ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

FREQUENCIES OF APPLICATION AND DILUTION OF NUTRIENT SOLUTION IN HYDROPONIC CULTIVATION OF ARUGULA

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1 ABSTRACT

Fertilizer formulation, such as irrigation frequency, is fundamental for the success of cultivation, since the absorption of nutrients from the nutrient solution is a selective and dynamic process. Thus, the present experiment was conducted to evaluate the production of arugula in hydroponic cultivation subjected to different dilutions and frequencies of application of the nutrient solution. The experiments were carried out in a randomized block design with four replicates. A split-plot in a 5 x 2 factorial arrangement was used, which consisted of five dilutions based on the electrical conductivity of the nutrient solution (EC_{sol}: 2.00 (control), 1.81, 1.62, 1.40, and 1.30 dS m^{-1}) and two application frequencies (variable and fixed), totaling 40 experimental plots. Yield and growth variables, relative chlorophyll index and macronutrients were analyzed. Regarding shoot fresh mass, there was an increase with the ECsol, reaching a maximum of 15.52 and 8.40 g $plant^{-1}$, with nutrient solutions of 1.77 dS m^{-1} (first cycle) and 1.88 dS m^{-1} (second cycle). Using only 90% of the recommended nutrient solution is the most appropriate from the commercial point of view, as it led to maximum potential in relation to yield, using a smaller number of inputs.

Keywords: electrical conductivity, greenhouse, temperature sensor

SANTOS, J. S. G.; SILVA, A. O.; LACERDA, C. F.; TÁVORA, R. N.; SILVA. G. F.; PUTTI, F. F.
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2 RESUMO

A formulação de fertilizantes assim como a frequência da irrigação são fundamentais para o êxito do cultivo, visto que a absorção de nutrientes da solução nutritiva é um processo seletivo e dinâmico. Desta maneira, o experimento foi conduzido objetivando-se avaliar a produção e o

Recebido em 30/11/2021 e aprovado para publicação em 19/07/2022
DOI: http://dx.doi.org/10.15809/irriga.2022v27n3p639-652

desenvolvimento da rúcula em cultivo hidropônico, submetida a diferentes diluições e frequências de aplicação da solução nutritiva. O experimento foi conduzido em blocos casualizados com quatro repetições em parcelas subdivididas em um arranjo fatorial 5 x 2, consistindo de cinco diluições baseadas na condutividade elétrica da solução nutritiva (EC_{sol}: 2,00 (controle), 1,81; 1,62; 1,40 e 1,30 dS m^{-1}) e duas frequências de aplicação (variável e fixa), totalizando 40 parcelas experimentais. Foram analisadas variáveis de rendimento e crescimento, índice SPAD e macronutrientes nas folhas. Observou-se um aumento da fitomassa fresca da parte aérea com incremento da EC_{sol}, atingindo um máximo de 15,52 e 8,40 g $planta^{-1}$, quando a EC_{sol} foi de 1,77 dS m^{-1} (primeiro ciclo) e 1,88 dS m^{-1} (segundo ciclo). O uso de apenas 90% da solução nutritiva recomendada se mostra a mais adequada do ponto de vista comercial, obtendo um potencial máximo com relação a produção, utilizando uma menor quantidade de insumos.

Palavras-chave: condutividade elétrica, casa de vegetação, sensor de temperatura

3 INTRODUCTION

Water has been the subject of concern in many parts of the world. Among the regions facing scenarios of water scarcity, semiarid areas stand out because they are subject to irregular distributions of rainfall in time and space, which leads to periods of acute drought and consequently low availability of water for agriculture (LIRA *et al.*, 2019; SOUZA *et al.*, 2020).

A solution considered viable and capable of enabling the production of agricultural crops under water scarcity is hydroponic cultivation, which consists of a set of techniques for growing plants without using soil, in which essential nutrients are supplied to plants through a balanced nutrient solution (BIONE *et al.*, 2021). All nutrients necessary for crop development should be supplied by the nutrient solution that circulates through hydroponic profiles in a sufficient time of circulation to promote their adequate supply to plants (SILVA *et al.*, 2020b).

Currently, nutrient solutions originally developed for lettuce are applied to the various crops produced in hydroponic medium in several regions (SILVA *et al.*, 2013; LIRA *et al.*, 2019; SOUZA *et al.*, 2020), without proper knowledge on the efficiency of these solutions and their concentrations for other species (LUZ *et al.*, 2018). In this context, with the second largest hydroponic production in Brazil (SILVA *et al.*, 2021), arugula (*Eruca sativa* L.) with rapid vegetative growth, short cycle and small size (PURQUERIO *et al.*, 2007) has good adaptability to hydroponic systems. According to Genuncio *et al.* (2011), arugula in hydroponic cultivation possibly has a higher yield in milder environmental conditions, such as higher temperature conditions, principally when handled efficiently as the solution flows. However, despite its high production and adaptability, this vegetable does not have its own nutrient solution, always using a basic commercial nutrient solution, which can often lead to overestimates of its nutritional demand (SILVA *et al.*, 2021; LUZ *et al.*, 2018).

Another problem in hydroponic management would be the circulation time of the nutrient solution. In the literature, there is only an indication of 15 minutes frequency to application in plants. However, many regions can have high temperatures with different water consumption that can change the frequency of irrigation in hydroponic systems (SOUZA *et al.*, 2020).

In view of the above, the objective of this study was to evaluate arugula subjected to different dilutions and frequencies of application of the nutrient solution in hydroponic conditions.

4 MATERIALS AND METHODS

4.1 Experimental area and structure used

The experiments were conducted in a 6.25-m-wide, 12-m-long greenhouse with a single arch covered with 100-µm-thick low-density polyethylene film. The experimental area was located in the Agriculture Engineering Department of the Federal University of Ceará (UFC), Pici, campus Fortaleza, with geographic coordinates of 3° 44’ 43.273” south latitude and 38° 34’ 56.650” west longitude and an average altitude of 22 m.

In 2019, three production cycles were carried out, the first from June 12 to July 22, the second from September 9 to October 9, and the third from October 15 to November 15. In these cycles, minimum temperatures of 24.8, 25.1 and 25.2 °C and maximum temperatures of 37.6, 37.8 and 39.9 °C were recorded, respectively.

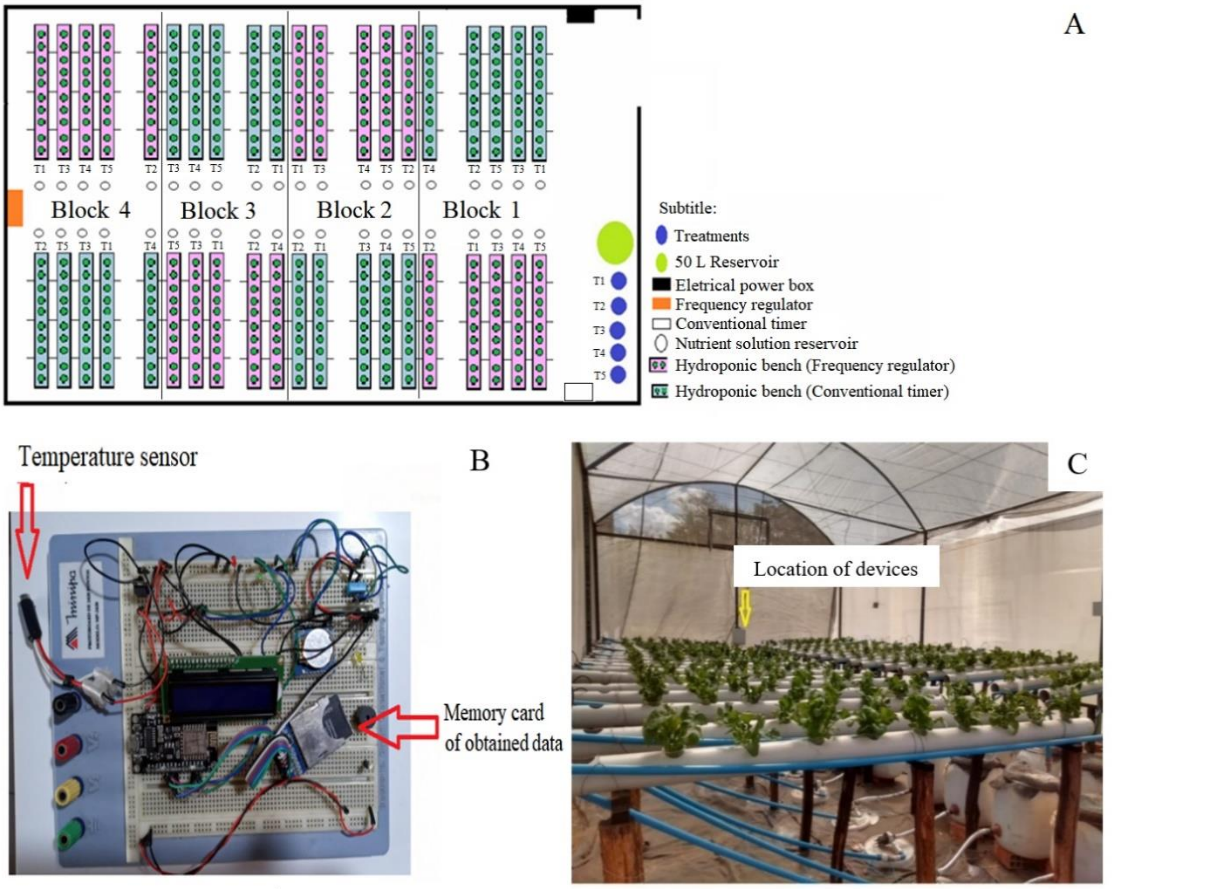
The hydroponic system used was the NFT (Nutrient Film Technique), composed of 40 profiles 2.5 m in length, in addition to electric pumps, individual reservoirs and microtubes with a flow rate of 1.5 L min^{-1}. The spacing adopted was 0.50 m between profiles and 0.30 m between plants, thus totaling eight plants per profile.

4.2 Statistical design and treatments

The experiments were carried out in a randomized block design with four replicates. A split-plot scheme in a 5 x 2 factorial arrangement was used, which consisted of five dilutions based on the electrical conductivity of the nutrient solution (EC_{sol}: 2.00 (control), 1.81, 1.62, 1.40, and 1.30 dS m^{-1}, corresponding to 100, 90, 80, 70, and 65% concentrations, respectively) recommended by Furlani (1999) and two application frequencies (fixed and variable), totaling 40 experimental plots (Figure 1A).

The fixed frequency was controlled using an analog timer based on the following planning: at the interval of 15 min (15 min of circulation and turned off for 15 min). The variable frequency was controlled using a microcontroller called the hydroponic irrigation frequency regulator (Figure 1B), developed by Silva *et al.* (2020a), in which the frequency of application was based on ambient temperature (Figure 1C). This regulator maintained frequencies of 15 min of circulation and 15 min of interval when the air temperature was between 26 and 30 ºC, 10 min of circulation and 30 min of interval when the temperature was below this range, and 10 min of circulation and 10 min of interval when the temperature was above this range.

Figure 1. Experimental overview (A), microcontroller developed (B) and sensor installation site in the experimental area (C).



Source: the authors (2020)

4.3 Crop conduction and nutrient solution management

The crop used was arugula (*Eruca sativa* L.*)* cv. 'Cultivada'. Sowing was carried out on July 12th, September 19th and October 25th in 2019 with plastic trays in 200 cells, containing as substrate a mixture of coconut powder and rice husks, in a volume 3 x 1 ratio, kept in a shaded environment, and four seeds were placed in each cell, after 10 days, three plants were thinned remaining one per cell. When the plants had five true leaves, they were transplanted to the hydroponic profiles.

The nutrient solution of the control was prepared based on the recommendation of nutrients suitable for leafy vegetables in hydroponic systems according to Furlani (1999). The water used to prepare the nutrient solution came from an artesian well and had an electrical conductivity of 1.1 dS m^{-1} and a pH of 7.4. During the experiments, daily monitoring of the electrical conductivity of the nutrient solution (EC_{sol}) and solution pH was performed using a digital conductivity meter and portable pH meter, respectively.

The nutrient solution was replaced with the consumption of 50% of the solution stored in individual reservoirs. The replacement was made with the same solution in which the treatment was started.

4.4. Variables analyzed during the experiment

During the entire experiment, daily

monitoring of pH and electrical conductivity of the nutrient solution (EC_{sol}) was performed using a portable pH meter (Pen Type pH meter) and a digital conductivity meter (TDS Meter®), respectively.

Growth measurements were performed according to Benincasa (1988). Three plants from each hydroponic profile were randomly selected at the end of the cultivation cycle; in this case, 30 days after transplantation (DAT) for the first cycle and 20 DAT for the second and third cycles, the difference between cycles was due to the variation in environmental temperature that influenced the growth of the plants. With a millimeter ruler, plant height (PH) was measured from the base to the end of the highest leaf (in cm). The number of leaves of the plants (NL) was determined by counting the number of leaves above five centimeters, going from the basal leaves to the last open leaf.

The collected plants had their organs separated into leaves and roots, and a precision scale (0.01 g) was used to determine shoot fresh mass (SFM). Then, the material was placed in individualized paper bags and dried in a forced air circulation oven at 65 ºC until reaching constant weight to obtain shoot dry mass (SDM). The relative chlorophyll index (RCI) was determined at 19 DAT in the three cultivation cycles using a SPAD-502 chlorophyll meter in the most developed leaves.

For the determination of nutrient concentrations, the aerial part of arugula plants was freeze dried. Soon after freeze drying, specific extracts were prepared to determine the nutrients, according to the method described by Silva (2009). The following nutrients were determined in the shoots: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S).

Total N quantification was performed by the Kjeldahl steam drag method; potassium by the flame photometry method; phosphorus by the molybdo-vanadate colorimetric method; sulfur by the turbidimetric method with barium sulfate; and calcium and magnesium by atomic absorption spectrophotometry (SILVA, 2009). Due to contamination (total carbonization of samples) from external factors, these analyses were not performed for the first production cycle.

4.5 Statistical analysis

The variables were subjected to the normality test and then to the F test (ANOVA) through the statistical program SISVAR (FERREIRA, 2011). When a significant effect was observed in the F test, the quantitative data were subjected to regression analysis ($p < 0.05$), while qualitative data were subjected to Tukey’s test ($p < 0.05$).

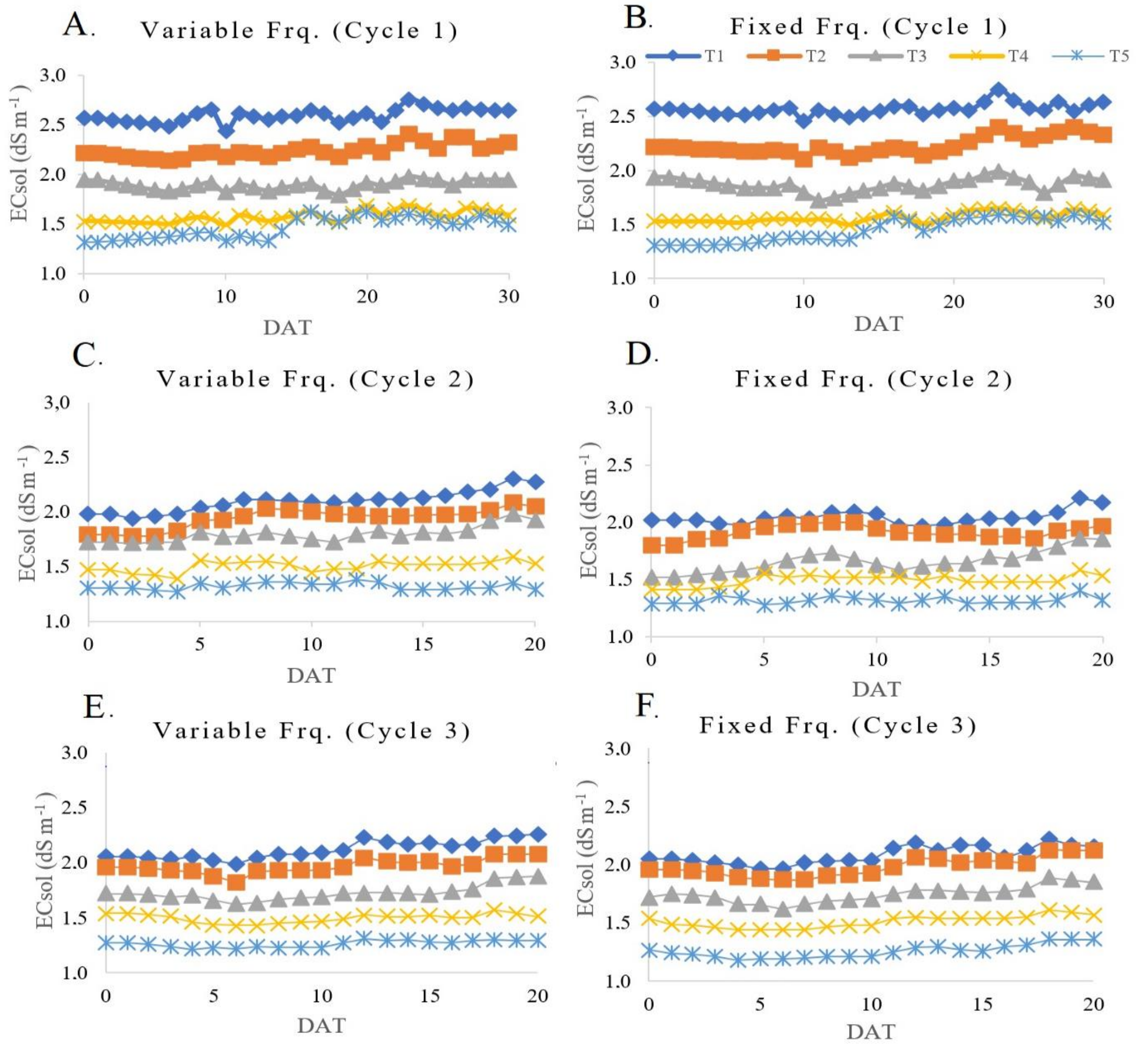
5 RESULTS AND DISCUSSION

5.1 Nutrient solution monitoring

Figure 2 presents the values of electrical conductivity of the nutrient solution (Ec_{sol}) according to the dilutions of the nutrient solution recommended by Furlani (1999) and the different frequencies of application studied.

The replacement of the nutrient solution promoted the increase in EC_{sol}; however, in treatments with 1.41 dS m^{-1} and 1.30 dS m^{-1}, whose nutrient solution was prepared with dilutions there was a small decrease in EC_{sol} as a function of time at both application frequencies, so the plants absorbed the nutrients necessary for their development.

Figure 2. Mean values of ECsol at different concentrations for variable frequency (A, C and E) and fixed frequency (B, D and F) in the cultivation of arugula cv. "Cultivada". Treatments represent: T1 – 100%; T2 – 90%; T3 – 80%; T4 – 70%; T5 – 65% of nutrient solution.

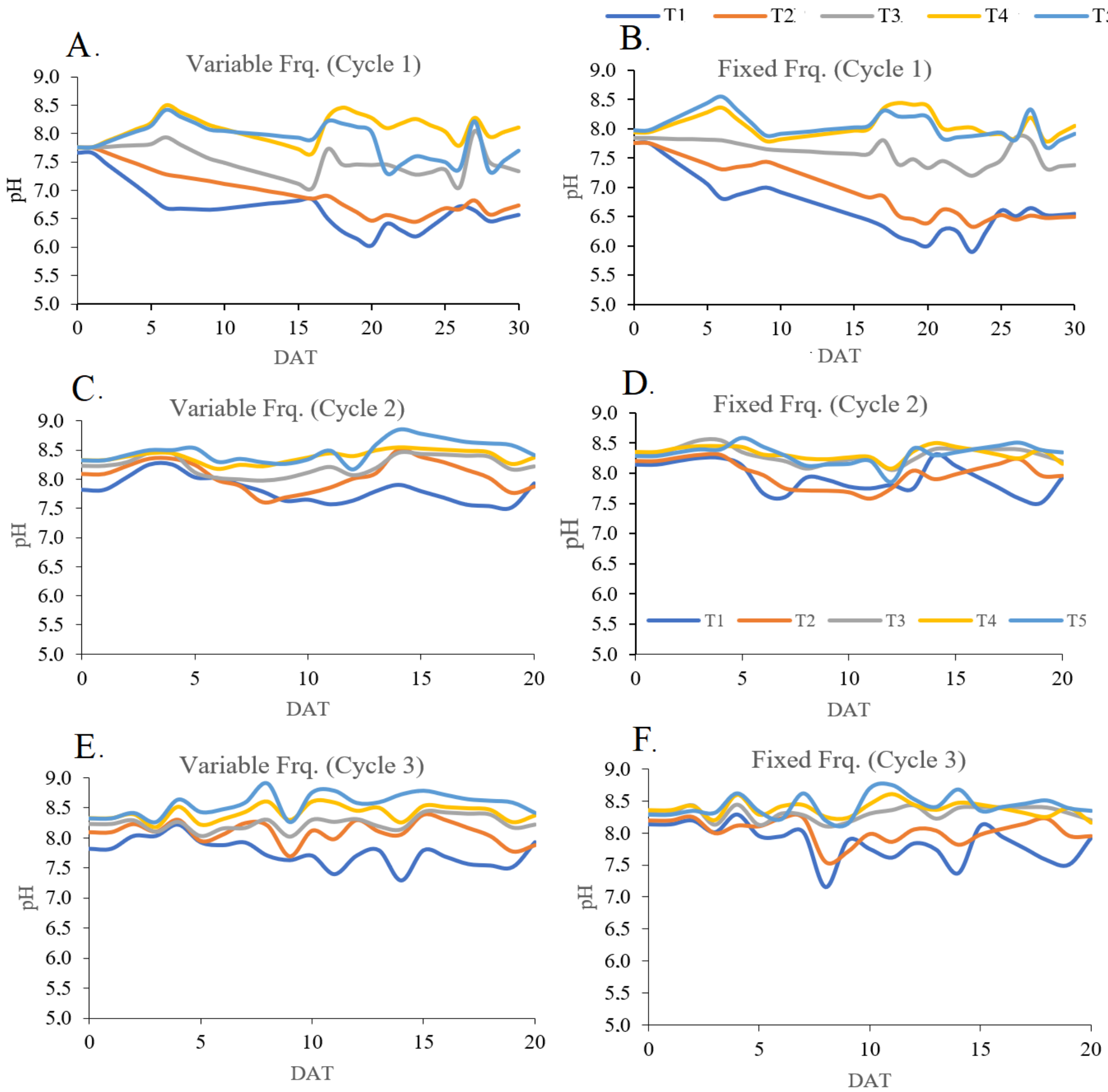


Source: The authors (2020)

The results presented in the experiment were different from those of many authors. Silva *et al.* (2021) observed a major yield in arugula with an increase in nitrogen in the nutrient solution with higher EC_{sol} and Guardabaixo *et al.* (2020) did not observe an increase in the nutrient consumption of arugula with higher EC_{sol} values. In another plant culture, Soares *et al.* (2016) worked with hydroponic lettuce under different salinity levels and observed that only in the treatment with lower electrical conductivity (EC) was there a reduction in the total consumption of nutrients by the plant throughout the experiment.

The pH values of the solution (Figure 3) remained well above the ideal range between 4.5 and 7.5 considered by Furlani (1999), since within this range, most nutrients that are essential to plant development are made available adequately.

Figure 3. Mean pH values of the nutrient solution for application frequencies in the first (A and B), second (C and D) and third (E and F) production cycles. Treatments represent: T1 – 100%; T2 – 90%; T3 – 80%; T4 – 70%; T5 – 65% of nutrient solution.



Source: The authors (2020)

The first cycle (Figures 3A and B) showed similar pH variations for both variable and fixed frequencies, with a reduction in pH, especially at the beginning of the cycle. The second cycle (Figures 3C and D) showed a lower variation in pH for both variable and fixed frequencies. The third cycle (Figures 3E and F), in turn, had higher pH values in the solutions. It is believed that these factors occurred due to the increase in greenhouse temperature. According to Borges and Silva (2011), the water temperature interferes with the solubility of the nutrient solution, in which a 20 °C temperature is ideal for solubility for most fertilizers, which favors nutrient consumption for the plants.

5.2 Yield and growth parameters

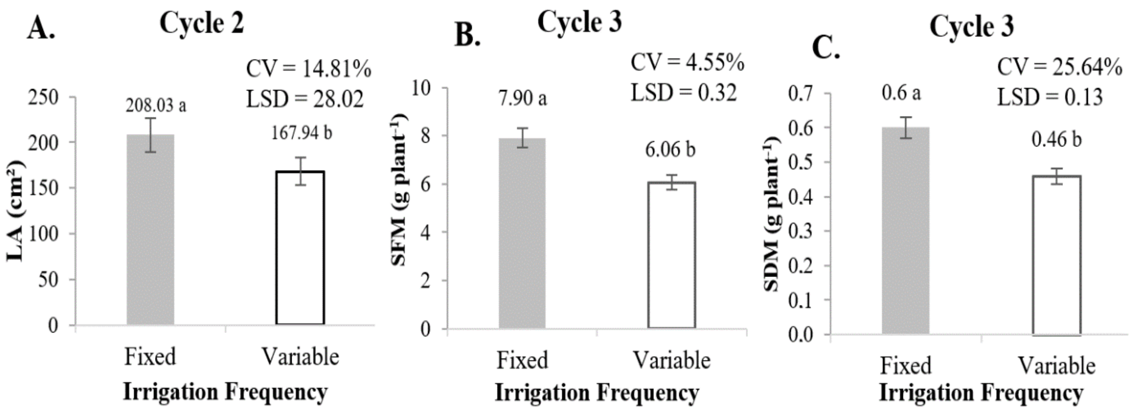
According to the analysis of variance, in the three cycles of cultivation, all variables studied were influenced ($p < 0.05$) in different ways both by the isolated factors and by the interaction between them, except for the number of leaves (NL), which was not influenced in any of the cycles studied.

In the first cycle, only the variables

SFM and RCI were influenced by the factors studied; the electrical conductivity of the solution (EC_{sol}) had a significant effect ($p < 0.05$) on SFM. In the second cycle, leaf area (LA) was influenced ($p < 0.05$) by the irrigation frequency factor, while RCI ($p < 0.05$) was influenced by the interaction between EC_{sol} and frequency. In relation to the third cycle, all variables were influenced by EC_{sol}, except NL. The variables SDM and LA were influenced ($p < 0.05$) by the interaction between EC_{sol} and irrigation frequency.

According to the Tukey's test ($p < 0.05$), the fixed frequency of application promoted higher values of LA (Figure 4A), SFM (Figure 4B) and SDM (Figure 4C) compared to the variable frequency of application. Possibly the increase in air temperature during the growing season (November) may have influenced the greater water consumption by plants.

Figure 4. Comparison between frequencies of application for the variables LA (A), SFM (B) and SDM (C) in hydroponic cultivation of arugula by Tukey's test at the 0.05 probability level.



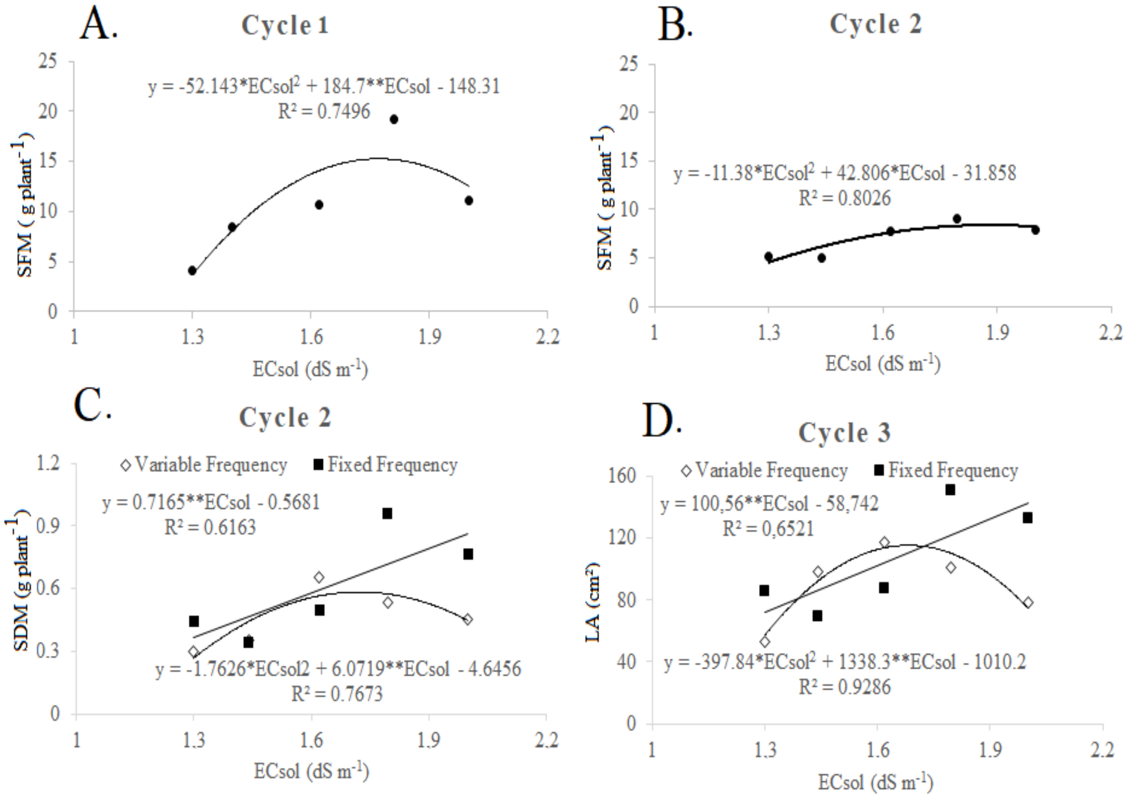
*Bars represent the standard deviation of the treatments; LSD - least significant difference; equal letters do not show significant differences by Tukey's test at the 0.05 probability level. CV – Variation coefficient (%).
Source: The authors (2020)

Possibly, the greater circulation of the nutrient solution promoted by the variable frequency caused stress due to excess water. Souza *et al.* (2020) observed that higher frequencies of circulation of the nutrient solution negatively interfered with the development of watercress in hydroponic systems, so the established frequency may not be adequate for the studied crop.

A quadratic fit was observed for the response variable SFM in the first cycle (Figure 5A), with higher values (15.29 g $plant^{-1}$) obtained at an ECsol of 1.77 dS m^{-1}, while in the second cycle (Figure 5B), maximum values of SFM (8.40 g $plant^{-1}$) were observed at an EC_{sol} of 1.86 dS m^{-1}.

For SDM (Figure 5C) in the second production cycle, the quadratic model was the one that best fitted the increase in EC_{sol} under the variable frequency, with a maximum of 0.58 g $plant^{-1}$ for EC_{sol} of 1.72 dS m^{-1}. Regarding the interaction between ECsol and fixed frequency, the fit was linear with an increase of 0.72 g $plant^{-1}$ for each unit increment in ECsol. For LA (Figure 5D) in the third production cycle, the regression analysis in the interaction between EC_{sol} and variable frequency showed maximum values of 115.28 cm² for the EC_{sol} of 1.68 dS m^{-1}, while for the interaction between EC_{sol} and fixed frequency, there was an increase of 100.56 cm² for each unit increase in EC_{sol}.

Figure 5. Shoot fresh mass (A and B), shoot dry mass (C) and leaf area (D) as a function of the electrical conductivity of the nutrient solution (Ecsol) and frequency of irrigation in arugula cv. "Cultivada".



* and ** - Significant at 0.01 and 0.05 probability levels by t test
Source: The authors (2020)

In an experiment involving the relationship between arugula and the salinity of nutrient solutions, Oliveira *et al.* (2013) observed SFM values of 23.6 g plant^{-1} for the 'folha larga' cultivar. Possibly, the difference in the values can be related to the experimental conduction and climate of the region, while Souza *et al.* (2020) observed SFM values of 20 g for arugula cultivated in soil with a water table near the surface in the same region.

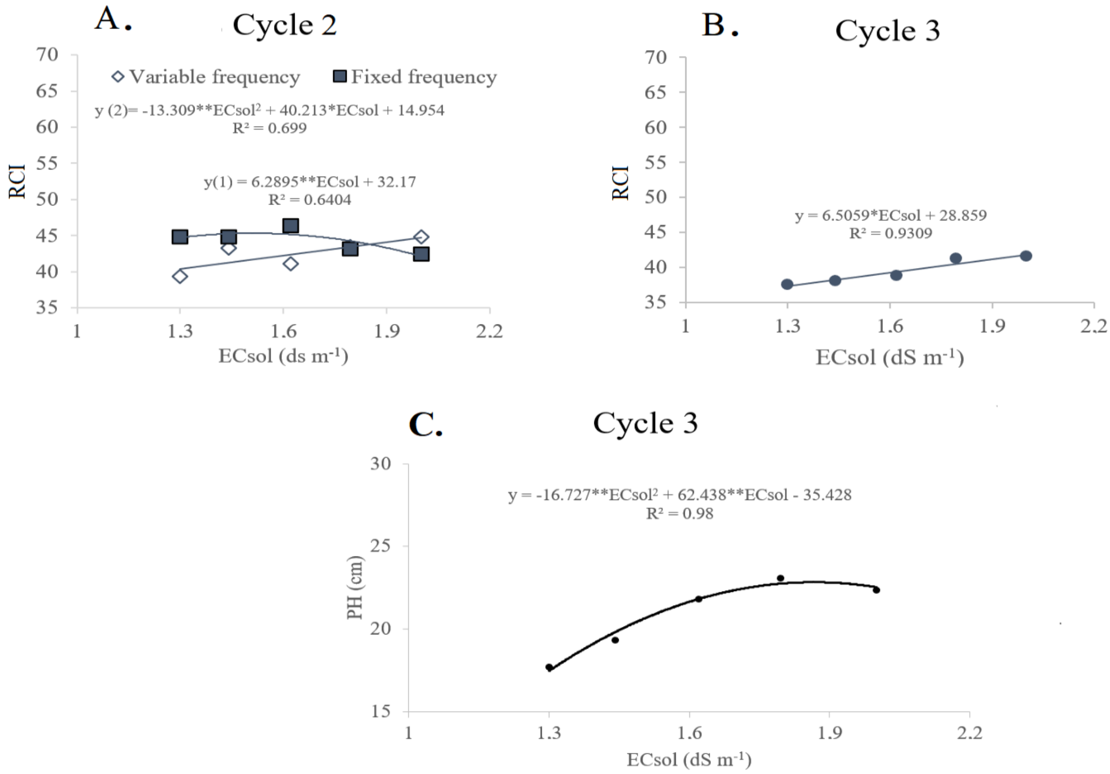
Silva *et al.* (2021), in studies with hydroponic arugula, observed maximum SDM values of 3.66 g plant^{-1}. These results are inferior to those of the present study. However, the concentrations of EC_{sol} of 1.72 dS m^{-1} (variable frequency) and 2.00 dS m^{-1} (fixed frequency) observed in the second cycle to maximum SDM indicate that nutrient absorption efficiency may be related to other factors, such as ambient temperature and relative humidity, thus favoring the increase in plant biomass (SILVA; SILVA; KLAR, 2017).

For the LA variable, similar studies that observed the increase in this variable with the increase in EC_{sol} were conducted by Lacerda *et al.* (2012), who worked with hydroponic collard greens production, using different nutrient concentrations and two different types of substrates, and obtained the highest value of leaf area (600 cm² per plant) for the concentration of 50% of nutrients in the nutrient solution.

The relative chlorophyll index (RCI) was significantly affected in the second cycle (Figure 6A); in turn, a better fit was observed with the linear model for the variable frequency, with an increase of 6.29 in RCI for each unit increment in EC_{sol}. For the fixed frequency, a quadratic fit was observed with higher values (RCI of 45.33) observed at the EC_{sol} of 1.51 dS m^{-1}. In the third cycle (Figure 6B), the fit was linear with an increase of 6.50 in RCI per unit increment in EC_{sol}. Figure 6C shows the fits of the response variables studied PH (third cycle) according to the EC_{sol}. The quadratic model also obtained the best fit with a maximum value of 22.84 cm at an EC_{sol} of 1.87 dS m^{-1}.

Different studies on nitrogen content in leaves involving RCI as a nondestructive method for available nitrogen leaves are presented. For cultivation in hydroponic systems, the RCI can demonstrate the nutritional status of plants in relation to N and a possible modification of the nutrient solution to supply a greater or lesser demand for N by the plants. The results observed by Silva *et al.* (2012) in studies with RCI in arugula subjected to different salinity levels in the nutrient solution were lower than those observed in the present experiment, but it is worth pointing out the different experimental conditions (substrate and NFT).

Figure 6. Relative chlorophyll index (RCI) in the second cycle (A) and third cycle (B) and plant height (PH) in the third cycle (C) as a function of electrical conductivity of the nutrient solution (ECsol) and application frequencies studied for arugula cv. "Cultivada".



* and ** - Significant at 0.01 and 0.05 probability levels by t test
Source: The authors (2020)

The values presented here are higher than the highest values obtained by Oliveira *et al.* (2013), who worked with arugula cultivars under nutrient solutions with different salinities and found a value of 18.6 cm, while Santos *et al.* (2018), in studies with arugula under nutrient solution and saline waters in coconut fiber substrate, obtained the highest mean value of 20 cm. Souza Neta *et al.* (2013), evaluating the effect of salinity in the nutrient solution with different substrates, obtained an average height of 19.4 cm; according to these authors, the height of arugula plants during harvest varied from 15 to 20 cm.

Similar results were observed by Oliveira *et al.* (2016) and Luz *et al.* (2018) in studies with cultivation of coriander and wormwood, respectively, under increasing concentrations of nutrient solution in hydroponics and they observed that the increase in nutrient concentration in the nutrient solution resulted in a significant increase in PH.

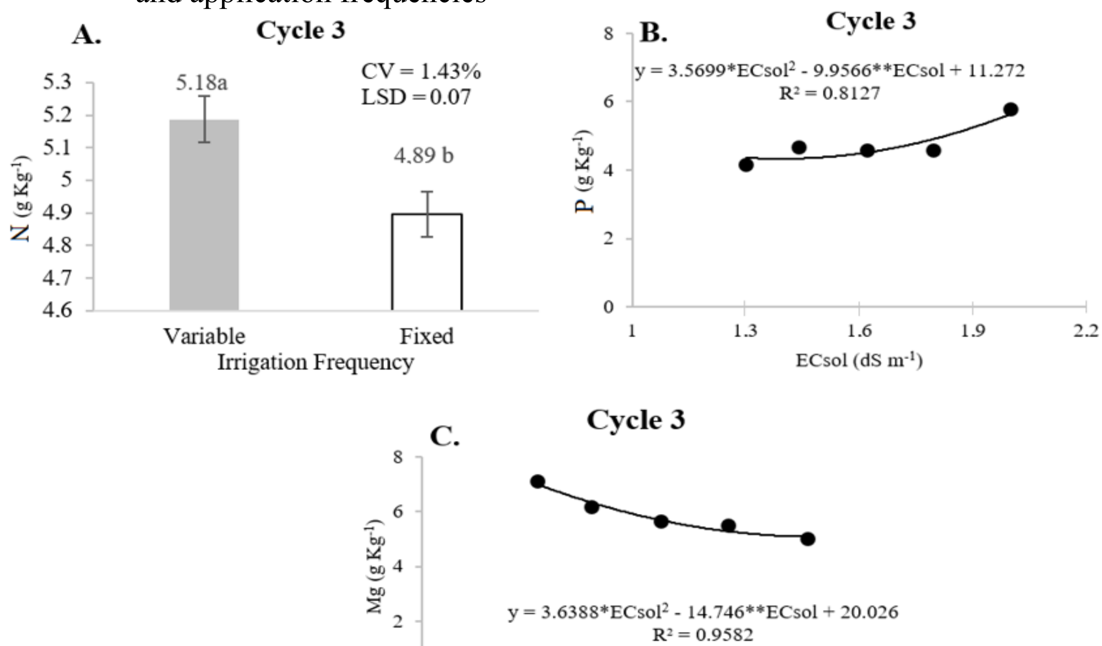
5.3 Nutritional analysis

According to the analysis of variance, it was observed that for the second cycle, the variables were not influenced by the factors studied; however, in the third cycle, the N concentration was influenced by the irrigation frequency ($p < 0.01$), and P and Mg concentrations were influenced ($p < 0.01$) by EC_{sol}, while K, Ca and S were not influenced.

It was verified for the third cycle that the N values (Figure 7A) obtained in the leaves were higher under the variable frequency (5.2 g kg^{-1}) according to the F test ($p < 0.05$), possibly due to its greater availability to plants during the circulation of the nutrient solution.

For the P content in arugula leaves, a quadratic fit was observed in the third cycle (Figure 7B), with higher concentrations at an EC_{sol} of 2.00 dS m^{-1}, while for the Mg content (Figure 7C), there were reductions with the increase in EC_{sol}.

Figure 7. Nitrogen - N (A), phosphorus - P (B) and magnesium - Mg (C) concentrations in hydroponic cultivation of arugula under different concentrations of nutrient solution and application frequencies



LSD - Least significant difference. Equal letters do not show significant differences by Tukey's test at the 0.05 probability level; * and ** - Significant at the 0.01 and 0.05 probability levels by t test. CV – variation coefficient (%).
Source: The authors (2020)

According to Grangeiro *et al.* (2011), nitrogen is the second most accumulated nutrient by arugula, with greater absorption in the final phase of the cycle. Despite the reduction in N in the nutrient solution, this decrease was not enough to cause visual deficiency since the crop responds positively to nitrogen supply (PURQUERIO *et al.*, 2007). The results present values similar to those of Genuncio *et al.* (2011) in studies with arugula in hydroponic cultivation that observed higher values with increased solution flow.

The results of this study possibly occurred due to the solubility of the nutrient solution that favored the greater availability of P and Mg, and the solubility has the main influence of water temperature and pH (BORGES; SILVA, 2011). Cavarianni *et al.* (2008) evaluated the nutritional content in arugula as affected by different nitrogen doses and observed a maximum P concentration of 4.08 g kg^{-1}. For the Mg content, Barlas and Tepecik (2011) conducted a study on mineral content in arugula and found a minimum value of 3.3 g kg^{-1} and maximum value of 7.9 g kg^{-1}.

6 CONCLUSIONS

Using only 90% of the recommended nutrient solution is the most appropriate from the commercial point of view, as it led to maximum potential in relation to production, using a smaller amount of inputs.

The reduction in nutrient solution to 90% of the recommended value did not influence the yield and growth variables and could be an alternative for use in hydroponic NFT systems observing the environmental conditions of cultivation.

The factor frequency of nutrient solution circulation with the stipulated intervals was not satisfactory to obtain a higher yield of arugula, so other studies with different circulation intervals are necessary. The fixed frequency of 15 min promoted better development of the crop under the experimental conditions studied.

7ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001 for fellowships and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for funding this research.

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