Regarding the SFM, at 20 DAT higher yield was observed in the summer-autumn experiment (Fig. 6B) when compared to the autumn experiment (Fig. 6A), while at 25 DAT the mean yields were similar in both experiments, of the order of 55.61 and 56.32 g (bunch), respectively, obtained





**Fig 5.** Plant height of the coriander grown under hydroponic conditions: follow-up analyses of the interactions between cultivars and the recirculation intervals and nutrient solution depths in the hydroponic channels (A); isolated effects of the recirculation intervals (B), cultivars (C) and solution depths (D). LSD - least significant difference; vertical bar indicate the standard deviation of the mean; Au - autumn; S-Au - summer-autumn; Figures a and d - lowercase letters compare the means of the cultivars in each recirculation interval (LSD = 2.10) or depth (LSD = 1.74 at 20 DAT and LSD = 3.69 at 25 DAT) and uppercase letters compare the means of the intervals (LSD = 2.55) or depths (LSD = 1.74 at 20 DAT and LSD = 3.69 at 25 DAT) in each cultivar; in all Figures different letters indicate significant differences at  $p \leq 0.05$  by Tukey-test.

under recirculation interval of 0.25 h, and regardless of the coriander cultivars (Fig. 6B). Such higher SFM accumulation within the 5-day period (between 20 and 25 DAT) in the autumn experiment, which was comparable to the production in the summer-autumn experiment, was due to higher height of the plants (Fig. 5B). Similar behavior was observed for SDM (Fig. 7).

In general, the highest means of SFM (Fig. 6A, 6C and 6D) and SDM (Fig. 7A, 7B and 7C) were obtained for the coriander cv. 'Verdão' in relation to the cv. 'Tabocas', under recirculation interval of 0.25 h in relation to the intervals of 12 and 24 h, and under solution depth of 0.02 m in relation to the 0.03 m depth in both experiments.

At 20 (Fig. 6A) and 25 DAT (Fig. 6C), the means of SFM of the coriander cv. 'Verdão' were approximately 23% higher compared to the cv. 'Tabocas' in the autumn experiment. For the summer-autumn experiment (Fig. 6D), when the plants of the cv. 'Tabocas' were grown under solution depth of 0.03 m the SFM was drastically affected, mainly at 25 DAT, with yield approximately 40% lower in comparison to the cv. 'Verdão'.

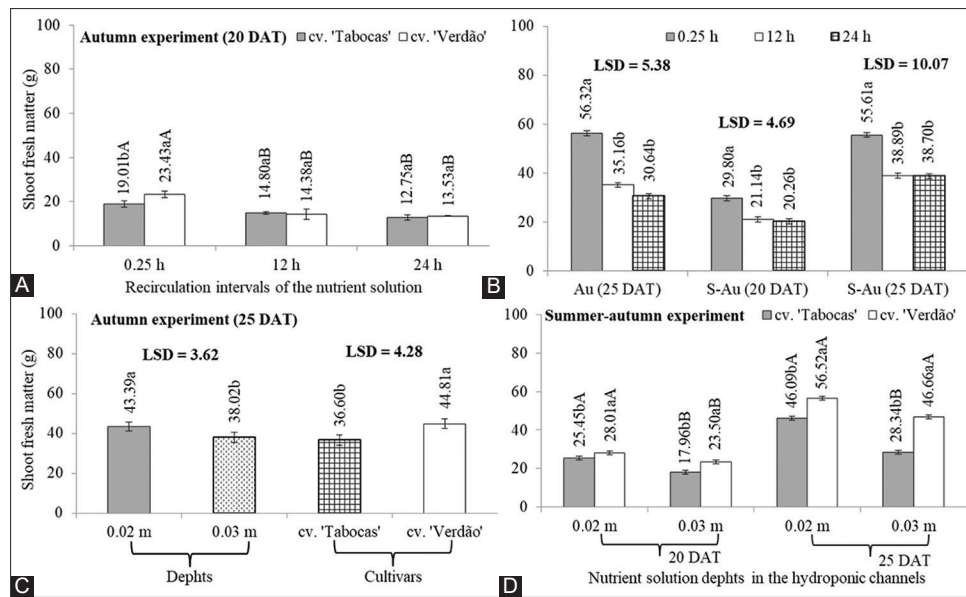
As observed in the present study, the production potential of the coriander cv. 'Verdão' compared to the cv. 'Tabocas' was reported by Pereira et al. (2011) cultivating in pots using soil, by Silva et al. (2015b) in the cultivation in soil and by Soares et al. (2017) in NFT hydroponics. In the cultivation of coriander in DFT system in tubes (with 0.02 m depth),

Silva et al. (2019) reported SFM yield of the cv. 'Verdão' approximately 80% higher compared to the cv. 'Tabocas' for 25 DAT. Different results were reported by Bonifacio et al. (2014) with coriander plants irrigated with nutrient solution without NaCl, where the fresh matter production was approximately 14% higher for the cv. 'Tabocas' compared to the cv. 'Verdão'.

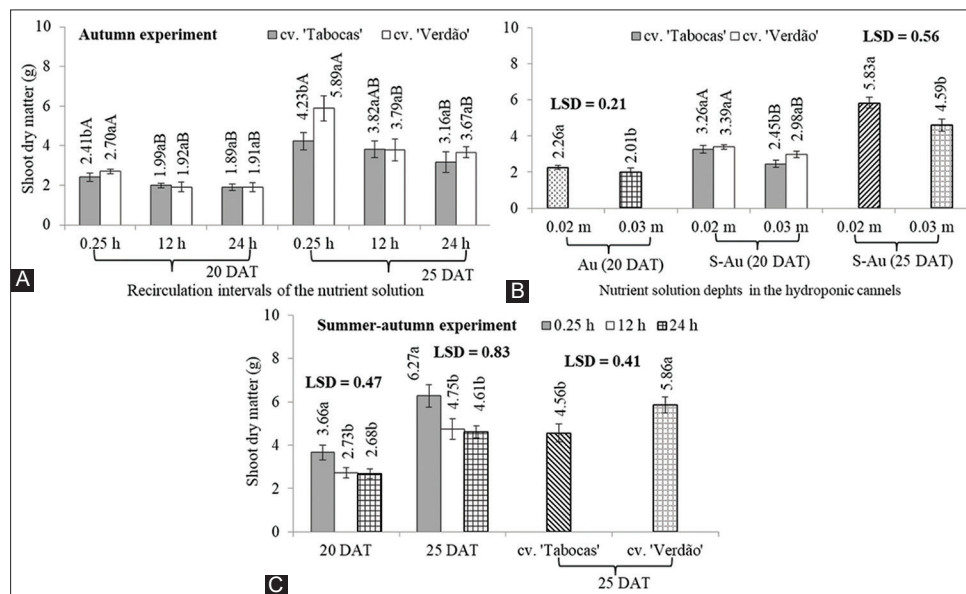
At 25 DAT, the SFM yields of the coriander cv. 'Verdão' of 44.81 g in the autumn experiment (Fig. 6C) and 46.66 g under solution depth of 0.03 m in the summer-autumn experiment (Fig. 6D) are compatible to the yields reported by Silva et al. (2016a) and Silva et al. (2018a). These authors reported SFM yields of 50.33 and 44.05 g (bunch of 12 plants), respectively, with plants of coriander cv. 'Verdão' grown in nutrient solution prepared with fresh water in DFT system in tubes with 0.045 m depth for 25 DAT.

Regarding the yield of the cv. 'Tabocas', at 25 DAT the SFM (46.09 g) obtained under solution depth of 0.02 m is compatible with the results reported by Cavalcante et al. (2016), who grew this cultivar in DFT hydroponic in tubes with 0.04 m depth for 28 days, with SFM of 45.44 g (bunch) at sowing rate of 0.5 g.

Regarding the differences on SFM in function of the recirculation intervals, at 25 DAT the mean yields under intervals of 12 and 24 h were approximately 42 and 30% lower compared to the interval of 0.25 h in the autumn and summer-autumn experiments, respectively (Fig. 6B). The



**Fig 6.** Shoot fresh matter of the coriander grown under hydroponic conditions: follow-up analyses of the interaction between cultivars and recirculation intervals (A), isolated effects of the recirculation intervals (B), solution depths and cultivars (C) and follow-up analyses of the interaction between cultivars and solution depths (D). LSD - least significant difference; vertical bar indicate the standard deviation of the mean; Au - autumn; S-Au - summer-autumn; Figures a and b - lowercase letters compare the means of the cultivars in each recirculation interval (LSD = 0.20 at 20 DAT and LSD = 0.76 at 25 DAT) or depth (LSD = 0.22) and uppercase letters compare the means of the intervals (LSD = 0.25 at 20 DAT and LSD = 0.92 at 25 DAT) or depths (LSD = 0.22) in each cultivar; in all Figures different letters indicate significant differences at  $p \leq 0.05$  by Tukey-test.



**Fig 7.** Shoot dry matter of the coriander grown under hydroponic conditions: follow-up analyses of the interaction between cultivars and recirculation intervals (A), follow-up analyses of the interaction between cultivars and nutrient solution depths in the hydroponic channels (B); isolated effects of the solution depths (B) and recirculation intervals and cultivars (C). LSD - least significant difference; vertical bar indicate the standard deviation of the mean; Au - autumn; S-Au - summer-autumn; Figure b - lowercase letters compare the means of the solution depths in each recirculation interval (LSD = 0.47) and uppercase letters compare the means of the interval in each solution depth (LSD = 0.57); in all Figures different letters indicate significant differences at  $p \leq 0.05$  by Tukey-test.

SFM yield of approximately 39 g (bunch) obtained under intervals of 12 and 24 h in the summer-autumn experiment is considered satisfactory, because this value being very close to that reported by Silva *et al.* (2016a). This author reported SFM of 40.72 g per bunch of 12 plants of the coriander cv. 'Verdão' grown under recirculation interval

every 8 h (three times a day) in DFT system in tubes with 0.045 m depth for 25 DAT.

In similar studies in DFT hydroponics in tubes, different frequencies of solution recirculation throughout the day were evaluated, such as three times a day (every 8 h) in

coriander (Silva et al., 2016a), rocket (Campos Júnior et al., 2018ab) and chives (Silva Júnior et al., 2019ab); six times a day (every 4 h) in lettuce (Cova et al., 2017) and four times a day (every 6 h) in basil (Santos et al., 2019). Such frequencies of solution recirculation were viable for the cultivation of these species.

The results of the present study indicate that the higher volume of nutrient solution (0.03 m depth) in the hydroponic channel did not result in benefits for growing coriander. In this case, it is preferred to use smaller volume of solution (0.02 m depth) in the channels, resulting in economy of the cost with water and fertilizers to prepare nutrient solution.

In the DFT system in tubes the volume of solution in the hydroponic channel will be able to maintain plants without water restriction in case of interruptions in the electricity supply, but when the solution remains static for a long period during the day, crop yield may be reduced due to lack of oxygenation. Therefore, according to Ikeura et al. (2017), it is important to maintain an optimal oxygen supply to the nutrient solution, in the case of the present study, by adjusting the recirculation intervals.

#### Water use efficiency and consumption of the coriander

The F-test of the analysis of variance showed a significant effect of the recirculation intervals on water consumption (WC) and water use efficiency (WUE) of the SFM of coriander plants at 20 and 25 DAT in both experiments (Table 2). The solution depths in the hydroponic channels had a significant effect on WUE of the SFM at 25 DAT

(autumn experiment) and on WC and WUE of the SFM in two evaluated periods (summer-autumn experiment).

The isolated effects of the factors and interactions between them caused no significant changes on WUE of the SDM in any evaluated period (Table 2), with means of 3.03 and 5.21 g L<sup>-1</sup> at 20 and 25 DAT, respectively. These results confirm those of Campos Júnior et al. (2018b), who found no significant effect on the WUE of the SDM of rocket plants grown in the hydroponic channels (0.04 m depth) with two and three times a day recirculation of nutrient solution.

As observed for growth and production variables, the highest means of the WC (Fig. 8A and 8B) and WUE of the SFM (Fig. 8C and 8D) were obtained, in general, under the recirculation interval of 0.25 h and solution depth of 0.02 m. Under recirculation interval of 0.25 h, the means of cumulative WC were 1.48 and 1.93 L per bunch in the periods of 20 and 25 DAT in the autumn experiment (Fig. 8A). In the first 20 days in the summer-autumn experiment the WC was higher than that found along the entire cycle in the autumn experiment under recirculation interval of 0.25 h, of the order of 2.06 L per bunch, while under the recirculation intervals of 12 and 24 h the means were approximately 22% lower (Fig. 8A).

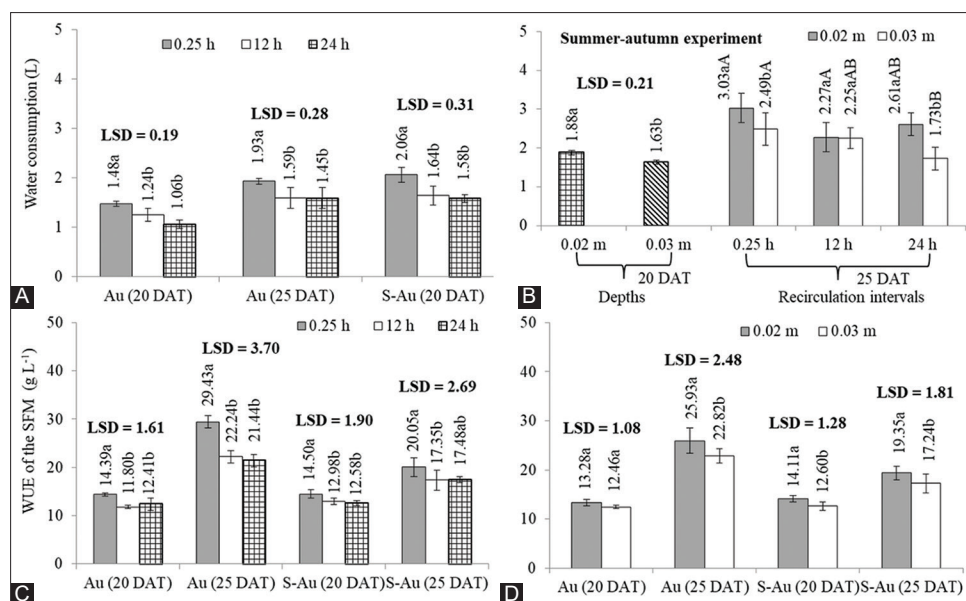
The negative effect on WC under highest level of nutrient solution in the channels (0.03 m depth) was more pronounced in the summer-autumn experiment, when the means were approximately 13 and 18% lower compared to the 0.02 m depth at 20 and 25 DAT, respectively (Fig. 8B).

**Table 2: Summary of F-test for water consumption (WC) and water use efficiency (WUE) of the shoot fresh matter (SFM) and shoot dry matter (SDM) of the coriander grown under different recirculation intervals (RI) and depths of nutrient solution (DNS) in the hydroponic channels**

Source of variation	Degrees of freedom	F-test					
		Water consumption		WUE - SFM		WUE - SDM	
		Days after transplanting (DAT)					
		1-20	1-25	20	25	20	25
Autumn experiment							
RI	2	**	**	**	**	ns	ns
DNS	1	ns	ns	ns	*	ns	ns
RI x DNS	2	ns	ns	ns	ns	ns	ns
Error	18	-	-	-	-	-	-
CV (%)		11.70	13.10	9.80	11.88	11.49	14.11
Summer-autumn experiment							
Blocks	4	ns	ns	ns	ns	ns	ns
RI	2	**	**	*	*	ns	ns
DNS	1	*	**	*	*	ns	ns
RI x DNS	2	ns	*	ns	ns	ns	ns
Error	20	-	-	-	-	-	-
CV (%) <sup>a</sup>		15.53	14.98	12.59	13.00	11.59	12.34

<sup>a</sup>Coefficient of variation; \*and \*\*significant respectively at p<0.05 and p<0.01; ns - not significant





**Fig 8.** Water consumption and water use efficiency of the shoot fresh matter of the coriander grown under hydroponic conditions: isolated effects of the recirculation intervals (A and C) and solution depths (B and D); follow-up analyses of the interaction between the recirculation intervals and solution depths in the hydroponic channels (B).

The percentage calculated at 25 DAT was obtained for the 0.25 h recirculation interval.

The depths of 0.02 and 0.03 m corresponded to approximately 6 and 12 L of nutrient solution in the channels; considering the period of greatest water demand of coriander plants (between 20 and 25 DAT) - 0.125 L per bunch, in case of interruption of the electricity supply, the system would have autonomy to maintain 20 bunches of plants (in each channel) without water restriction for more than two and four days, respectively.

The WC values of 1.93 and 3.03 L observed in the autumn and summer-autumn experiments, respectively, are within the range reported in other studies with coriander, of 2.59 L per bunch of 8 plants in the winter (Cazuza Neto *et al.*, 2014) and 2.21 L per bunch of 24 plants in the spring (Silva *et al.*, 2017) in NFT hydroponic system. In studies using DFT system in tubes, lower WC values were found, 1.45 L in the summer (Silva *et al.*, 2016a) and 0.89 L in the winter (Silva *et al.*, 2018a) for bunch of 12 plants. In these studies the coriander cv. 'Verdão' was used.

The differences in WC values in the different studies are justified by the availability of solution per bunch of plants because, in the present study, the availability was equal to 2.76 and 3.10 L (calculated from the volume divided by the number of bunches of plants in the hydroponic channel) with nutrient solution depths of 0.02 and 0.03 m, whereas Cazuza Neto *et al.* (2014) and Silva *et al.* (2017) used greater availability of solution (above 5.0 L), and it did not exceed 1 L in the studies conducted by Silva *et al.* (2016a) and Silva *et al.* (2018a).

At 20 DAT, the means of WUE of the SFM had the same magnitude in both experiments, not exceeding 15 g L<sup>-1</sup> under recirculation interval of 0.25 h (Fig. 8C). At 25 DAT there was an increase in WUE in the autumn experiment, due to the greater increase in SFM production with the use of lower water volume, with means of 29.43 and 20.05 g L<sup>-1</sup> under recirculation interval of 0.25 h in the autumn and summer-autumn experiments.

In general, the means of WUE of the SFM obtained in function of the solution depths (Fig. 8D) are very close to those found under the recirculation intervals.

## CONCLUSIONS

The coriander cv. 'Verdão' was more tolerant to climatic variations of autumn and summer-autumn, especially when plants were grown in channels with nutrient solution depth of 0.02 m and recirculation of the nutrient solution every 0.25 h, presenting higher growth and production. The lower level of nutrient solution in the hydroponic channel (0.02 m depth) promoted better responses of the variables evaluated in coriander plants, despite increasing the solution temperature. There was a greater reduction in the dissolved oxygen concentrations under the recirculation interval of the nutrient solution of 0.25 h, due to the larger volume of roots produced; however, the yield of the coriander was not affected. The recirculation intervals of the nutrient solution of 12 and 24 h had a negative effect on the variables evaluated and, this effect was more significant in the summer-autumn experiment,

affecting the quality of the plants evaluated, especially those of the cv. 'Tabocas'.

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## Declarations of conflict of interest

The authors report no declarations of conflict of interest.

## Authors' contributions

All authors contributed to the work presented here, read and approved the final manuscript. Mairton Gomes da Silva, Tales Miler Soares and Hans Raj Gheyi conceived, designed the experiments, analyzed the data and wrote the paper. Mairton Gomes da Silva, Islan Passos Costa and Rafael Souza Vasconcelos carried out the experiments in field and collected, tabulated and analysed data.

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