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Fertigation of arugula crops grown in saline soils

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Abstract

Arugula is a leafy vegetable that has been standing out in terms of consumption due to its nutritional content. The crop has low tolerance to water salinity (ECw), and information on the management of fertilization in saline environments is scarce. In this context, this study aimed to analyze the nutritional aspects of arugula under different soil salinity levels and fertilization doses via fertigation. The experiment was conducted in a greenhouse during two production cycles in 2021 in a randomized block design and a 4 x 3 factorial arrangement, with four replications. The treatments consisted of four soil salinity levels (ECse = 0.57, 1.3, 2.3, and 3.3 dS m^{-1}) and three doses of a mineral fertilizer based on the recommended fertilization via fertigation (F1 = 100%, F2 = 50%, and F3 = 25%). The contents of N, P, K, Ca, Mg, S, Na, Cu, Fe, Zn, and Mn were evaluated after harvesting. Salinity directly affected the concentration of mineral elements in arugula leaf during the first cycle, mainly Ca, Mg, Zn, and Mn. The fertigation strategy with 100% of the recommended fertilization showed better results than the other doses for N, P, K, and S. In the second cycle, all elements showed a reduction due to the high ECse, mainly the value of 3.3 dS m^{-1}. The fertigation strategy that used 100% of the recommended fertilization promoted higher nutrient accumulation in arugula. The order of nutrient accumulation in arugula leaf was K>N>Ca>S>Mg>P>Fe>Zn>Mn>Cu.

Keywords: salinity, *Eruca sativa*, plant nutrition

Introduction

Arugula (*Eruca sativa*) is a leafy vegetable belonging to the family Brassicaceae with a low height and a short cycle, which guarantees a faster economic return for producers who invest in its cultivation. The crop has stood out in the last decades due to an increase in its consumption, which is related both to its nutritional properties, as it is rich in vitamins and minerals, and its antioxidant action for the body (Sediyama et al., 2019).

Nutrition is an important factor in arugula production, as success in the cultivation of vegetables is obtained through the adequate supply of nutrients from the seedling stage to harvest, and the nutritional imbalance can be irreversible due to their fast cycle (Chen et al., 2020). Therefore, knowledge about the amount of nutrients to be applied and the periods of highest demand are factors that require information on soil-water-plant relationships and productivity under different conditions (Silva et al., 2020).

Arugula is produced under irrigation in the Brazilian Northeast. However, the water quality in this region has high salt levels and arugula has low tolerance to salinity (Hamilton & Fonseca, 2010), limiting its production in several regions. The plant under salinity conditions can suffer from the direct action of salts, reducing water absorption due to an increase in osmotic pressure, and excess ions can enter the transpiration flow and cause injuries to the leaves due to specific effect, reducing growth or negatively inducing the absorption of essential elements (Souza et al., 2019; Shakeri et al., 2020).

A well-conducted fertigation can be used even in a saline environment, without adding more salts to the soil, leaving the soil solution with tolerable electrical conductivity levels for absorption by plant roots (Silva et al., 2013) due to the split of fertilizers during the cycle and their reduction when signs of toxicity are observed

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in the plants. According to Venezia et al. (2022), the use of fertigation in a saline environment is possible as long as more adequate strategies are found to manage the supply of water and nutrients that meet the real needs of the plant, without generating accumulations of ions in the substrate.

Given the lack of information regarding the management of fertilization in a saline environment for arugula, this study aimed to analyze the nutritional aspects of arugula under different soil salinity levels and fertilization doses via fertigation.

Material and Methods

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

Two production cycles were conducted. The first cycle occurred from May to June 2021 and the second cycle from July to August 2021. The arugula cultivar 'broad leaf' was sowed in expanded polyethylene trays filled with coconut fiber. Plants with three definitive leaves were transplanted to beds measuring 0.5 x 0.15 m with a spacing of 0.10 m between plants at 20 days after sowing (DAS) (Trani et al., 2014).

The soil used in the experiment is classified as a loamy sandy Oxisol (EMBRAPA, 2018). A soil chemical analysis was also conducted (**Table 1**) using the methodology described by Teixeira et al. (2017).

The experiment was conducted in a randomized block design arranged in a 4 x 3 factorial scheme, with four replications. The treatments consisted of four soil salinity levels (ECse = 0.57, 1.3, 2.3, and 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 plot had four plants in the beds. Fertigation was carried out manually together with the application of irrigation depths based on the readings of soil water tension, obtained by puncture tensiometers and the characteristic curve with the parameters of the Van Genuchten equation.

The artificial salinization of the soil in the beds was conducted using the salts (NaCl) dissolved in water and inserted into five test pots with a volume of 5L each. The amount of salts added to the soil was estimated using the equation for the amount of salts, in which Qs is the amount of salts applied per pot (mg L^{-1}), Vs is the volume of water present in the soil when it is saturated (L), and ECse is the electrical conductivity of the saturation extract (dS m^{-1}).

The ECse values were obtained using the methodology of Donagema (2014). The data allowed obtaining the soil salinity curve and the amount of salts to be applied in each bed to reach the desired salinity of the study was obtained through its equation (Silva et al., 2013).

The fertilizers were dissolved in 15-liter containers and applied via fertigation, according to the recommended values for arugula, in which the 100% recommended dose was composed of 140 kg N ha^{-1}, 30 kg P_2O_5 ha^{-1}, and 50 kg K_2O ha^{-1}. The fertilizer sources were urea (45% N), MAP (12% N and 61% P_2O_5), and Dripsol NKS (45% K_2O and 12% N). Secondary macronutrients (Ca, Mg, and S) and micronutrients were included based on the soil chemical analysis and recommendations by Trani et al. (2014).

The plants were harvested at 30 DAT and dried in a forced-air circulation oven at a temperature of 65 °C for 72 hours. After obtaining a constant weight, the dry material was ground and the samples were submitted to sulfuric digestion, followed by distillation and titration to determine the total nitrogen (N) contents (g kg^{-1}).

Nitric-perchloric digestion was used to determine phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), sodium (Na), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) by inductively coupled plasma–optical emission spectrometry (ICP–OES), according to procedures described by Miyazawa et al. (2009). The data from these analyses were multiplied by the total dry matter of the plants to obtain the accumulation of these nutrients in the arugula leaf tissue in g $plant^{-1}$.

Finally, the results underwent an evaluation of normality (Bartlett) and homogeneity (Shapiro-Wilk), followed by analysis of variance (ANOVA) when they were normal and homogeneous. Subsequently, the data referring to the quantitative variables were submitted to regression analysis and the means compared by Tukey's test with a 1% (p<0.01) and 5% (p < 0.05) probability. All

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} ---		$mgkg^{-1}$	-------------------- $cmol_c$ kg^{-3} ----------						H_2O	dSm^{-1}	%
11.30	0.61	32	0.6	0.36	1.2	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.

statistical analyses were conducted using the software SAS version 9.4.

Results and Discussion

The analysis of variance (**Table 2**) showed that the results obtained for the leaf chemical analyses in the first cycle of the study were significant for the interaction between soil salinity (ECse) and fertilization doses via fertigation (F) for the variables N (p=0.0030), P (p=0.0217), potassium K (p=0.0214), and S (p=0.0285). The variables Ca (p=0.0003), Mg (p=0.0015), Na (p=0.0285), Zn (p<0.0001), and Mn (p=0.0011) were significant only for the ECse factor, while Cu was not significant (p>0.05) for the studied factors.

Table 2. Summary of analysis of variance in the first arugula cultivation cycle for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), sodium (Na), copper (Cu), zinc (Zn), and manganese (Mn) contents

SV	DF	MS				
		N	P	K	Ca	Mg
1st cycle						
S	3	288.1**	0.37^{NS}	1478.2*	111.1*	16.27*
F	2	314.9**	5.06*	665.7*	31.35^{NS}	2.32^{NS}
S x F	6	367.2*	1.10**	196.3**	30.82^{NS}	4.04^{NS}
Residual	36	88.93	0.38	68.19	13.39	2.58
CV (%)		38.15	38.55	30.24	33.3	36.72
		S	Na	Cu	Zn	Mn
S	3	25.4*	312**	6.02^{NS}	22040*	1056*
F	2	4.6^{NS}	90.8^{NS}	5.08^{NS}	13.77^{NS}	146.3^{NS}
S x F	6	12**	76.5^{NS}	6.08^{NS}	1851^{NS}	35.27^{NS}
Residual	36	4.48	92.41	3.29	1556	158.06
CV (%)		35.44	57.16	41.31	40.84	48.10

SV: sources of variation; DF: degrees of freedom; CV: coefficient of variation. *Significant by the F-test at 5%; **Significant by the F-test at 1%; ns: Not significant.

The N content in leaves showed a quadratic polynomial fit for the three evaluated fertilizer doses (**Figure 1**A). At the 100% of the recommended fertilization dose, the minimum point was at an ECse of 2.45 dS m^{-1}, presenting 22.86 g kg^{-1} of N in the leaves. In contrast, the 50% dose had the maximum point at an ECse of 1.94 dS m^{-1}, with about 29.6 g kg^{-1}. The maximum ECse of 1.96 dS m^{-1} was obtained for the 25% of the recommended dose, totaling 30 g N kg^{-1} of arugula leaves. The fertilization doses via fertigation of 50% and 25% showed a reduction in N concentration with an increase in ECse, specifically around 1.95 dS m^{-1}.

This reduction in leaf N at doses 25 and 50% may be related to an increase in the electrical conductivity of the soil saturation extract. Electrical conductivity is an indicator of soil salinity, and higher levels can affect nutrient uptake by plants. The 100% dose obtained opposite results, with an increase in the content at the highest saline level. Higher N doses can attenuate the harmful effects of salinity and the plant can osmoregulate more efficiently and accumulate more of this nutrient (SOUSA et at., 2021).

The results found for P (Figure 1B) were significant, and an increasing linear model was fitted for the 100% fertilization dose. The other doses of 50% and 25% of fertilization fitted better to the quadratic polynomial model, with the maximum point of 1.64 g kg^{-1} at an ECse of 1.48 dS m^{-1} and 1.35 g kg^{-1} at an ECse of 1.25 dS m^{-1}, respectively. Similarly, Chaichi et al. (2017) observed a higher accumulation of P and S in tomato plants irrigated with saline water. Regarding K (Figure 1C), the 100% fertilization dose fitted the quadratic polynomial model, with a minimum point of 27.89 g kg^{-1} at an ECse of 2.35 dS m^{-1}. The other fertilization doses via fertigation fitted better the linear model (Figure 1C), with a reduction of 10.93 (50%) and 12.14 g kg^{-1} (25%) at each unit increment of ECse.

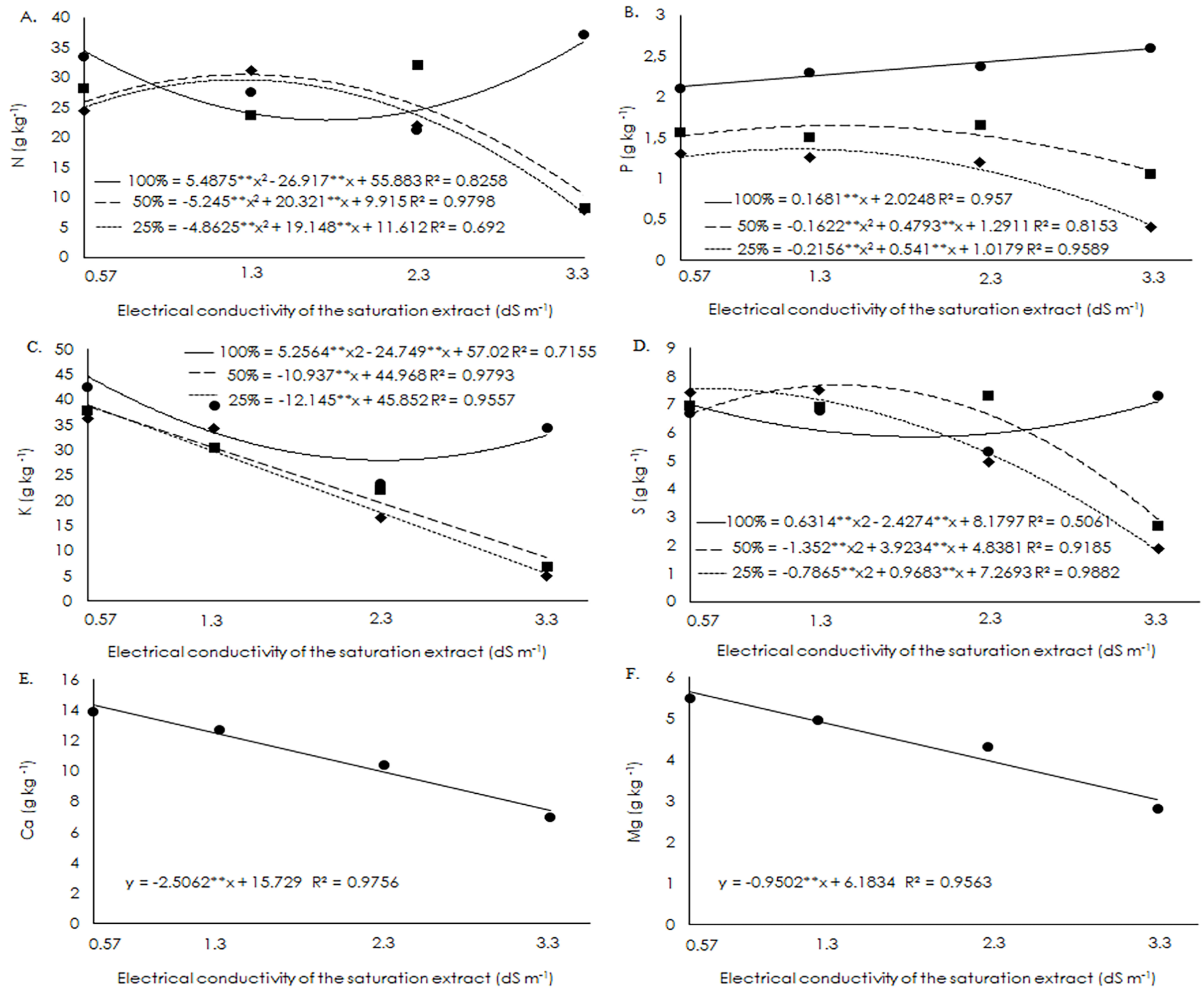
The results for K may be related to its important function as a macronutrient, playing several roles in the physiological and metabolic processes of plants, such as increasing plant tolerance to biotic and abiotic stresses, including salinity (FERREIRA et al., 2020). The presence of K can reduce Na absorption and accumulate more in plant tissues, as observed in the present study.

The S content (Figure 1D) showed a quadratic polynomial response in the three fertilization doses via fertigation. The 100% of the recommended dose had the minimum point of 5.8 g kg^{-1} at an ECse of 1.92 dS m^{-1}, and the reduction of the dose to 50% led to a maximum point of 7.68 g kg^{-1} at an ECse of 1.45 dS m^{-1}. Finally, the maximum point at 25% management was 7.58 g kg^{-1} at an ECse of 0.62 dS m^{-1}. Ca (Figure 1E) and Mg (Figure 1F) contents presented a reduction of 2.50 and 0.95 g kg^{-1} for each unit increment of ECse.

The saline environment caused disturbances that limited S absorption, mainly at doses of 25 and 50% of the recommended dose. Regarding the 100% dose, the highest salinity of 3.3 dS m^{-1} presented a growth trend in the presence of S, with a behavior similar to that of nitrogen.

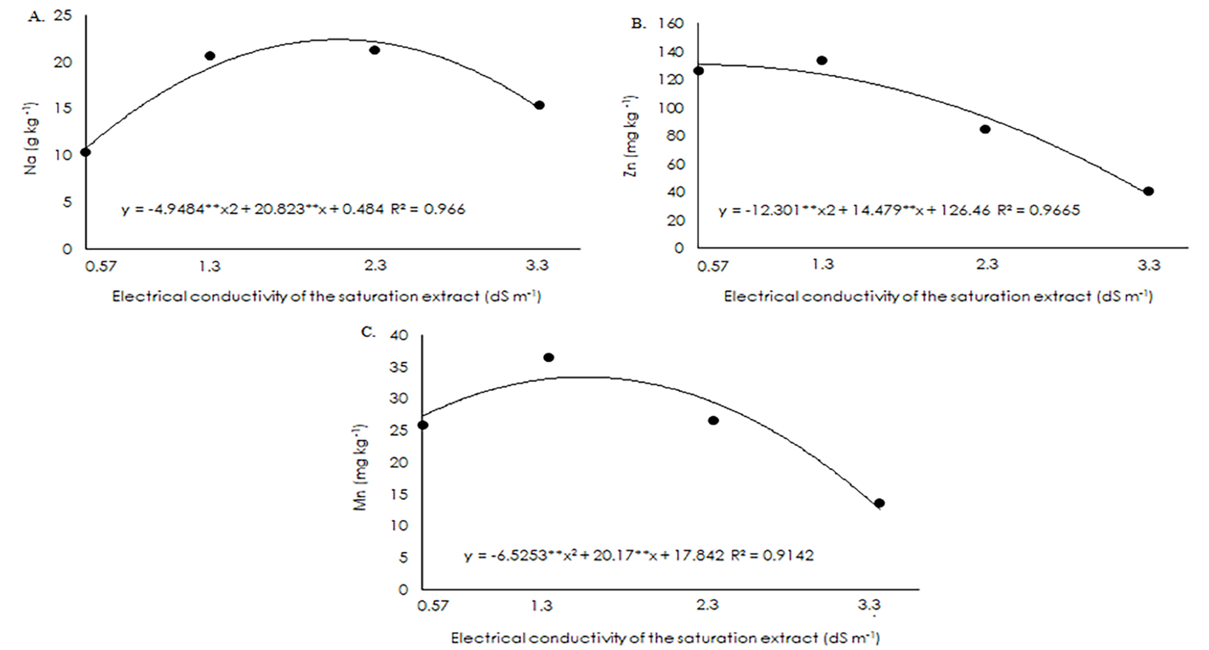
Na had its maximum point at 22.31 g kg^{-1} at an ECse of 2.1 dS m^{-1}, Zn at 130.72 mg kg^{-1} at an ECse of 0.58 dS m^{-1}, and Mn had an accumulation of 33.43 mg kg^{-1} at an ECse of 1.54 dS m^{-1} (**Figures 2**A, 2B, and 2C). The excess of ions such as chlorine (Cl^-) leads to a reduction in water movement, causing competition for the absorption, assimilation, and movement of Na and Mn in plant organs (Parihar et al., 2015; Taiz et al., 2017).

Excess sodium impairs the functioning of



**Significant at p<0.01 by the F-test.

Figure 1. Nitrogen (A), phosphorus (B), potassium (C), sulfur (D), calcium (E), and magnesium (F) contents in the leaves of *Eruca sativa* grown under different fertilization doses and soil salinity conditions in the first production cycle.



**Significant at p<0.01 by the F-test.

Figure 2. Sodium (A), zinc (B), and manganese (C) contents in *Eruca sativa* leaves grown under soil salinity conditions in the first production cycle

several enzymes and physiological processes in which K^+ is involved. Arugula reduces the Na content when exposed to an environment with a high concentration of salts, which shows a potential to maintain potassium homeostasis, improving its salt stress tolerance (Chen et al., 2020). These results corroborate what was found by Chen et al. (2015) when studying the osmotic and ionic effects of salinity.

The results of the second cycle of the study showed a significance for the two factors: soil salinity and fertilizer doses in isolation in the variables N ($p<0.0001$ for the factor ECse and $p=0.0401$ for the factor F), P ($p=0.0024$ for the factor ECse and $p=0.0232$ for the factor F), and K ($p<0.0001$ for the factor ECse and $p=0.048$ for the factor F). Ca ($p<0.0001$), Mg ($p<0.0001$), S ($p<0.0001$), Na ($p=0.0099$), Cu ($p=0.0298$), Zn ($p< 0.0001$), and Mn ($p<0.0001$) were significant only for the factor ECse (**Table 3**).

(**Figures 3**A and 3C) show that N and K concentrations decreased significantly as the electrical conductivity of the saturation extract (ECse) increased, with the decreasing linear model showing the best fit to the data. This effect indicates that saline stress affected the absorption and translocation of these nutrients in arugula plants. On the other hand, P fitted better the quadratic polynomial model, with a maximum of 2.13 g P kg^{-1} at an ECse of 1.40 dS m^{-1} (Figure 3E).

Table 3. Summary of analysis of variance in the second arugula cultivation cycle for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), sodium (Na), copper (Cu), zinc (Zn), and manganese (Mn) contents

SV	DF	MS				
		N	P	K	Ca	Mg
2nd cycle						
S	3	889.7*	4.20*	2748*	317.8*	41.67*
F	2	329.2**	3.00**	276.2**	36.45NS	1.86NS
S x F	6	44.58NS	0.37NS	97.90NS	10.22NS	1.78NS
Residual	36	93.53	0.72	83.71	22.84	3.71
CV (%)		43.92	50.6	38.1	42.63	45.14
		S	Na	Cu	Zn	Mn
S	3	87.9*	885.9*	15.63**	36910*	2192*
F	2	6.3NS	17.5NS	3.1NS	168NS	62.6NS
S x F	6	3.3NS	44.3NS	1.28NS	1333NS	107NS
Residual	36	4.30	201.9	4.68	884.8	221.4
CV (%)		40.73	69.6	64.1	37.97	52.74

SV: sources of variation; DF: degrees of freedom; CV: coefficient of variation. *Significant by the F-test at 5%; **Significant by the F-test at 1%; ns: Not significant.

Similarly, Sousa et al. (2022) worked with corn under saline stress and observed that it occurs because salinity causes an ionic strength effect that reduces the presence of phosphates in the soil, thus reducing the solubility of this fertilizer and, consequently, its absorption by the roots.

The increased presence of Na^+ and Cl^- in the soil solution may cause physiological disturbances, impairing the absorption of ions such as K^+ and NH_4^+, whereas Cl^- in excess interferes and has an antagonistic effect with NO_3^- (PARIHAR et al., 2015), which may explain our results.

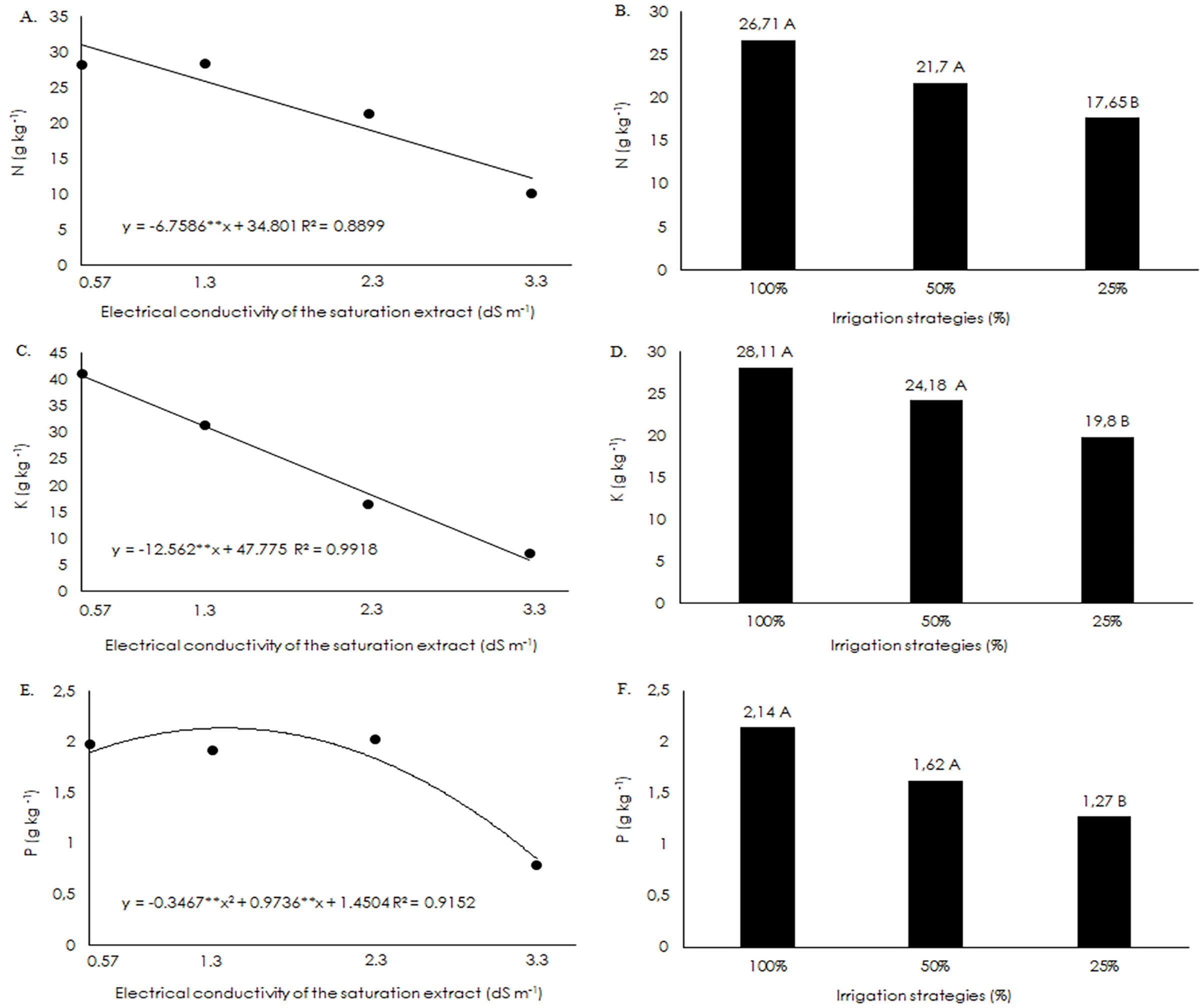
Regarding fertilization, 100 and 50% of the recommended doses showed better results in terms of N, K, and P concentrations in arugula leaf tissue. It means that the proper application of fertilizers at these doses resulted in higher absorption and accumulation of these nutrients in the plants. However, the treatment with 25% of the recommended fertilizer dose showed a significant reduction in the concentrations of these nutrients (Figures 3B, 3D, and 3F).

Similarly, Das et al. (2022) worked with different fertilization doses and management and found an increase in the concentration of N, P, and K for the highest fertilization doses in the three crop cycles. The increase in the availability of these elements in the soil is essential, mainly for P, which plays a vital role in plant development in tropical regions, being crucial for energy production in the form of ATP in plants (Taiz et al., 2017).

The results of the second cycle showed that all secondary macronutrients (Ca, Mg, and S) had similar trends, with a linear decrease in their concentrations (4.18, 1.51, and 2.25 g kg^{-1}) in the arugula leaf tissue for each unit increase in ECse (**Figures 4**A, 4B, and 4C).

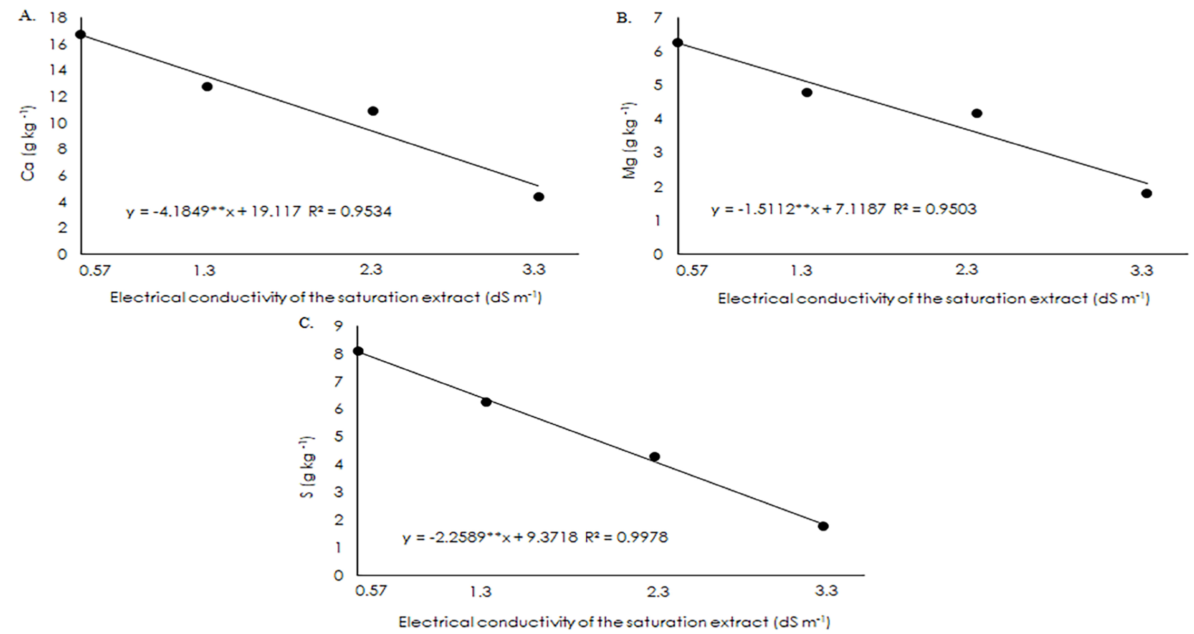
Akter & Oue (2018) found that salt accumulation directly affects the plasma membrane of plants, displacing Ca^{2+} out of the plant cell, thus restricting the concentration of this element in the leaf. The same is observed with Mg, which is a constituent of chlorophyll just as N. Therefore, salt (NaCl) accumulation can lead to chlorosis by reducing chlorophyll contents in plant tissue and, consequently, its central mineral element (Sousa et al., 2022).

S is the last secondary macronutrient. N in the first cycle helped the absorption of this element, but its concentration was reduced in the second cycle with an increase in ECse. Therefore, the presence of S was also affected and showed similar behavior (Figure 4C). In this case, the plants have a lower amount of nitric oxide, which helps in the absorption and assimilation of sulfur by reducing its presence, and S concentration dropped



**Significant at $p<0.01$ by the F-test. Means followed by the same letter do not differ from each other by Tukey's test ($p<0.05$).

Figure 3. Nitrogen (A and B), phosphorus (C and D), and potassium (E and F) concentrations in leaves of *Eruca sativa* grown under different conditions of electrical conductivity of the saturation extract (A, C, and E) and fertigation strategies (B, D, and F) in the second production cycle.



**Significant at $p<0.01$ by the F-test.

Figure 4. Calcium (A), magnesium (B), and sulfur (C) concentrations in leaves of *Eruca sativa* grown under soil salinity conditions in the second production cycle.

significantly, as observed by Scagel et al. (2019).

Cu and Mn presented similar results in the second cycle: both adjusted better to the polynomial model. Cu reached its peak at 4.15 mg kg^{-1} at a salinity of 1.35 dS m^{-1}, whereas Mn was 38.34 mg kg^{-1} at an ECse of 1.19 dS m^{-1}, with a similar result to that found in the first study cycle (**Figures 5**A and 5B).

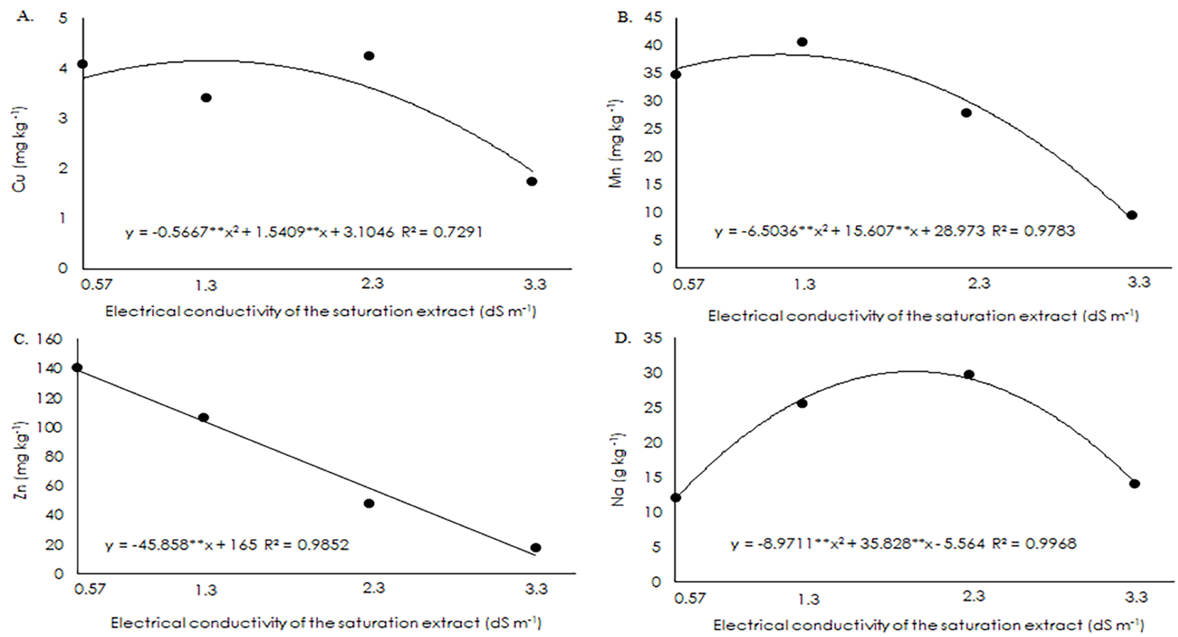
The results found for Zn fitted the linear model, with a decrease of 45.858 mg kg^{-1} at each unit increase in ECse (Figure 5C). This reduction in the micronutrients Cu, Mn, and Zn is related to two factors. First, ECse releases toxic ions, which prevent the absorption of essential elements due to antagonistic effects. Second, the pH tends to become alkaline in environments in which soil electrical conductivity soil is high, and this increase in the soil pH reduces micronutrient availability (Parihar et al., 2015).

Na in the second cycle had a quadratic polynomial fit with higher values (30 g kg^{-1}) in ECse (2.0 dS m^{-1}) (Figure 5D). These results can be explained by the same factors that occurred in the first cycle, in which Na was expelled from the plant cell cytosol, a mechanism performed by some vegetables to mitigate the deleterious effects of this salt (Chen et al., 2020).

The analysis of variance (**Table 4**) for nutrient accumulation in the plant in the first cycle showed a significance for the two factors (ECse and F) in isolation in all macronutrients, namely: N ($p<0.0001$ for ECse and $p=0.0006$ for F), P ($p<0.0001$ for ECse and $p<0.0001$ for F), P ($p<0.0001$ for ECse and $p=0.013$ for F), Ca ($p<0.0001$ for ECse and $p=0.0042$ for F), Mg ($p<0.0001$ for ECse and $p=0.0083$ for F), and S ($p<0.0001$ for ECse and $p=0.0287$ for F). The results are repeated in the second cycle, with significance for the two factors (ECse and F) in isolation: N ($p<0.0001$ for ECse and $p=0.0016$ for F), P ($p<0.0001$ for ECse and $p=0.0009$ for F), P ($p<0.0001$ for ECse and $p=0.0095$ for F), Ca ($p<0.0001$ for ECse and $p=0.0070$ for F), Mg ($p<0.0001$ for ECse and $p=0.016$ for F), and S ($p<0.0001$ for ECse and $p=0.0175$ for F).

The variables N (**Figures 6**A and B), P (Figures C and D), and K (Figures 6E and 6F) showed a trend to reduce accumulation in the leaf tissue. N and P were expressed in a decreasing linear model in both cycles and K was fitted to the quadratic polynomial model, with a minimum of 80.2 mg plant^{-1} at an ECse of 3.2 dS m^{-1} for the first cycle and a decreasing linear in the second cycle. This reduction in the accumulation of primary macronutrients was due to excess Cl^- and Na^+, with chlorine showing an antagonistic effect with nitrate and sodium with potassium. Moreover, both elements in the soil solution cause an ionic force that reduces the availability of phosphorus in the soil solution due to a decrease in its solubility (Freire et al., 2020).

Ca, Mg, and S showed reductions in accumulation with an increase in ECse. Ca had a linear adjustment with a decrease of 69.21 mg plant^{-1} for each increment of ECse in the first cycle (**Figure 7**A) and a minimum accumulation of 14.47 mg plant^{-1} at an ECse of 3.3 dS m^{-1} in the second cycle (Figure 7B). Moreover, Mg had a linear fit in the first cycle, with a reduction of 26.961 mg plant^{-1} for each



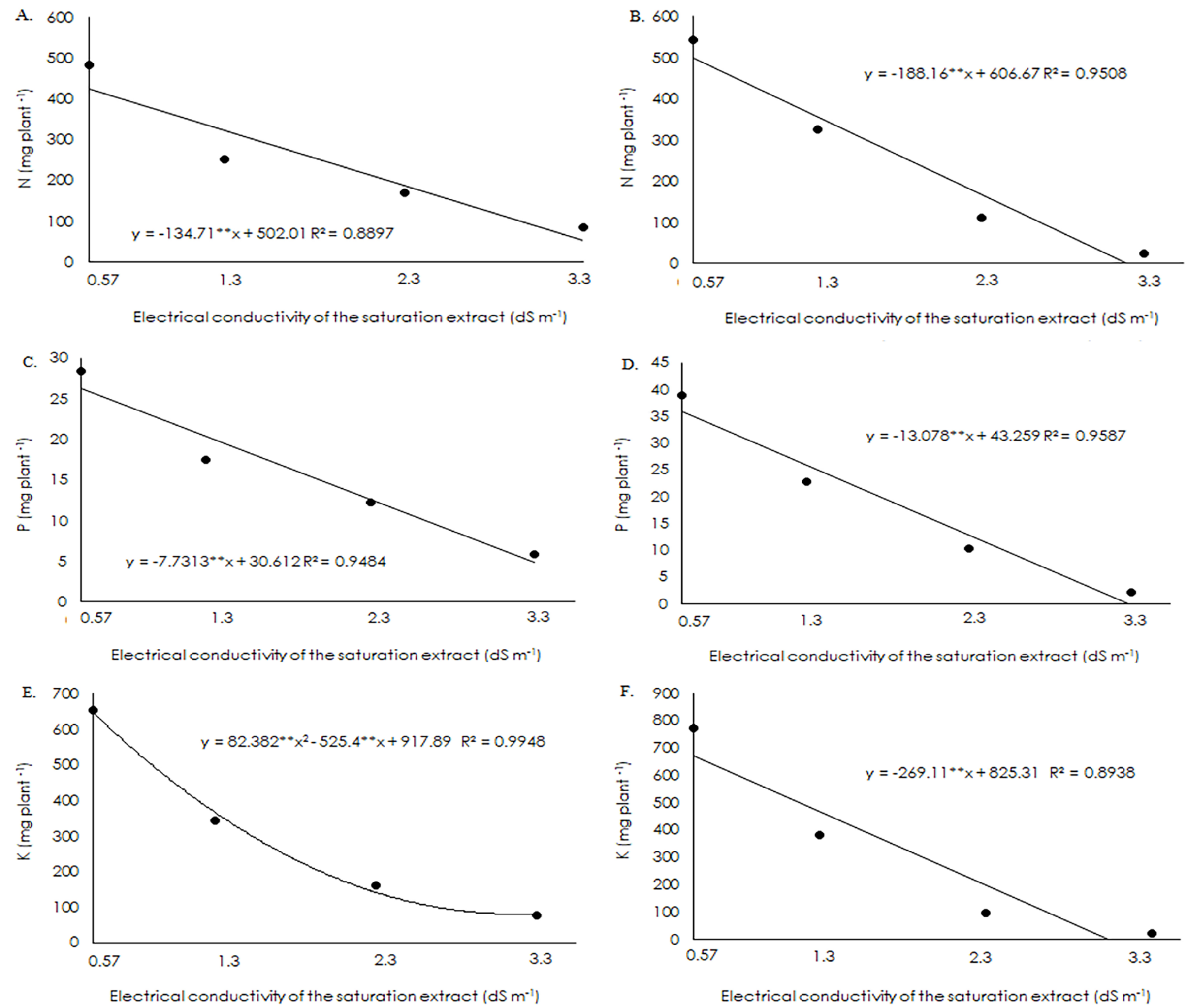
**Significant at $p<0.01$ by the F-test.

Figure 5. Copper (A), manganese (B), zinc (C), and sodium (D) concentrations in leaves of *Eruca sativa* grown under soil salinity conditions in the second production cycle.

Table 4. Summary of analysis of variance for the first and second cycles of arugula cultivation for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) accumulations

SV	DF	MS					
		N	P	K	Ca	Mg	S
				1st cycle			
S	3	352712.0**	1089.6**	788032.4**	91769.5**	14015.1**	21863.7**
F	2	153690.4**	1437.19**	278451.1**	24907.1**	2828.3**	4490.0*
S x F	6	20940.7^{ns}	49.86^{ns}	16592.1^{ns}	3844.4^{ns}	562.4^{ns}	1168.1^{ns}
Residual	36	16788.8	105.61	34637.8	3902.6	515.03	1144.1
CV (%)		52.37	64.1	60.4	54.1	50.67	55.31
				2nd cycle			
S	3	643762.9**	3084.8**	1401173.7**	216136.7**	29281.9**	53055.0**
F	2	270498.7**	2114.7**	279911.6**	39316.3**	3427.9*	8263.6*
S x F	6	40968.6^{ns}	291.57^{ns}	46898.8^{ns}	6115.9^{ns}	639.8^{ns}	1489.42^{ns}
Residual	36	35044.6	246.3	52712.6	6882.5	737.1	1822.7
CV (%)		74.6	84.63	72.5	63.9	56.95	68.23

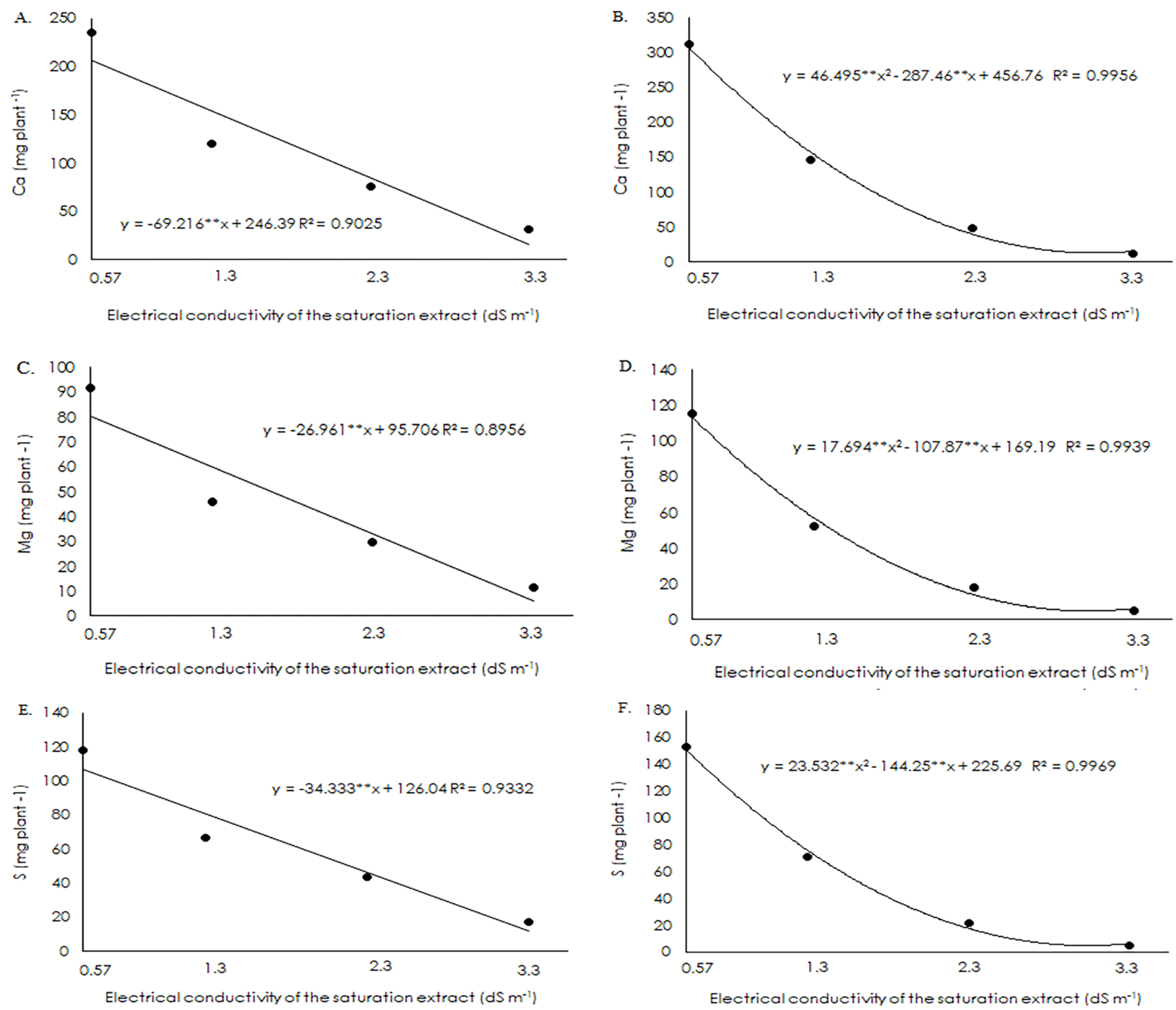
SV: sources of variation; DF: degrees of freedom; CV: coefficient of variation. *Significant by the F-test at 5%; **Significant by the F-test at 1%; ns: Not significant.



**Significant at p<0.01 by the F-test.

Figure 6. Nitrogen (A and B), phosphorus (C and D), and potassium (E and F) accumulation in leaves of *Eruca sativa* grown under soil salinity conditions in the first (A, C ,and D) and second (B, D, and F) cycles.

increment of ECse (Figure 7C) and a polynomial fit in the second cycle (Figure 7D), with a lower value (5.90 mg plant^{-1}) at an ECse of 3.3 dS m^{-1}. S showed a decrease of 34.33 mg plant^{-1} for each unit increase in ECse in the first cycle (Figure 7E) and a quadratic fit in the second cycle, with lower values observed for ECse (3.3 dS m^{-1}) (Figure 7F). As observed for the primary macronutrients, magnesium, calcium, and sulfur accumulations in leaf tissue were impaired by excess salts in the soil, especially the presence of Na^+. Importantly, this element has an



**Significant at p<0.01 by the F-test.

Figure 7. Calcium (A and B), magnesium (C and D), and sulfur (E and F) accumulations in leaves of *Eruca sativa* grown under soil salinity conditions in the first (A, C, and D) and second (B, D, and F) cycles

antagonistic effect with Mg^{2+}, Ca^{2+}, and S. These ionic effects cause damage to the absorption, transport, and assimilation of mineral elements, directly affecting accumulation (Silva et al., 2020).

Regarding the factor F, the fertilization dose of 100% via fertigation showed the best accumulations, statistically differing from the 50 and 25% strategies for the variables N, P, and K, except for K accumulation in the second cycle, with no differences between the 100 and 25% strategies for the 50% dose. Ca, Mg, and S showed higher accumulations in the strategy of 100% of the recommendation in the first and second cultivation cycles (Table 2).

Ca showed higher values in the first and second production cycles for the treatment with 100% of the recommended fertilization dose via fertigation. Mg also showed high values for 100% of the dose in the first and second cycles. Treatments with 100 and 50% did not differ statistically by Tukey's test in both cycles for S.

Macronutrients show better accumulation results in the 100% dose strategy considering the higher presence of NPK. The accumulation of elements is a function of plant dry matter. N is directly associated with biomass production and vegetative growth. In addition, the absorption process demands energy, which is provided by phosphorus (Silva et al., 2018; Freire et al., 2020). Also, potassium assists in the translocation of elements through the opening and closing of stomata (Taiz et al., 2017) (**Table 5**).

Micronutrients accumulation in the first cultivation cycle sowed a significance for the two factors (ECse and F) in isolation in the following elements: Na (p=0.0007 for ECse and p=0.0075 for F), Cu (p<0.0001 for ECse and p=0.0044 for F), and Mn (p<0.0001 for ECse and p=0.0080 for F), while Fe (p<0.0001) and Zn (p<0 .0001) were significant only for the factor ECse. For the second cycle, a significant effect was observed for the two factors (ECse and F) in isolation in the following elements: Na (p<0.0001 for ECse and p=0.0095 for F) and Cu (p<0.0001 for ECse and p=0.0266 for F) relative to Fe (p=0.0177), Zn (p<0.0001), and Mg (p<0.0001), which were significant only for the factor ECse (**Table 6**).

Na was the only element that showed a different trend, with the data fitting a quadratic polynomial regression both in the first and second cycles, with a maximum accumulation of 180.1 and 237 mg plant^{-1} at an ECse of 1.31 and 0.57 dS m^{-1}, respectively (**Figures 8**A and 8B).

Table 5. Nitrogen (N), phosphorus (P), potassium (P), calcium, magnesium (Mg), and sulfur (S) accumulations in leaves of *Eruca sativa* grown at different doses of recommended fertilization via fertigation in the first and second production cycles

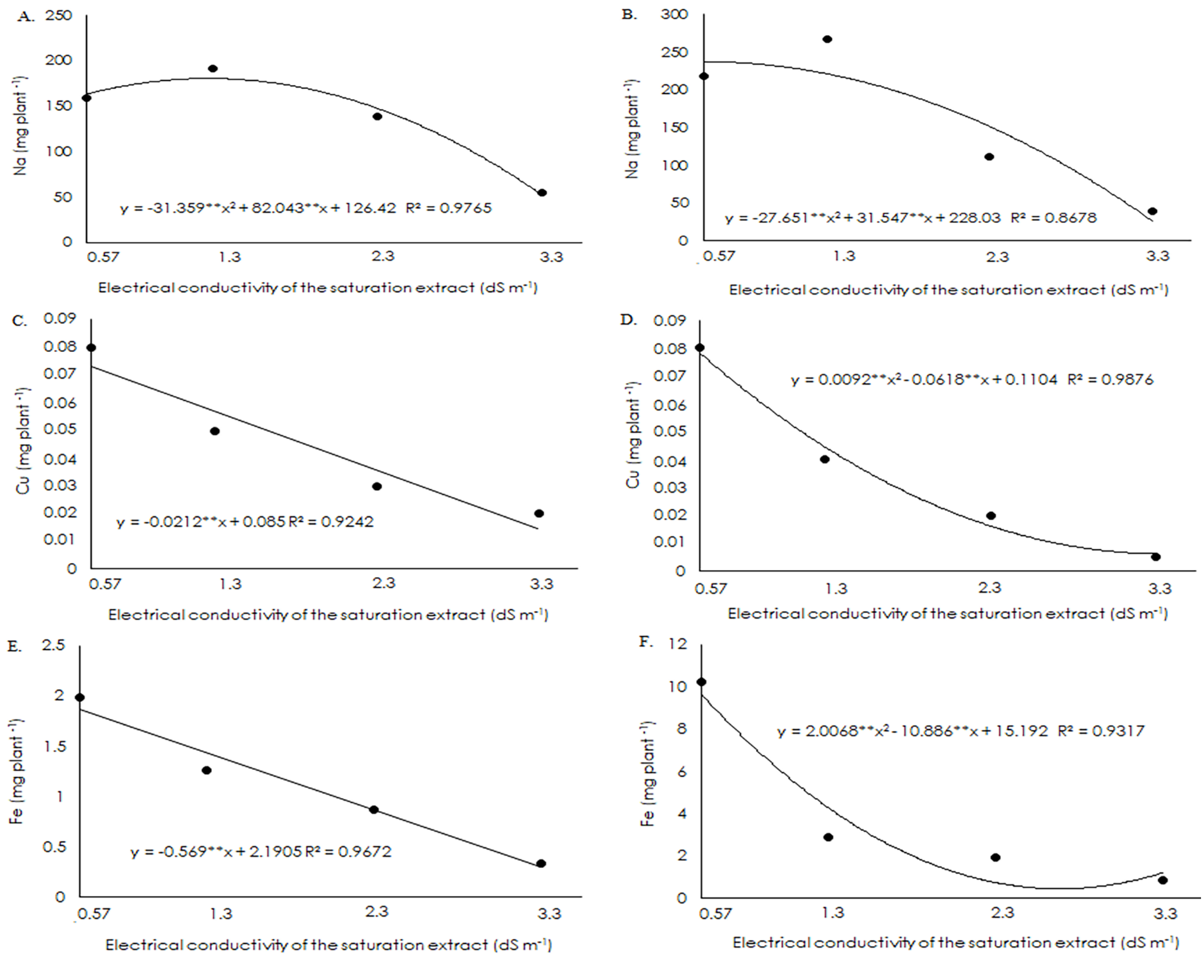
Fertilization dose (%)	N	P	K	Ca	Mg	S
	1st cycle					
	mg plant^{-1}					
100	358.4A	26.7A	460.4A	160.7A	60.0A	80.1A
50	211.1B	12.6B	238.7B	97.9B	38.5B	55.0AB
25	172.7B	8.7B	225.7B	88.0B	35.7B	48.3B
	2nd cycle					
100	393.1A	31.4A	458.2A	183.3A	63A	85.7A
50	222.0B	14.9B	295.7AB	120.7AB	46.1AB	61.6AB
25	138.0B	9.3B	196.2B	85.5 B	33.8B	40.3B

Means followed by the same letter in the columns do not differ from each other by Tukey's test

Table 6. Summary of analysis of variance for the first and second cycle of arugula cultivation for sodium (Na), copper (Cu), zinc (Zn), and manganese (Mn) accumulations

SV	DF	MS Na	Cu	Fe	Zn	Mn
		1st cycle				
S	3	40431.3**	0.0098**	5.83**	8.03**	0.29**
F	2	31840.2**	0.0039**	1.48ns	0.87ns	0.10**
S x F	6	5527.4ns	0.0005ns	0.37ns	0.52ns	0.009ns
Residual	36	5663.4	0.0006	0.58	0.27	0.019
CV (%)		55.5	56.84	68.1	51.7	56.42
		2nd cycle				
S	3	127092.1**	0.01**	215.1*	15.19**	0.87**
F	2	53617.5**	0.004*	132.8ns	0.52ns	0.09ns
S x F	6	16857.2ns	0.001ns	73.88ns	0.29ns	0.041ns
Residual	36	10082.5	0.001	56.13	0.26	0.03
CV (%)		63.16	96.61	188.04	52.20	59.58

SV: sources of variation; DF: degrees of freedom; CV: coefficient of variation. *Significant by the F-test at 5%; **Significant by the F-test at 1%; ns: Not significant.



**Significant at p<0.01 by the F-test.

Figure 8. Sodium (A and B), copper (C and D), and iron (E and F) accumulations in leaves of *Eruca sativa* grown under conditions of soil salinity in the first (A, C, and D) and second (B, D, and F) cycles.

The other micronutrients (Cu, Fe, Zn, and Mn) had similar results in both cultivation cycles. In the first cycle, all of them fitted a decreasing linear model, with a reduction of 0.06 mg plant^{-1} in Cu (Figure 8C) and 1.65 mg plant^{-1} in Fe (Figure 8E) for each unit increase in ECse. In contrast, a quadratic polynomial was fitted in the second cycle, with lower values observed for ECse of 3.3 dS m^{-1} for Cu and Fe (Figures 8D and 8F).

The variable Zn showed a linear fit in the first cycle (**Figure 9**A), with a decrease of 0.676 mg plant^{-1} for each unit increment of ECse, and a quadratic fit (Figure 9B) with lower values for an ECse of 3.3 dS m^{-1}. Mn presented a linear fit in the first (Figure 9C) and second (Figure 9D) production cycles, with a linear adjustment and reduction of 0.1317 and 0.2208 mg plant^{-1}, respectively, for each unit increase in ECse.

The results for sodium and copper accumulations relative to the factor fertilizer doses via fertigation in the first and second cultivation cycles showed better results for the 100% of the recommended doses, statistically differing from the 25% dose (Table 3).

Similarly, Schmitt et al. (2020) observed an increase in Cu concentrations in the shoot of beet and cabbage plants when the nutrient solution concentration was increased for both crops.

Na is a high-mobility element and promoted a higher accumulation in the shoot of arugula leaves when its concentration was increased in the management of 100%. On the other hand, the fertilization using 100% of the recommended dose promoted the highest manganese accumulation in the first cycle although it did not differ statistically from the 50% dose. The second cycle of cultivation showed no significant effect of the studied treatments (**Table 7**).

Table 7. Sodium (Na), copper (Cu), and manganese (Mn) accumulations in leaves of *Eruca sativa* grown under different fertigation strategies in the first and second cycles

Fertilization doses (%)	1st cycle			2nd cycle	
	Na	Cu	Mn	Na	Cu
	mg plant^{-1}				
100	179.2A	0.06A	0.33A	223.6A	0.053A
50	137.5AB	0.04B	0.22AB	141.5 AB	0.031AB
25	90.1B	0.03B	0.17B	111.9B	0.02B

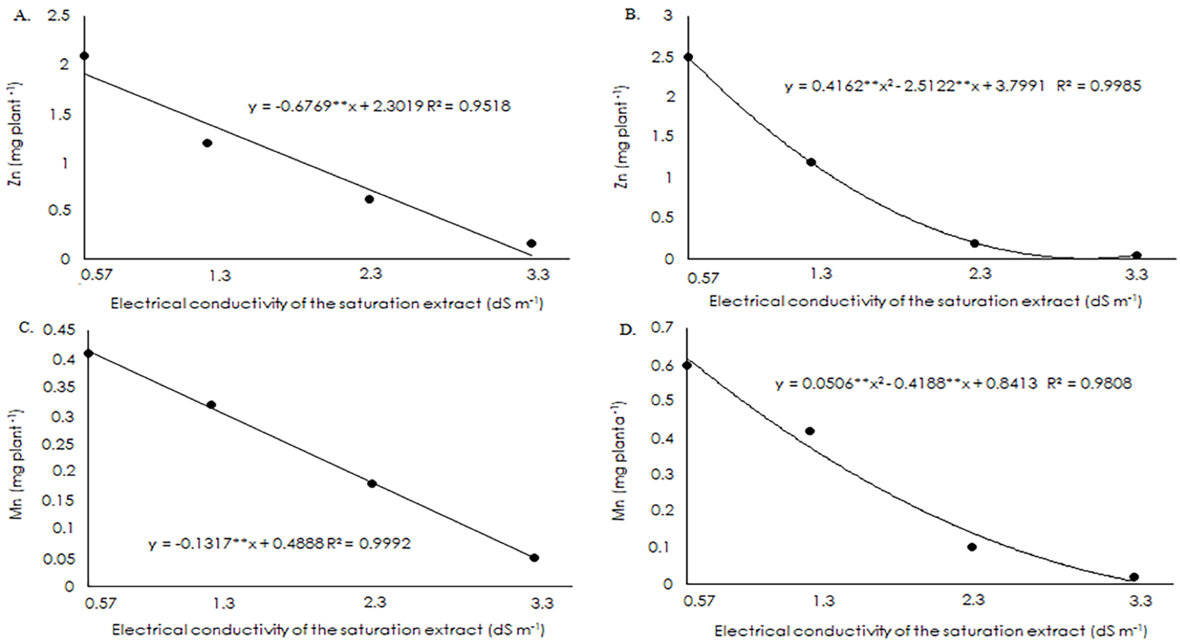
Means followed by the same letter in the columns do not differ from each other by Tukey's test ($p<0.05$).

Conclusions

The use of 100% of the recommended fertilization promoted higher N, P, K, and S accumulations even under high ECse concentration in the soil in the first cycle.

The use of 50% of the recommended fertilization did not reduce N, P, and K contents in the leaves in the second cycle, thus allowing a possible reduction in the management of fertilization of this crop in saline environments.

The fertigation strategy using 100% of the recommended fertilization promoted higher nutrient accumulation for arugula. The order of nutrient accumulation in the arugula leaf was K>N>Ca>S>Mg>P>Fe>Zn>Mn>Cu.



**Significant at $p<0.01$ by the F-test.

Figure 9. Zinc (A and B) and manganese (C and D) accumulations in leaves of *Eruca sativa* grown under soil salinity conditions in the first (A and C) and second (B and D) cycles

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