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Scientific Article

Growth and physiological aspects of arugula subjected to soil salinity and fertilizer doses

Crescimento e aspectos fisiológicos da rúcula submetida a salinidade do solo e doses de adubação

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ABSTRACT - Arugula is a vegetable with considerable prominence in the commercial sector, so knowing the ideal dose of fertigation and the effects of soil salinity on its agronomic characteristics is essential for good production. The aim of the study was to evaluate the morphological and physiological aspects of arugula, cultivar Broadleaf, at different levels of soil salinity and doses of fertilization via fertigation. The experiment was conducted in a greenhouse during two consecutive growing cycles, from May to June and from July to August 2021. The experimental design used was randomized blocks, arranged in a 4 x 3 factorial scheme, with four replicates. Treatments consisted of four levels of electrical conductivity of the saturated extract (ECse = 0.57, 1.3, 2.3, and 3.3 dS m^{-1}) and three doses of fertilization via fertigation (F1= 100%, F2= 50%, and F3= 25% of the recommended NPK doses). The variables analyzed were: plant height (cm), number of leaves, leaf area (m^2 $plant^{-1}$), shoot fresh mass and shoot dry mass (g $plant^{-1}$), leaf water percentage, SPAD, and gas exchange (photosynthesis, transpiration, stomatal conductance, and internal CO_2 concentration). There was a reduction in arugula growth in soil with ECse above 2.1 dS m^{-1}. Fertigation using the full dose of fertilizer recommended for arugula cultivation proved to be an effective strategy for increasing both biomass production and physiological activity.

Keywords: Electrical conductivity. *Eruca sativa* L. Salt stress.

RESUMO - A rúcula é uma hortaliça que apresenta considerável destaque no setor comercial, logo conhecer a dose ideal de fertirrigação e os efeitos da salinidade do solo nas suas características agronômicas é essencial para uma boa produção. O objetivo do estudo foi avaliar os aspectos morfológicos e fisiológicos da rúcula, cultivar 'folha larga' em diferentes níveis de salinidade do solo e doses de adubação via fertirrigação. O experimento foi conduzido em casa de vegetação, durante dois ciclos de cultivo consecutivos, durante os meses de maio a junho e julho a agosto de 2021. O delineamento experimental utilizado foi o de blocos casualizados, arranjados em esquema fatorial 4 x 3, com quatro repetições. Os tratamentos foram constituídos de quatro níveis de condutividade elétrica do extrato saturado (CEes = 0,57, 1,3, 2,3 e 3,3 dS m^{-1}) e três doses de adubação via fertirrigação (F1= 100%, F2= 50% e F3= 25% das doses de NPK recomendada). As variáveis analisadas foram: altura de planta (cm), número de folhas, área foliar (m^2 $planta^{-1}$), massa fresca da parte aérea e massa seca da parte aérea (g $planta^{-1}$), umidade foliar, SPAD e trocas gasosas (fotossíntese, transpiração, condutância estomática e concentração interna de CO_2). Houve redução no crescimento da rúcula no solo com CEes acima de 2,1 dS m^{-1}. A fertirrigação utilizando a dose completa de adubação recomendada para a cultura da rúcula, demonstrou ser uma estratégia eficaz para aumentar tanto a produção de biomassa quanto a atividade fisiológica das plantas.

Palavras-chave: Condutividade elétrica. *Eruca sativa* L. Estresse salino.

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INTRODUCTION

Soil salinity has been a widely discussed topic nowadays, especially in arid and semi-arid regions, such as the Brazilian Northeast. This is due to the climatic conditions in these territories, in which low rainfall and high evapotranspiration lead to the accumulation of salts in the soil, thus causing salinity problems. According to Corwin (2021), climate change tends to have an even greater impact on salinization problems in the future, in view of the reduction and/or poor distribution of rainfall, in addition to the increase in temperature, which will consequently increase evapotranspiration.

High concentrations of salts in the soil are common in the Northeast, due to high rates of evapotranspiration and irregular rainfall, causing soil salinization. One of the consequences of excess salts is the reduction in the growth and yield of economically important crops, because salinity directly affects the osmotic potential of the soil, thus impairing water absorption and causing damage to physiological processes such as gas exchange (RODRIGUES et al., 2022).

Arugula (*Eruca sativa* L.) is a leafy and herbaceous species of the Brassicaceae family and depends directly on the availability of water and nutrients to maintain its leaf turgor and thus achieve the quality of the final product marketed, which is the leaf itself (SANTOS et al., 2020). This crop has gained more and more space in the national market, as it is rich in vitamin A and C, proteins, calcium and iron, besides having an anti-inflammatory effect (MATTOS et al., 2020).

Excessive use of fertilizers can lead to an increase in soil salinity, further impairing the performance of crops, especially arugula, which has a salinity threshold of 2.57 dS m^{-1}, leading to limitations in its production under higher values (SILVA et al., 2013). In this context, fertigation management emerges as a viable alternative since it provides a precise control of water and nutrients applied to the soil and promotes a dilution of salts that may accumulate. Thus, by adopting this strategy, it becomes possible to split the fertilization and apply the essential mineral elements more uniformly, facilitating ion-root contact.

Studies with soil salinization as a stress-causing agent in arugula plants are not common in the literature, as in most studies salinity is caused by irrigation water alone. In view of the above, the study aims to evaluate the growth and physiological aspects of arugula at different levels of soil salinity and doses of fertilization via fertigation.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse at the Agrometeorological Station of the Department of Agricultural Engineering, Federal University of Ceará (UFC), Pici Campus, Fortaleza, CE, Brazil (3° 44' 43.273"S 38° 34'56.650"W) with average altitude of 22 m. The climate of the municipality is Aw', tropical rainy, according to Köppen (1923).

Two production cycles were carried out, the first cycle between May and June 2021 and the second cycle between July and August 2021. The selected arugula cultivar was the Broadleaf, due to its greater availability. Sowing was carried out in expanded polyethylene trays filled with coconut fiber. At 20 days after sowing, when the plants had three true leaves, they were transplanted into beds. The soil used was collected near the experimental area in the 0.20-0.40 m layer and classified as *Latossolo Vermelho Amarelo* (Oxisol) with loam texture (EMBRAPA, 2006). Chemical analysis was also performed (Table 1) following the methodology contained in Donagema et al. (2014).

Table 1. Chemical characteristics of the soil used in the experiment.

OM	N	P	Mg	K	Ca	Na	CEC	SB	pH	ECse	V
------ g kg^{-1} ----		mg kg^{-1}	------------------------- $cmol_c$ kg^{-3} -------------------------						H_2O	dS m^{-1}	%
11.30	0.61	32	0.6	0.36	1.20	0.23	4.37	1.58	6.0	0.35	42

OM = organic matter, CEC = cation exchange capacity, SB = sum of bases; ECse = electrical conductivity of the saturation extract, V = base saturation.

The experiment was conducted in a randomized block design, arranged in a 4 x 3 factorial scheme, with four replicates, totaling 48 experimental plots. Treatments consisted of four levels of soil salinity, obtained by the electrical conductivity of the soil saturation extract (ECse = 0.57, 1.3, 2.3, 3.3 dS m^{-1}) and three different doses of fertilization via fertigation with a frequency of two days (F1 = 100%, F2 = 50% and F3 = 25% of the recommended fertilization). Each experimental unit (EU) consisted of beds with dimensions of 0.55 m x 0.10 m, with 4 plants spaced 0.10 m apart.

Fertigation was performed manually along with the application of irrigation depths, which were based on soil water tension readings obtained by puncture tensiometers and with the aid of a characteristic curve in which the Van Genuchten's equation parameters were modeled (Equation 1) to obtain volumetric moisture.

$$\theta = \frac{0.190}{[1+(13.09\ [h])^{1.503}]^{0.337}} + 0.239 \qquad (1)$$

Where, θ – volumetric soil moisture (cm^3 cm^{-3}), h – soil water tension in kPa.

To perform the artificial salinization of the soils in the beds, sodium chloride (NaCl) was dissolved in water and applied into five test pots with a volume of 5 dm^3 each. The quantity of salts added to the soil was estimated by the equation of Richards (1954) according to Equation 2:

$$Qs = EC_{se}\ x\ 640\ x\ Vs \qquad (2)$$

Where: Qs - Quantity of salts applied per pot, mg L^{-1},
Vs - Volume of water present in the soil when saturated, L,
ECse - Desired electrical conductivity in saturation extract, dS m^{-1}.

ECse values were obtained by following the methodology of Donagema et al. (2014), by means of the saturation paste. The collected data were then used to generate the salinization curve of the pots. Using the corresponding equation (y = 1.2384x - 0.1185 R^2 = 0.9776), it was possible to calculate the amount of salt needed to achieve the desired salinity in each bed according to Silva et al. (2013).

The fertilizers were dissolved in 15 dm^3 containers and applied by fertigation, according to the recommended values for arugula crop. The dose of 100% of the recommendation was composed of: 140 kg ha^{-1} of N, 30 kg ha^{-1} of P_2O_5 and 50 kg ha^{-1} of K_2O. The fertilizer sources used were: Urea (45% N), MAP (12% N and 61% P_2O_5) and Dripsol NKS (45% K_2O and 12% N). The other nutrients, in addition to basal fertilization, were applied based on soil chemical analysis and recommendations by Trani et al. (2014).

Growth variables were determined at 15 and 30 days after transplantation (DAT). The following growth variables were measured: plant height (PH, cm), with a millimetric ruler; number of leaves (NL), considering leaves larger than 5 centimeters; and leaf area (LA, cm^2 $plant^{-1}$), estimated with a LI-COR 3100C area meter only at the end of each production cycle, 30 DAT.

At 30 DAT of each cycle, shoot fresh mass (SFM) in g plant^{-1} was also quantified, obtained by weighing on a 0.01 g precision scale. Soon after being harvested, the plants were packed in paper bags, previously identified and dried in a forced air circulation oven at a temperature of 65 °C until reaching constant weight. After drying, the material was weighed on a scale to obtain shoot dry mass (SDM) in g plant^{-1}. After obtaining these variables, it was possible to calculate the percentage of water in the leaf (U), through the following Equation 3:

$$U = (SFM - SDM) / SFM \times 100 \quad (3)$$

At 27 DAT in the two production cycles, the following gas exchange variables were determined: photosynthesis (A), transpiration (E), stomatal conductance (gs) and internal CO_2 concentration (Ci), obtained using the Portable Infrared Gas Analizer (IRGA), model LCPro+ Portable Photosynthesis System® (ADC BioScientific Limited, UK) with temperature control at 25ºC, air flow of 200 mL min^{-1}, under saturating light (1200 µmol m^{-2} s^{-1}) and constant CO_2 concentration (400 ppm). Readings were taken from 9:30 a.m. to 11:30 a.m.

Other physiological variables estimated were: instantaneous water use efficiency (WUEi), obtained by the ratio between photosynthesis and transpiration (A/E) and instantaneous carboxylation efficiency, obtained by dividing photosynthesis by internal CO_2 concentration (A/Ci). Relative chlorophyll index (SPAD index) was determined in the same period of gas exchange (27 DAT) and estimated using a SPAD-502 chlorophyll meter in both cycles.

Finally, the results were evaluated for normality (Bartlett test) and homogeneity (Shapiro-Wilk test), and when they were normal and homogeneous, they were subjected to analysis of variance (ANOVA). Afterwards, the data referring to the quantitative variables were subjected to regression analysis, and the parameters of the equations were subjected to the t-test at 1% ($p < 0.01$) and 5% ($p < 0.05$) probability levels, and the means were compared by Tukey test with a probability level of up to 5% ($p < 0.05$). All statistical analyses were performed using SAS version 9.4. Finally, the data were processed using Excel 2013 Plus Version to construct the graphs.

RESULTS AND DISCUSSION

According to the analysis of variance, the results obtained for the growth variables in the first and second cycles of the study were not significant ($p < 0.05$) for the interaction between the factors soil salinity (ECse) and fertilization doses via fertigation (FDF). However, the ECse factor significantly influenced all variables, both in the first evaluation (PH-1 and NL-1) performed at 15 DAT, and in the second evaluation (PH-2 and NL-2) performed at 30 DAT. The FDF factor significantly influenced ($p < 0.05$) only the variables NL-1 and NL-2 (second cycle) and LA (first and second cycle).

For the variable PH at 15 DAT (Figure 1A) and 30 DAT (Figure 1C) in the first cycle, a linear fit was observed with reductions of 1.17 (15 DAT) and 3.24 cm (30 DAT) per unit increment in ECse. In the second cycle, a polynomial fit was observed for PH at 15 DAT (Figure 1B), with maximum value (7.9 cm) obtained at ECse of 2.63 dS m^{-1}; for PH at 30 DAT (Figure 1D), a linear fit was observed with reduction of 3.06 cm per unit increment in ECse. Similar results were reported by Dias et al. (2019), who evaluated the growth of arugula in different substrates and under different levels of electrical conductivity of irrigation water (ECw) and found reduction in plant height at the highest ECw, regardless of the substrate used.

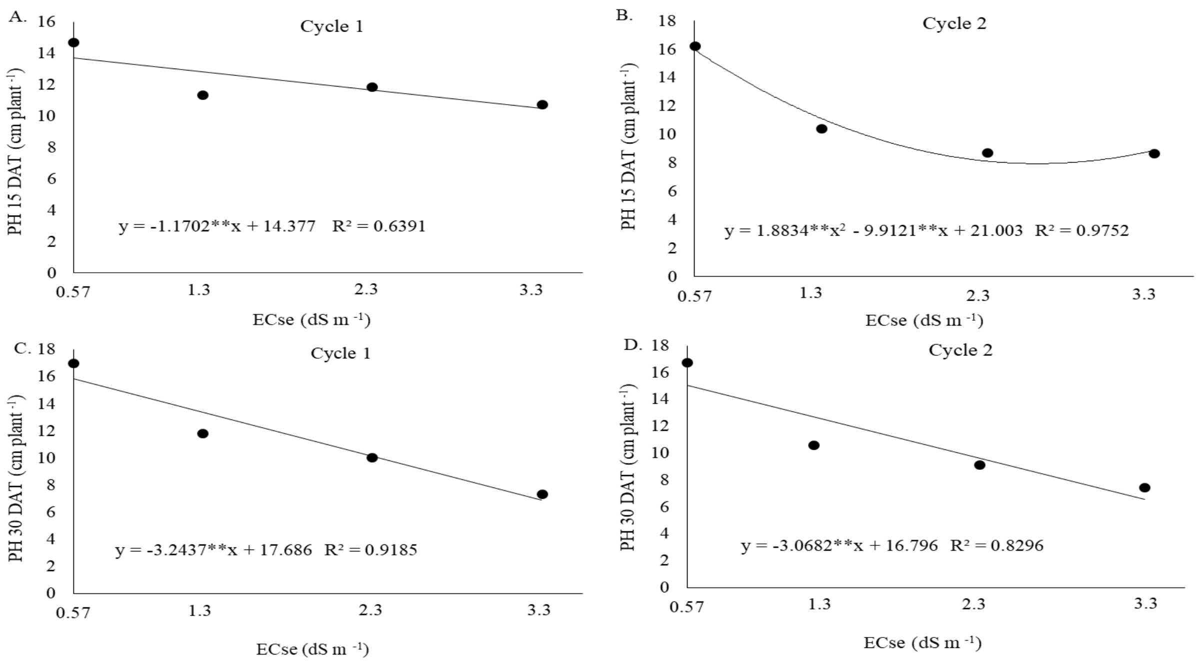

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Figure 1. Average plant height (PH) of arugula in two cultivation cycles, evaluated at 15 and 30 days after transplanting (DAT), in response to variation in the electrical conductivity of the soil saturation extract (ECse). Results are presented for cycle 1 (A and C) and cycle 2 (B and D).

The reduction in plant height is related to the excess of NaCl in the soil extract, and this high concentration of salts increases the osmotic potential, reducing the capacity of the roots to extract water and consequently nutrients from the soil, besides causing changes in the metabolic activities of the cells in the cell elongation process and, as a consequence, in plant growth (DIAS et al., 2019).

For the NL variable, in relation to the ECse factor, a linear fit was observed, with reductions of 0.76 (15 DAT) and 1.53 (30 DAT) in the first cycle (Figures 2A and 2C) and 1.06 (15 DAT) and 1.33 (30 DAT) in the second cycle (Figures 2C and 2D) per unit increase in ECse. There was no statistical difference between the doses according to Tukey test for the FDF factor in relation to the NL variable in the second cycle, at 15 DAT (Figure 2E). At 30 DAT (Figure 2F), the 100% dose promoted highest NL (5.44) compared to the fertilization doses of 50% (4.53) and 25% (3.87). These results can be explained by the high nutritional requirement of plants at more advanced stages of growth; as the photosynthesis rate is higher, the plant will need more nutrients to sustain the increase in biomass and leaf production. Thus, higher doses of fertilization can provide the plant with the nutrients it needs to meet this growing demand, resulting in a greater number of leaves.

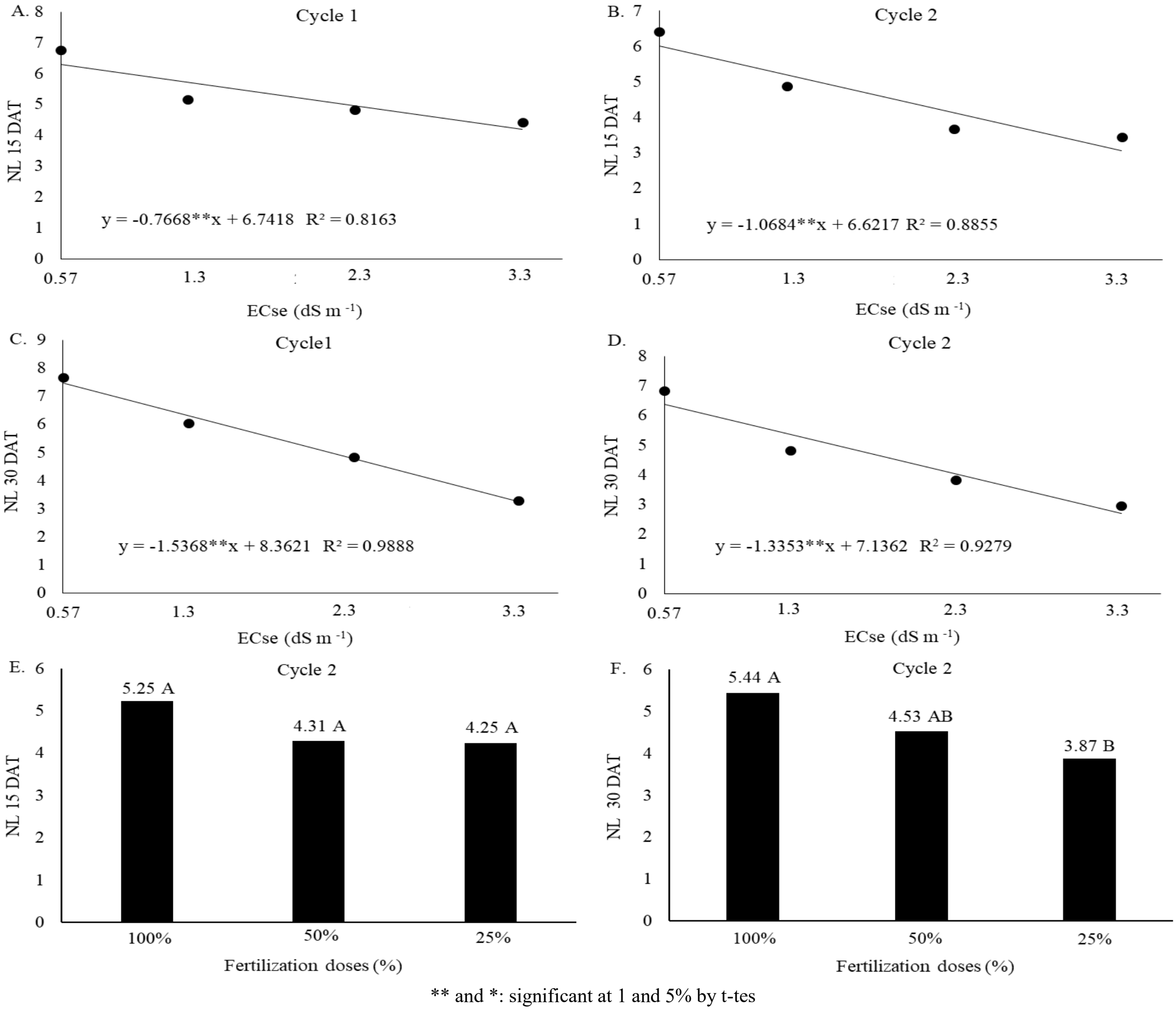

Figure 2. Number of leaves (NL) of arugula in two cultivation cycles, evaluated at 15 and 30 days after transplanting (DAT), in response to variation in the electrical conductivity of the soil saturation extract (ECse). Results are presented for cycle 1 (A and C) and cycle 2 (B and D), fertilization doses in cycle 2 at 15 DAT (E) LSD (0.98) and 30 DAT (F) LSD (2.51).

The reduction in NL, according to Sousa et al. (2021), is related to the osmotic effect on the soil, caused by the excess of NaCl, reducing the amount of water in the leaf, causing scorch and consequently the senescence of the leaf tissue, aiming to avoid water loss through transpiration. Another limiting factor for the development of arugula crop is related to the high demand for nutrients such as N, as the presence of this element directly favors this variable;

according to Lima et al. (2021) and Silva et al. (2021), this macronutrient can increase the number of leaves in arugula by 23%.

For the LA variable, in relation to the ECse factor, the fit was linear with reductions of 37.20 cm^2 plant^{-1} (Figure 3A) and 47.77 cm^2 plant^{-1} (Figure 3B) per unit increase in ECse. For the FDF factor, in the first cycle (Figure 3C), the dose equivalent to 100% of the recommended fertilization led to the highest value (104.86 cm² plant^{-1}) compared to the other doses, by Tukey test ($p<0.05$), whereas in the second cycle (Figure 3D), the doses of 100% (94.26 cm² plant^{-1}) and 50% (76.19 cm² plant^{-1}) of the recommended fertilization were similar, while the 25% dose resulted in the lowest values, according to Tukey test ($p<0.05$).

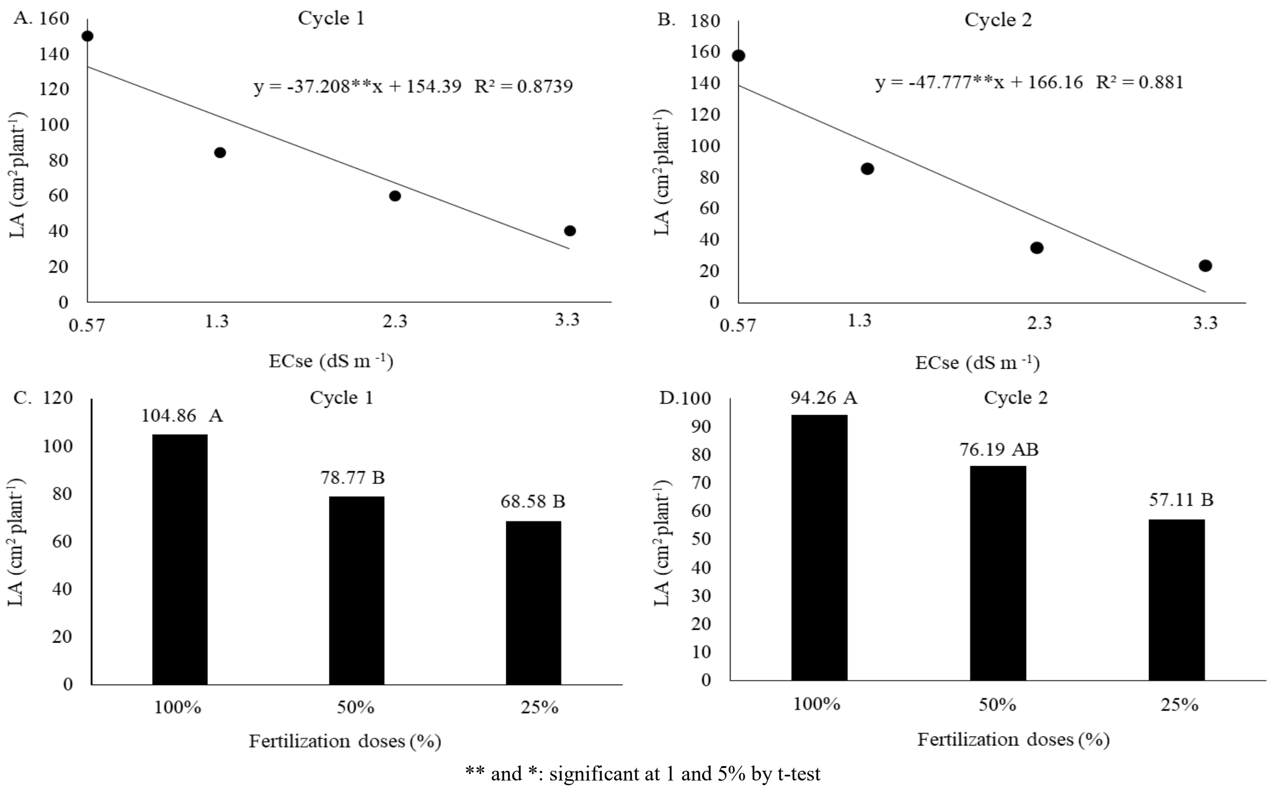

Figure 3. Average leaf area (LA) of arugula in response to variation in the electrical conductivity of the soil saturation extract (ECse), presented for cycle 1 (A) and cycle 2 (B), as well as for the different fertilization doses in cycle 1 (C) LSD (20.46) and cycle 2 (D) LSD (26.59).

Faced with the stress caused by the excess of salt ions in the soil, arugula plants reduced their leaf area. This adjustment allowed for more effective osmoregulation, because by reducing their leaves, they were able to reduce transpiration and consequently water loss. Studies using brackish water in arugula cultivation obtained results similar to those of the present study. Dias et al. (2019) observed a reduction of 71.36% in the leaf area of arugula under ECw of 4.5 dS m^{-1}. Reis (2018) also obtained reductions of 73.71% (ECw of 3.5 dS m^{-1}) and 72.31% (ECw of 4.5 dS m^{-1}).

Reduction in leaf area with the decrease in fertilization doses occurs with many crops of the genus Brassicaceae, and high levels of soil fertility are necessary to ensure good quality production (GUIMARÃES et al., 2019). According to Silva et al. (2015), arugula responds well to an adequate supply of nutrients, so any nutritional imbalance may be irreversible because the crop has a short growth period.

According to the regression analysis (Figure 4), the variable SFM was negatively influenced ($p<0.01$) by the ECse factor, with reductions of 4.45 g plant^{-1} (first cycle) and 5.93 g plant^{-1} (second cycle) per unit increase in ECse (Figures 4A and 4B). In accordance with the present study, Reis (2018) also found reduction in fresh mass for arugula when subjected to salinity, with reductions of 64% for 3.5 dS m^{-1} and 67.07% for 4.5 dS m^{-1}.

For the FDF factor, at the dose equivalent to 100% of the recommended fertilization, higher values ($p<0.05$) of SFM were observed in the first (11.88 g plant^{-1}) and second (11.75 g plant^{-1}) production cycle, according to the Tukey test (Figures 4C and 4D). This probably resulted from the relationship between absorption and the availability of nutrients in the soil (SILVA et al., 2021). In the second cycle, under the fertilization doses equivalent to 100% and 50% of the recommendation, although they did not differ statistically, in total values the maximum dose was also the one that promoted the highest shoot fresh mass, with values of 11.88 g and 11.75 g, for the first and second cycle, respectively.

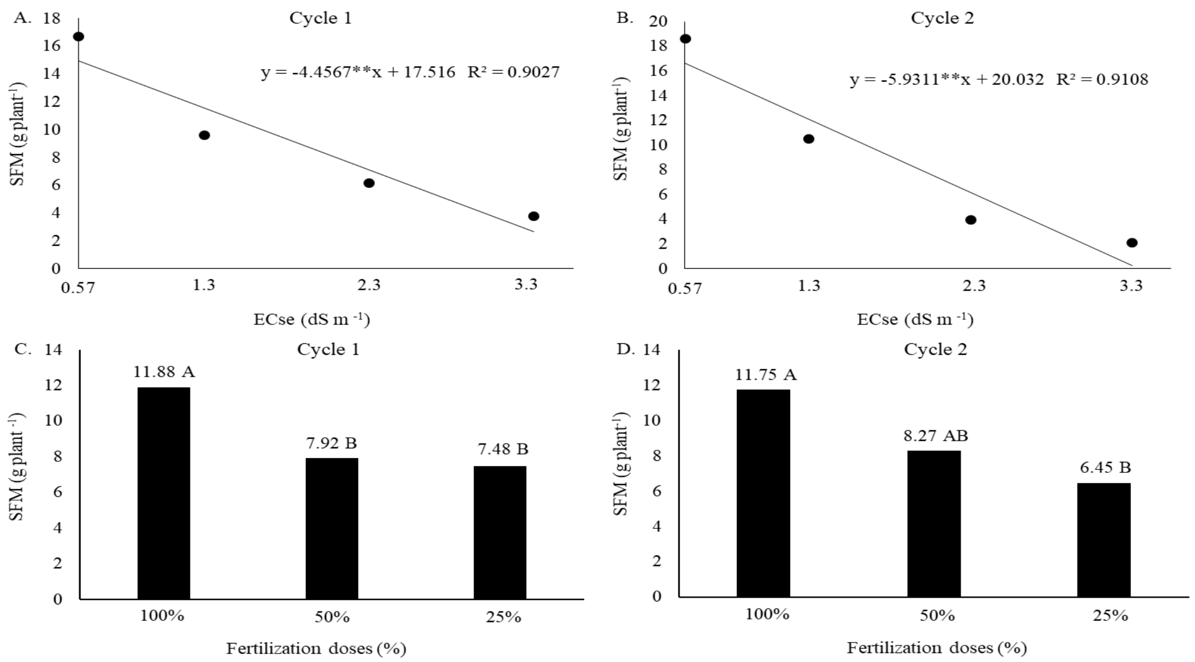

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Figure 4. Shoot fresh mass (SFM) of arugula subjected to electrical conductivity of the soil saturation extract (ECse), cycle 1 (A), cycle 2 (B), and fertilization doses, cycle 1 (C) LSD (3.51) and cycle 2 (D) LSD (4.37).

According to the regression analysis (Figure 5), the variable SDM was negatively influenced (*p<0.01*) by the ECse factor, with reduction of 0.572 g plant^{-1} (first cycle) and 0.576 g plant^{-1} (second cycle) per unit increase in ECse (Figures 5A and 5B). These results are similar to those found by Petretto et al. (2019), who observed a reduction in the dry biomass of arugula plants irrigated with different concentrations of NaCl. This reduction that occurs in shoot dry mass in plants irrigated with brackish water is related to energy diversion due to the increase in soil salinity levels, so this reduction may be a consequence of the metabolic cost of energy (MENEZES et al., 2017).

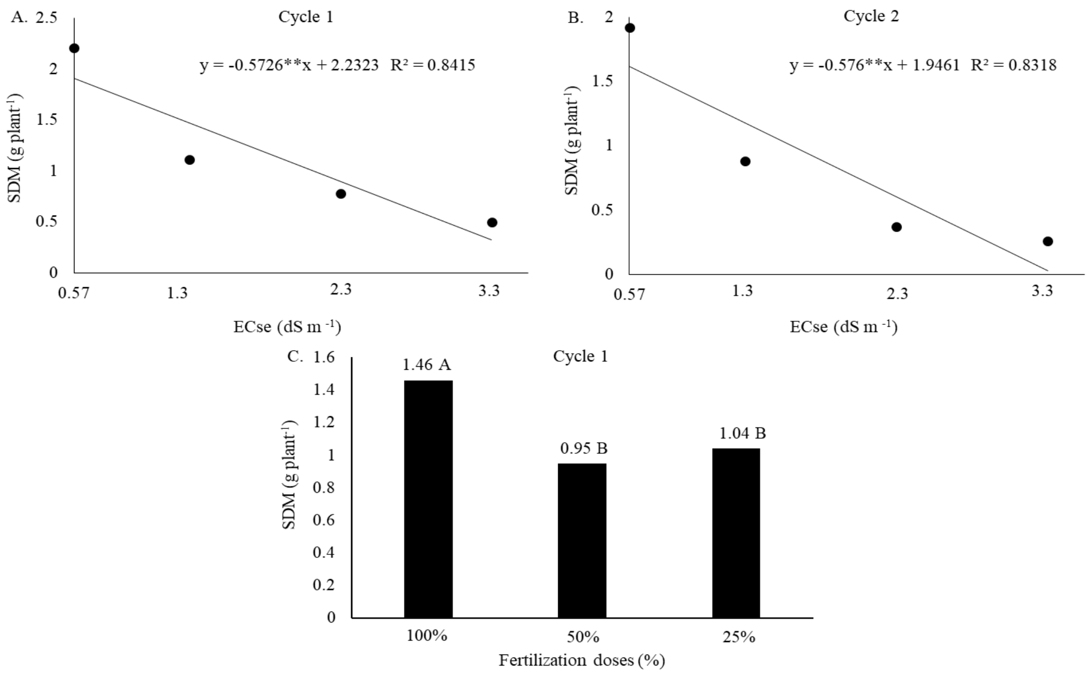

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Figure 5. Shoot dry mass (SDM) of arugula subjected to electrical conductivity of soil saturation extract (ECse), cycle 1 (A), cycle 2 (B), and fertilization doses, cycle 1 (C) LSD (0.54).

For the FDF factor, the dose equivalent to 100% of the recommended fertilization led to higher values (*p<0.05*) of SDM (1.46 g plant^{-1}), while the doses of 50% (0.95 g plant^{-1}) and 25% (1.04 g plant^{-1}) of the recommended fertilization did not differ significantly, according to the Tukey test (Figure 5C). By providing 100% of the primary macronutrients required by the crop, it is possible to obtain greater vegetative growth, especially with nitrogen, which is directly linked to this function, and consequently increase dry biomass.

The regression analysis performed for U was significant for the interaction between the factors in the second cycle, where all fertilization doses caused quadratic polynomial responses (Figure 6). The fertilization doses of 100% and 25% led to maximum points at ECse levels 1.46 and 1.77 dS m^{-1}, equal to 92.6 and 91.3%, respectively.

At the 50% dose, the minimum point is 87% at the salinity of 2.1 dS m^{-1}. Fertilization is a strategy to minimize the effects of salinity, but when the salinity level exceeds the tolerance limit of the crop, there is a reduction in water absorption and cell turgor (LIMA et al., 2021). The reduction of water in the leaf observed in this study is a consequence of the salinized soil, from which the roots are unable to absorb water due to the increase in osmotic potential.

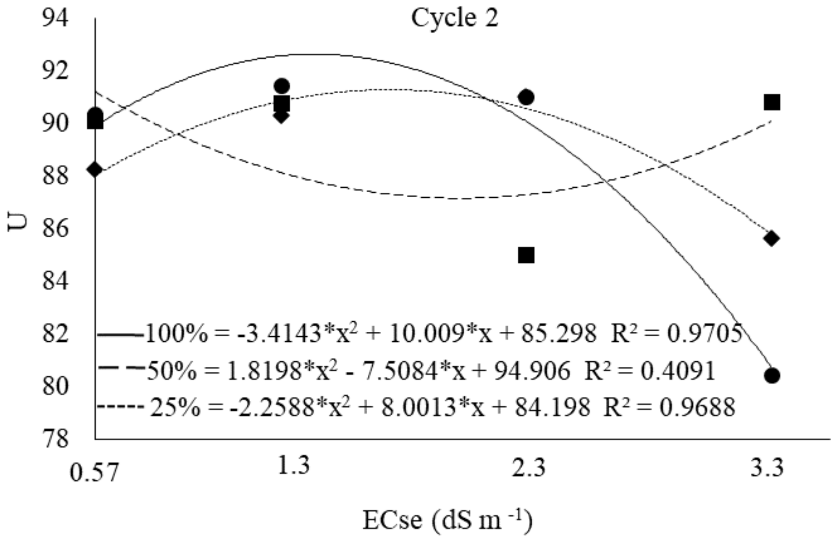

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Figure 6. Percentage of water (U) in leaves of arugula subjected to electrical conductivity of the soil saturation extract (ECse) and different fertilization doses.

In both cycles, the behavior of relative chlorophyll index (SPAD) tended towards a quadratic polynomial (Figures 7A and 7B). In the first cycle, the maximum point was 57.91 at the ECse of 1.78 dS m^{-1}. In the second cycle, the 100% and 25% doses led to maximum values of 59.71 and 51.81 at ECse of 1.65 and 1.26 dS m^{-1}, respectively, while the 50% dose led to minimum point of 44.01 at ECse of 2.41 dS m^{-1}.

When plants are under some stress, it is common for them to look for ways to mitigate the impacts, so one of the amino acids most consumed by plants under these conditions is proline (LIMA et al., 2021). However, this consumption ends up limiting the action of the enzyme glutamate, the precursor of chlorophyll biosynthesis, causing damage to the production of this pigment.

The SPAD index is directly linked to the presence of chlorophyll in the leaf, and this pigment is a direct indicator of photosynthesis functioning (SALES et al., 2018). Studies such as those conducted by Afsar et al. (2020) point out that salt stress can lead to reduction in the amount of chlorophyll in leaves, especially if the crop is sensitive. These results are in agreement with those found in the present study, since chlorophyll decreased with increasing salinity in both study cycles (Figure 7A and 7B), so the behavior of photosynthesis was similar in both study cycles (Figures 7C and 7D). Chlorophyll is the most important pigment in the absorption of light, so with its reduction it becomes impossible to convert light energy into chemical energy, that is, photosynthesis is negatively affected, reducing the production of photoassimilates and consequently the growth and biomass of plants (ZHANG et al., 2023).

It is observed that the variable photosynthesis (A) was significantly affected only by the ECse factor in both study cycles. In the first cycle, the fit was quadratic, with a maximum of 7.72 μmol m^{2} s^{-1} for ECse of 1.95 dS m^{-1} (Figure 7C). On the other hand, in the second cycle, the trend line showed a decreasing linear behavior, with reduction of 3.13 μmol m^{2} s^{-1} per unit increase in ECse (Figure 7D). Salinity affects photosynthesis in several ways, as it reduces the amount of water used, alters the structure of cell membranes that participate in the process, reduces the activity of enzymes, and causes limitations in the ability of plants to perform photosynthesis, due to the accumulation of toxic ions (SOUSA et al., 2021).

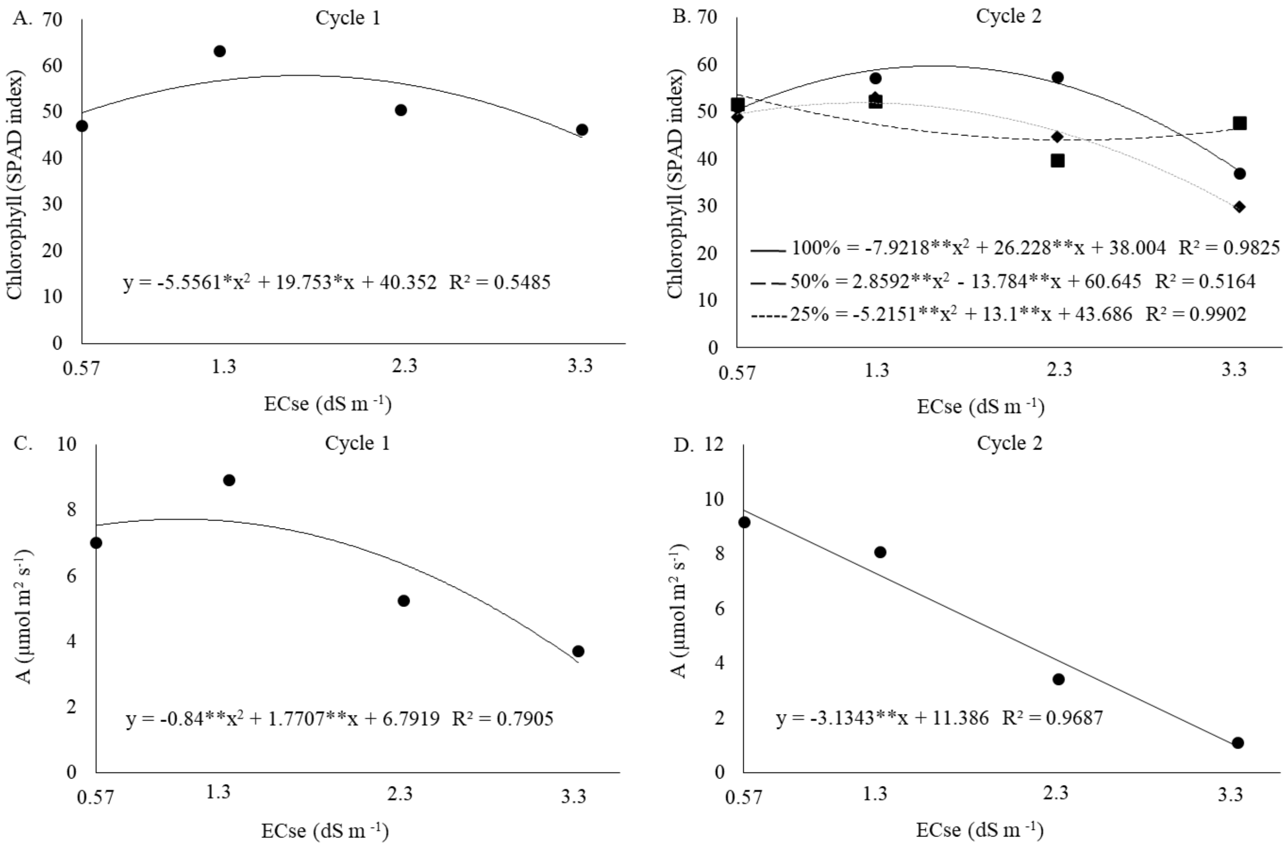


Figure 7. SPAD index, cycle 1 (A) and cycle 2 (B), and photosynthesis rate, cycle 1 (C) and cycle 2 (D), of arugula subjected to electrical conductivity of the saturation extract (ECse).

For the variable transpiration (E), the results were similar to those of photosynthesis, as in the first cycle the regression analysis showed a quadratic polynomial behavior, with maximum point of 3.02 mmol m^2 s^{-1} at ECse of 1.43 dS m^{-1} (Figure 8A). On the other hand, in the second cycle, a decreasing linear fit was observed, with a 66.12% reduction in the response variable E when the ECse is increased (Figure 8B).

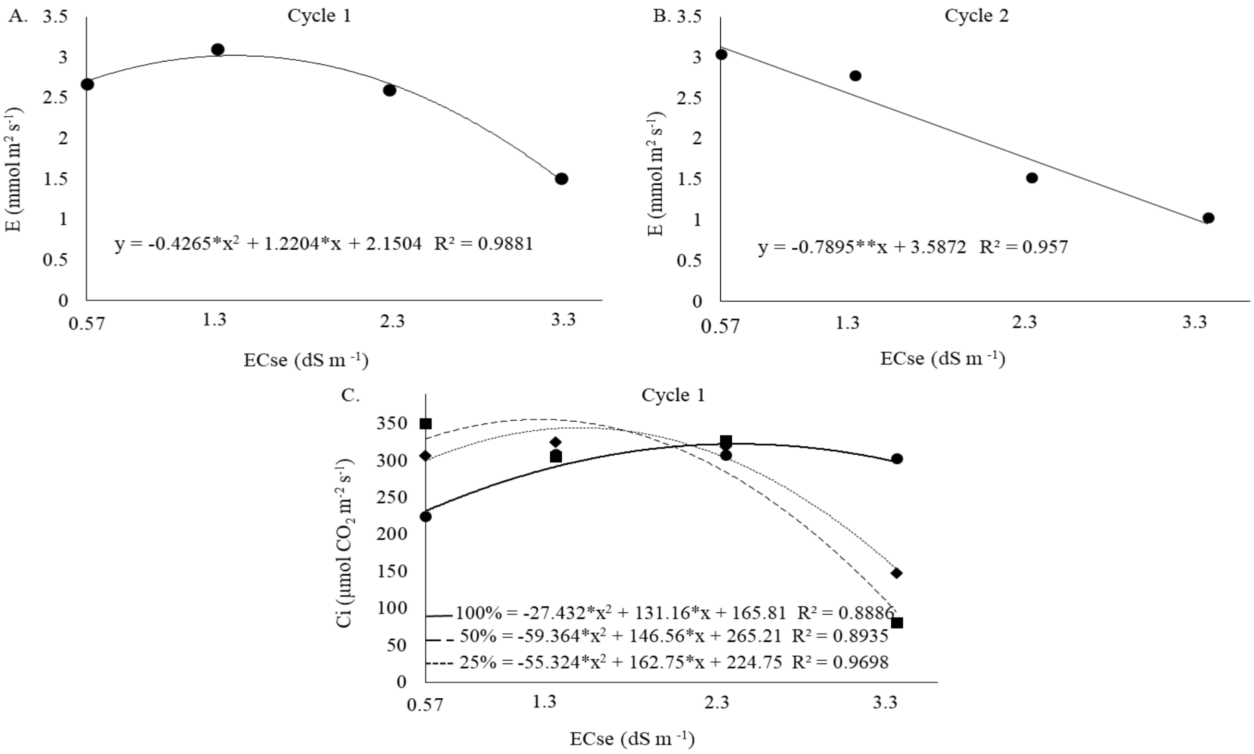
This result is directly linked to the reduction of leaf area, caused by the osmotic stress suffered by the plant, thus limiting transpiration. Saline soils are defined by the presence of high concentrations of soluble salts, mainly sodium (Na^+) and chlorine (Cl^-) ions, which result in a significantly reduced osmotic potential (SAHIN et al., 2018). From this pressure differential, the roots cannot absorb water and consequently the transpiration process is affected, because in order not to lose water, plants keep their stomata partially closed (PEREIRA FILHO et al., 2019).

In the regression analysis for the response variable Ci, the interaction between the FDF and ECse factors was significant with quadratic fit (Figure 8C). The fertilization doses of 100, 50 and 25% had their maximum values of 322, 355 and 344 mmol m^2 s^{-1} at ECse levels of 2.4, 1.23 and 1.47 dS m^{-1}, respectively.

The decrease in internal CO_2 concentration was expected because plants that are under this salt stress end up partially closing their stomata to reduce water loss and, consequently, the diffusion of CO_2 in the stomata is drastically reduced (OLIVEIRA et al., 2017). A higher tolerance to ECse is noticeable at the fertilization dose equivalent to 100% of the recommendation, for which the maximum Ci occurred at ECse of 2.4 dS m^{-1}. According to Alvarenga et al. (2019), nitrogen associated with potassium improves the enzymatic activity of plants, thus favoring better osmotic adjustment and consequently the assimilation and concentration of CO_2 in plant cells.

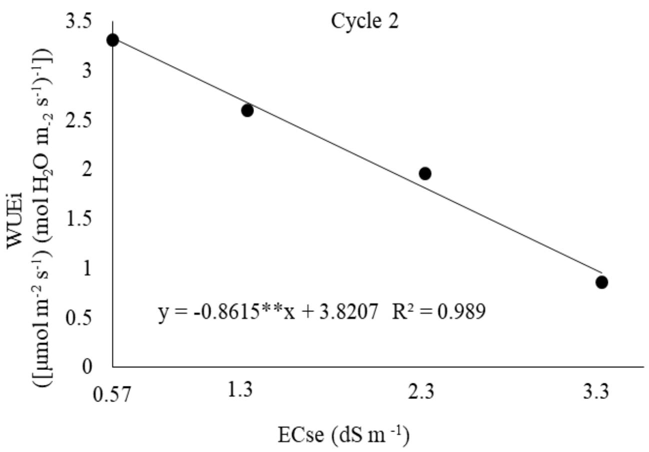
The instantaneous water use efficiency (WUEi) was significantly affected by the ECse factor and showed a decreasing linear behavior, with a reduction of 0.86 [µmol m^2 s^{-1} mol H_2O m² s^{-1}]$^{-1}$ per unit increase in ECse (Figure 9).

Plants that have compromised stomatal opening tend to reduce their water use efficiency (LIMA et al., 2021). According to Evelin et al. (2019), Na^+ and Cl^- reduce the water potential of the soil, causing plants to close their stomata in order to avoid cell dehydration; consequently, their WUEi is impaired. Studies focused on saline soils in the field and different crops, both sensitive and tolerant, have reported results close to that found in the present study, where water use efficiency decreased significantly with increasing ECse (GIL-MUÑOZ et al., 2020).



** and *: significant at 1 and 5% by t-test

Figure 8. Transpiration (E) in arugula plants, cycle 1 (A) and cycle 2 (B), subjected to electrical conductivity of the saturation extract (ECse), and internal CO_2 concentration (Ci) of arugula subjected to ECse and fertilization doses, cycle 1 (C).



** and *: significant at 1 and 5% by t-test

Figure 9. Instantaneous water use efficiency (WUEi) in arugula subjected to electrical conductivity of saturation extract (ECse) in the second production cycle.

The results for instantaneous carboxylation efficiency of (CEi) were similar results to those of transpiration and photosynthesis in both cycles (Figures 10A and 10B). In the first cycle, the regression analysis was significant (*p<0.05*) for a quadratic polynomial fit, with a maximum of 0.025 [(µmol m^{-2} s^{-1}) (µmol mol^{-1})$^{-1}$] at ECse 0.93 dS m^{-1}, while in the second cycle, the instantaneous carboxylation efficiency was described by a decreasing linear function, decreased by 89.3% at the salinity of 3.3 dS m^{-1} (Figure 10).

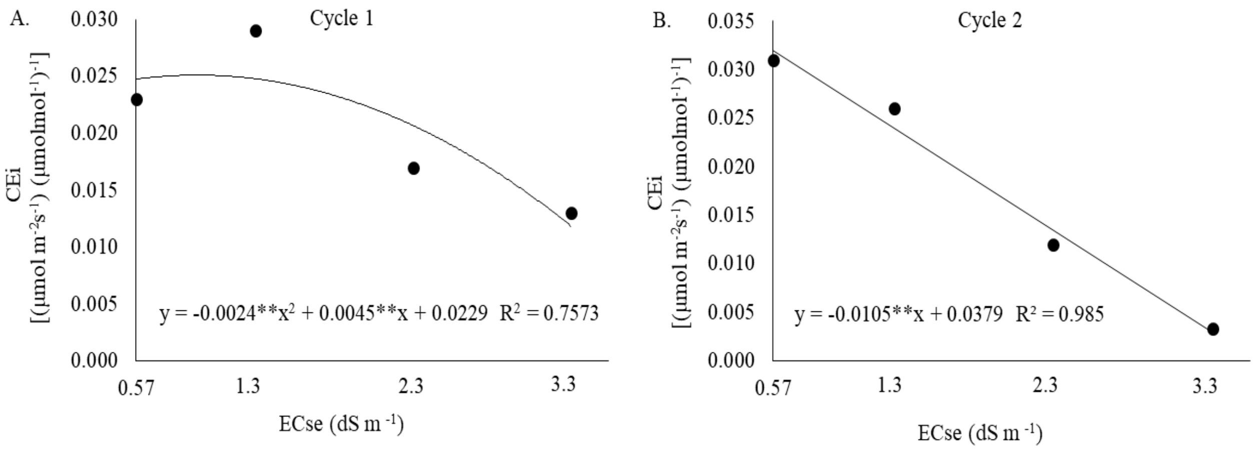


Figure 10. Instantaneous carboxylation efficiency (CEi) in arugula subjected to electrical conductivity of saturation extract (ECse) in the first (A) and second (B) production cycle.

CEi is directly linked to the internal concentration of CO_2 and its assimilation. When plants close their stomata due to stress, they end up compromising CO_2 assimilation, photosynthesis, transpiration and, consequently, CEi (JACINTO JÚNIOR et al., 2019). According to Soares et al. (2021), low CEi is indicative of an inhibition in the photosynthetic process, impairing the production of photoassimilates and, consequently, plant growth.

CONCLUSIONS

The addition of fertilizers in salinized soils, with recommended doses, did not cause marked reductions in the morphological and physiological variables of arugula crop in the present study.

Electrical conductivity of the soil saturation extract above 2.1 dS m^{-1} causes reduction in the growth and yield parameters of arugula crop.

The strategy of reducing fertilizer doses was not interesting for arugula crop, according to the conditions of the present study.

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