horticultura brasileira

Research

OLIVEIRA, FA; SILVA, DD; SANTOS, ST; OLIVEIRA, MKT; NASCIMENTO, L; SILVA, RT; SOUSA NETO, ON; PINTO, FFB. Mineral nutrition and hydroponic kale production under saline stress and calcium nitrate. *Horticultura Brasileira*, v.41, 2023, elocation e2615. DOI: http://dx.doi.org/10.1590/s0102-0536-2023-e2615

Mineral nutrition and hydroponic kale production under saline stress and calcium nitrate

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ABSTRACT

An adequate use of brackish water in agricultural production is one of the main challenges for researchers and rural producers, since saline stress may cause physiological and nutritional changes in plants, affecting the crop yield. An appropriate mineral nutrition is essential for plants, grown under saline stress, to express their productive potential. The aim of this study was to evaluate the mineral nutrition and hydroponic kale production under saline stress and calcium nitrate. The experiment was carried out using one hydroponic system in substrate, following a randomized block design, with five treatments and four replicates. The treatments consisted of five nutrient solutions, with a control treatment {S1 = standard nutrient solution using low salinity water, 0.5 dS/m [750 mg/L of $Ca(NO_3)_2$]}, and four nutrient solutions prepared using brackish water (6.0 dS/m) containing four concentrations of $Ca(NO_3)_2$ (S2 = 750 mg/L, S3 = 1,125 mg/L, S4 = 1,500 mg/L, S5 = 1,875 mg/L). We determined the levels of N, P, K, Ca, Mg and S in leaf tissue at three evaluation times (50, 64 and 78 DAT). Mineral levels in the leaves, stem and root were also evaluated at the end of the experiment (100 DAT). In addition, leaf production and the agronomic efficiency of $Ca(NO_3)_2$ were verified. The highest leaf production (1780 g/plant) and agronomic efficiency [2.37 g fresh matter/mg of $Ca(NO_3)_2$] were obtained in the standard nutrient solution, and both were reduced at 55.6% by salinity. The extra addition of 50% $Ca(NO_3)_2$ in the saline nutrient solution reduced the effect of salinity on Mg absorption and the effect of NaCl addition on kale production.

Keywords: *Brassica oleracea* var. *acephala*, soilless, salinity, macronutrients.

RESUMO

Nutrição mineral e produção de couve folha hidropônica sob estresse salino e nitrato de cálcio

O uso de águas salobras na produção agrícola é um dos principais desafios para pesquisadores e produtores rurais, pois sob estresse salino as plantas podem apresentar alterações fisiológicas e nutricionais, que afetam o rendimento das culturas. Com isso, adequada nutrição mineral é fundamental para que as plantas cultivadas sob estresse salino possam expressar seu potencial produtivo. Objetivou-se com o presente estudo avaliar a nutrição mineral e a produção de couve folha hidropônica sob estresse salino e nitrato de cálcio. O experimento foi desenvolvido utilizando um sistema hidropônico em substrato, seguindo o delineamento de blocos casualizados, com cinco tratamentos e quatro repetições. Os tratamentos foram compostos por cinco soluções nutritivas, sendo um tratamento controle {S1 = solução nutritiva padrão usando água de baixa salinidade, 0,5 dS/m [750 mg/L de $Ca(NO_3)_2$]}, e quatro soluções nutritivas preparadas em águas salobras (6,0 dS/m) contendo quatro concentrações de $Ca(NO_3)_2$ (S2 = 750 mg/L, S3 = 1.125 mg/L, S4 = 1.500 mg/L, S5 = 1.875 mg/L). Foram determinados os teores de N, P, K, Ca, Mg e S no tecido foliar em três épocas de avaliações (50, 64 e 78 DAT), além de uma avaliação dos teores minerais nas folhas, caule e raiz ao final do experimento (100 DAT). As variáveis produção de folhas e eficiência agronômica do $Ca(NO_3)_2$ foram avaliadas. A maior produção de folhas (1780 g/planta) e eficiência agronômica [2,37 g matéria fresca/mg de $Ca(NO_3)_2$] foram obtidas na solução nutritiva padrão, e ambas foram reduzidas em 55,6% pela salinidade. A adição extra de $Ca(NO_3)_2$ em 50% na solução nutritiva salinizada reduziu o efeito da salinidade sobre a absorção de Mg e reduziu o efeito da adição de NaCl sobre a produção da couve.

Palavras-chave: *Brassica oleracea* var. *acephala*, cultivo sem solo, salinidade, macronutrientes.

Received on April 3, 23; accepted on September 1st, 2023

Kale is considered an annual or biennial cycle crop and the leaves are harvested periodically throughout its vegetative cycle. The leaves have high nutritional content, being rich in carotenoids, vitamins C and K, phenolic compounds and organic acids (Sikora *et al*., 2008; Null & Feldman, 2011), antioxidant and antimicrobial properties, and some herbal properties, acting on gastric ulcers and many types of cancer (Vilar *et al*., 2008; Agbaje & Okpara, 2013).

Due to an imminent water crisis, mainly under arid and semi-arid conditions, low quality water, particularly saline water, had been used for irrigation (Silva *et al*., 2020).

Kale is classified as a moderately salt sensitive crop, showing a threshold salinity of 1.8 dS/m for soil saturation extract (Ayers & Westcot, 1999). However, the crop tolerance to salinity can vary in relation to several factors, such as genetic material and growing system.

Traditionally, kale is conventionally grown under field conditions. Nevertheless, current researches on hydroponic cultivation, show that this kind of growing allows early harvest and the leaves show the same organoleptic qualities, such as aroma, sweet and bitter tastes, and crunchiness, comparing with the leaves produced under conventional system (Silva *et al*., 2021b).

Some authors (Soares *et al*., 2016; Silva *et al*., 2021a; Muchecua *et al*., 2022) have verified that some plants grown under saline stress, especially in environments rich in sodium (Na^+) and chlorine (Cl^-) ions, may present nutritional imbalance caused by an increased absorption of Na^+ and Cl^-, to the detriment of nitrogen absorption (NO_3^-), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}).

Since Ca^{2+} plays a role as a second messenger, being involved in regulation of physiological developmental processes and stress responses, this ion increases plant tolerance to saline stress, improving water balance, Na^+ secretion, cell membrane integrity and regulation of ionic homeostasis (Köster *et al*., 2019). Calcium nitrate is one of the essential nutrients whose absorption is most affected by salinity, since excess Na^+ ions show an antagonistic effect on the absorption of Ca^{2+}, as they compete for the same absorption site (Ahmed *et al*., 2021).

Due to the importance of Ca^{2+} ion for many vital physiological processes in plants, such as growth, physiology and perception and stress response (Xu *et al*., 2022), several studies had been developed in order to evaluate the effect of calcium nutrition as an agent to alleviate salt stress, whether in the nutrient solution condition (Silva *et al*., 2020), working with green pepper, through fertigation (Oliveira *et al*., 2021) studying tomato, or via foliar application (Samarakoon *et al*., 2020) studying lettuce.

However, few studies on saline stress and calcium nitrate in kale, such as the one carried out by Karagöz & Dursun (2021) using ornamental kale, can be found in literature. In this study, the authors observed that calcium nitrate applications may be recommended to mitigate the negative effects of stress and minimize damage to physiological and biometric processes.

Given the inevitable need to use saline water in food production and the importance of $Ca(NO_3)_2$ for vital processes in plants, this study aimed to evaluate the mineral nutrition and production of hydroponic leaf kale under saline stress and calcium nitrate concentrations in Brazilian semi-arid conditions.

MATERIAL AND METHODS

Experimental area

The experiment was carried out from June to October 2019, in a protected environment (illuminated roof 50%) at Universidade Federal Rural do Semi-Árido (UFERSA), in the municipality of Mossoró, Rio Grande do Norte (5°12'48''S and 37°18'44''W, 37 m altitude).

During the experiment, the authors collected climatic data such as maximum (Tmax), medium (Tmed) and minimum (Tmin) temperatures, maximum (URmax), medium (URmed) and minimum (URmin) relative humidity, monitored by an automatic meteorological station (Campbell Scientific Inc. model CR1000), installed inside a greenhouse.

Experimental design and treatments

The experimental design used was randomized blocks, with five treatments and four replicates. Each experimental unit consisted of three 5 dm^3-capacity pots containing one plant, totalizing 60 plants. The treatments consisted of five nutrient solutions, considering one as a control treatment {S1 = standard nutrient solution using low-salinity water, 0.5 dS/m [750 mg/L of $Ca(NO_3)_2$]}, and four nutrient solutions prepared using brackish water (6.0 dS/m, obtained by dissolving NaCl) containing four concentrations of $Ca(NO_3)_2$ [(S2 = 750 mg/L, S3 = 1.125 mg/L, S4 = 1.500 mg/L, S5 = 1.875 mg/L)].

The water used to prepare the standard nutrient solution was of the campus water supply system of UFERSA, whose physical and chemical analyses determined the following characteristics: pH= 7.30; CE= 0.50 dS/m; Ca^{2+}= 3.10; Mg^{2+}= 1.10; K^+= 0.30; Na^+= 2.30; Cl^-= 1.80; HCO_3= 3.00 and $(CO_3)^{2-}$= 0.20 ($mmol_c$/L).

The standard nutrient solution was prepared according to Furlani *et al*. (1999) recommendation, presenting the following fertilizer concentrations, in mg/L; calcium nitrate = 750; potassium nitrate = 500; monoammonium phosphate = 150; magnesium sulfate = 400. The micronutrients were made using the commercial compost (Rexolin® BRA Yara), containing the following composition: 11.6% potassium oxide (K_2O), 1.28% sulfur (S), 0.86% magnesium (Mg), 2.1% boron (B), 2.66% iron (Fe), 0.36% copper (Cu), 2.48% manganese (Mn), 0.036% molybdenum (Mo), 3.38% zinc (Zn). The compost was applied using the dose recommended by the manufacturer (30 grams of the compost for 1,000 liters water). We applied 0.1 mol/L solutions of KOH or HCl in order to adjust the pH of the solution (from 6.0 to 6.5). After preparing the nutrient solutions, the electrical conductivity was measured, obtaining 2.29; 7.48; 8.14; 8.29 and 8.64 dS/m, for S1, S2, S3, S4 and S5,

respectively.

The seedlings of kale cv. Manteiga (Feltrin® Sementes, Farroupilha, Brazil) were produced in 128-cell polystyrene trays, using coconut fiber as filling substrate. After emergence, thinning was performed, keeping one seedling per cell. The seedlings were transplanted into pots filled with the substrate and washed sand (2:1) when four definitive leaves were noticed, 35 days after sowing.

A drip irrigation system was used, with the recirculation of the nutrient solution (closed system), in which the drained nutrient solution returned to the reservoir by gravity. For each nutrient solution, an independent irrigation system was used, consisting of a 210 liter capacity PVC reservoir. The lateral lines of the system were equipped with flexible hoses (16 mm diameter hoses). Microtubes emitters (spaghetti), measuring 10 cm long, average flow of 3.5 L/h, were used.

The irrigation system was controlled by a digital timer, programmed for six daily irrigations (7 a.m., 9 a.m., 11 a.m., 1 p.m., 3 p.m. and 5 p.m.). The duration of each event throughout the crop cycle was the following: 1.0 min from the transplant (DAT) up to 30 DAT, 2.0 min from 31 DAT up to 45 DAT, and 3.0 min from this time until the end of the experiment. The water consumption of the plants was not taken into account, however, in all irrigations the substrate moisture was increased to its maximum water retention capacity, based on the visualization of drainage in the pots.

Study factors

During the experiment, six leaf harvests were carried out (50, 57, 64, 71, 78 and 87 days after transplanting), with the main leaf blade longer than 20 cm, keeping five leaves per plant (Trani *et al*., 2015). In each harvest, the leaves were weighed with the aid of an analytical scale, and at the end of the experiment, we determined the production of leaves per plant (g/plant).

Using the obtained data for leaf production and concentration of $Ca(NO_3)_2$, the authors determined the agronomic efficiency (EA = production/ concentration), being the results expressed in grams of leaf fresh mass (MF) per calcium nitrate concentration [g MF/mg $Ca(NO_3)_2$].

At the end of the experiment (100 DAT) the plants were collected, separated into leaves, stem and roots. Plant tissues were analyzed using the leaves harvested at 50, 64 and 78 DAT, as well as the stem and the roots. The plant material was dried in an oven with forced air, at 65ºC, for 72 hours. After dried, the material was crushed in a Willey mill (40-mesh). The samples were submitted to digestion process, according to the methodology described by Malavolta *et al.* (1997). We determined the contents of N, P, K, Ca, Mg and S as recommended by Trani & Raij (1997).

Statistical analysis

Data were submitted to normality analysis (Shapiro-Wilk test), and then to the variance analysis by F test. The averages obtained in each treatment were compared to each other by Tukey test ($p \leq 0.05$). Statistical analysis of the data was performed using the software Sisvar (Ferreira, 2014).

RESULTS AND DISCUSSION

Nitrogen

The use of saline solution (S2) reduced leaf nitrogen contents at 50 (NF-50) and 64 DAT (NF-64), in the stem (NC-120) and in roots (NR-120) at the end of the experiment, resulting in losses of 31.4; 15.1; 19.7 and 63.2%, respectively. Besides, we verified that the extra addition of 50% $Ca(NO_3)_2$ (S3) reduced the effect of NaCl addition on N contents, except the N content in the roots (NR-120), in which the addition of extra $Ca(NO_3)_2$ did not change the crop response to salinity. The extra addition of 50% $Ca(NO_3)_2$ (S3) was efficient to reduce the effect of salt stress on N uptake, which can be attributed to the greater availability of NO_3^- in the nutrient solution. However, the use of excessive doses of $Ca(NO_3)_2$ (S4 and S5) did not show a significant gain in N uptake, possibly due to an increased nutrient solution EC (Table 1).

The N contents obtained in this study ranged from 21.92 g/kg in NF-50 (S2) to 36.47 g/kg in NF-78. Most data found for N content in leaf tissue is in accordance with the amount recommended by Trani *et al*. (2015), which ranges from 30 to 55 g/kg. Thus, the reduction in N uptake observed in this study, in saline solution (S2), except for NF-78 and NF-120, can be attributed to a high concentration of chloride ions (Cl^-) related to NaCl addition, considering that the N addition was performed using nitric sources [$Ca(NO_3)_2$ and KNO_3], in relation to antagonistic relationship between Cl^- and NO_3^- ions. This response corroborates, somehow, with the changes observed by Cova *et al*. (2017), who observed reduction in NO_3^- contents and an increase in Cl^- contents in lettuce grown in hydroponic system

Table 1. Average nitrogen contents (g/kg) on plant tissues of kale fertigated with saline nutrient solutions enriched with calcium nitrate. Mossoró, UFERSA, 2020.

Treatments	NF-50	NF-64	NF-78	NF-120	NC-120	NR-120
S1	31.94 a	34.37 a	36.80 a	27.37 a	20.71 a	24.78 a
S2	21.92 b	29.19 b	31.28 a	30.95 a	16.62 b	9.12 b
S3	31.72 a	31.50 ab	36.47 a	33.03 a	19.47 ab	12.58 b
S4	27.71 ab	30.54 b	33.36 a	32.37 a	20.01 a	11.78 b
S5	28.44 ab	30.80 ab	33.16 a	27.12 a	14.32 b	13.85 b
F test	*	*	ns	ns	*	**
CV (%)	13.72	7.72	14.27	13.14	12.87	18.18

ns; *; ** = not significant, significant at 5 and 1%, respectively. S1 = standard nutrient solution (SNP), S2 = SNP + NaCl (6.0 dS/m), S3 = S2 + $Ca(NO_3)_2$ (50% extra), S4 = S2 + $Ca(NO_3)_2$ (100% extra), S5 = S2 + $Ca(NO_3)_2$ (150% extra). NF, NC and NR = N contents in the leaf, stem and root, respectively. Averages followed by the same letter, in the columns, do not differ significantly by Tukey test ($p<0.05$).

with saline nutrient solution.

In the presence of high chloride contents, nitrate translocation from root to shoot may be reduced at the site of entry into xylem parenchyma cells to compete for the same channel (Borgognone *et al*., 2016). Still, according to these authors, high contents of Na^+ and/or Cl^- in the roots decreased the net nitrate absorption rate and nitrate translocation to shoots in many vascular plants.

Phosphor

Phosphor content in plant tissues was affected by nutrient solutions for leaf contents at 50 DAT (PF-50) and 120 DAT (PF-120), in stem (PC-120) and in roots (PR-120). P content was reduced by adding NaCl in nutrient solutions (S2), resulting in reductions of 27.3; 35.4; 51.7 and 31.4%, for P contents in the leaves (PF-50 and PF-120), in stem (PC-120) and in roots (PR-120), respectively. Moreover, the authors verified that the addition of extra $Ca(NO_3)_2$ in the saline nutrient solution reduced the effect of salinity on P uptake in these evaluations. Nevertheless, we did not observe any effect of salinity and addition of extra $Ca(NO_3)_2$ in saline nutrient solution on PF-64 and PF-78, obtaining average contents of 4.85 and 5.39 g/kg, respectively (Table 2).

However, although the use of saline water caused a reduction in P absorption, the contents of this nutrient in leaf tissue are within the range indicated by Trani *et al.* (2015), from 3 to 7 g/kg. Reduction of foliar P content in kale, in relation to salt stress, was also observed by Viana *et al*. (2021) working with hydroponic system NFT (Nutrient Film Technique), as well as in studies with lettuce (Soares *et al*., 2016; Cova *et al*., 2017; Sardar *et al*., 2023). According to Santos *et al*. (2017), the reduction in P contents may have occurred by the fact that the water salinity causes P precipitation or due to its antagonism with other nutrients, resulting in a lower uptake of this nutrient by the plants.

Potassium

Potassium content in plant tissues was affected by salt stress in all evaluation times and parts of the evaluated plants ($p<0.01$). The authors verified that the addition of NaCl in the nutrient solution (S2) caused reductions in K content in 54.3; 37.7; 42.0; 24.8; 46.8 and 38.6%, for KF-50, KF-64, KF-78, KF-120, KC-120 and KR-120, respectively. We still noticed that the deleterious effect of NaCl was reduced when adding extra 50% $Ca(NO_3)_2$ for KF-64 and KF-78, and 100% for KF-120. On the other hand, we did not verify any effect of the extra addition of $Ca(NO_3)_2$ in saline solution on the variables KF-50, KC-120 and KR-120 (Table 3).

Evaluating K contents in all nutrient solutions, a range from 57.44 g/kg to 21.06 g/kg was observed. Thus, although the addition of NaCl to the nutrient solution provided a reduction in leaf K contents, all saline solutions, regardless the extra addition of $Ca(NO_3)_2$, provided K contents within the range recommended by Trani *et al*. (2015) which ranges from 20-40 g/kg.

Reductions in K contents in relation to a saline increase of the nutrient solution have been reported by other authors working with other leafy greens, with lettuce (Soares *et al*., 2016) and parsley (Muchecua *et al*., 2022). The reduction in K^+ uptake occurred in relation to a higher Na^+ concentration in the nutrient solution and antagonistic interaction between these ions, which affects the uptake and transport to the cell membrane (Marschner, 2012). Therefore, the decrease in K^+ contents caused by the increase in Na^+ uptake can lead to an ionic disorder in cellular homeostasis (Willadino & Camara, 2010).

The increase of K^+ uptake in plants submitted to salt stress, due to an application of Ca^{2+}, is a response of the plants to keep K^+/Na^+ homeostasis in roots (Sun *et al*., 2009). However, under high concentrations of Ca^{2+} in the root system, a reduction in K^+ uptake by the plants may occur due to an antagonistic interaction between these ions (Marschner, 2012).

Calcium

The authors verified a significant effect of nutrient solutions on calcium contents in the plant tissue at 1% probability level, except for Ca content in the roots (CaR-120), showing 5% significance of probability (Table 4).

The addition of NaCl in the nutrient solution (S2) caused a reduction in Ca^{2+} uptake in all evaluations, resulting in losses of 39.9; 37.8; 52.5; 18.5; 22.5 and 32.0%, for CaF-50, CaF-64, CaF-78, CaF-120, CaC-120 and CaR-120, respectively. Moreover, the authors verified that the extra addition of 50% $Ca(NO_3)_2$ (S2) was sufficient to reduce the effect of salt stress for most variables, except of Ca^{2+} content in stem (CaC-120), in which an addition of 150% $Ca(NO_3)_2$ (S4) was enough to reduce the saline effect (Table 4).

Other authors, studying some leafy plants in hydroponic system, also

Table 2. Average phosphor contents (g/kg) on plant tissues of kale fertigated with saline nutrient solutions enriched with calcium nitrate. Mossoró, UFERSA, 2020.

Treatments	PF-50	PF-64	PF-78	PF-120	PC-120	PR-120
S1	4.67 a	4.77 a	5.11 a	5.85 a	4.66 a	5.50 a
S2	3.38 b	4.58 a	5.47 a	3.78 b	2.25 b	3.77 b
S3	4.42 ab	5.61 a	6.23 a	3.97 b	3.56 ab	4.32 ab
S4	3.92 ab	4.41 a	4.89 a	4.48 b	3.89 ab	4.01 b
S5	4.07 ab	4.86 a	5.87 a	4.67 ab	3.93 ab	4.32 ab
F test	*	ns	ns	**	*	*
CV (%)	12.79	11.04	14.37	13.16	26.90	13.85

ns; *; ** = not significant, significant at 5 and 1%, respectively. S1 = standard nutrient solution (SNP), S2 = SNP + NaCl (7.0 dS/m), S3 = S2 + $Ca(NO_3)_2$ (50% extra), S4 = S2 + $Ca(NO_3)_2$ (100% extra), S5 = S2 + $Ca(NO_3)_2$ (150% extra). PF, PC and PR = P contents in the leaf, stem and root, respectively. Averages followed by the same letter, in the columns, do not differ significantly by Tukey test ($p<0.05$).

verified a reduction in calcium contents in response to salt stress, such as lettuce (Silva *et al*., 2021a) and parsley (Muchecua *et al*., 2022).

The increase of calcium contents in S3 can be explained by a greater availability of Ca^{2+} in the nutrient solution, increasing an availability of this nutrient and favoring its uptake to the detriment of Na^{+} uptake, since this nutrient shows antagonistic interaction (Marschner, 2012).

According to Duman (2012), an increase in external concentration of calcium provides an increase in the uptake and absorption of Ca^{2+} to the detriment of the absorption of Na^{+}, as Ca^{2+} restricts the uptake of Na^{+} and interferes with the non-selective cation channel.

On the other hand, the low Ca^{2+} uptake observed in S5 may be due to an increase of the nutrient solution CE, for the high dose of $Ca(NO_3)_2$ used. Considering that the appropriate Ca contents in kale leaf tissue should be from 15 to 25 g/kg (Trani *et al*., 2015), we noticed that only S2 solution, except of Ca-final, provided a Ca content lower than recommended. These results showed the importance of an adequate calcium nutrition in kale crop when this vegetable is grown under salt stress conditions.

Magnesium

For magnesium contents, we noticed an effect of the nutrient solution for all the evaluated variables, with a significance at 1% probability for MgF-50, MgF-64, MgF-120, MgC-120 and MgR-120; and 5% for MgF-120 (Table 5). All the variables were reduced by the water salinity used in the nutrient solution, with losses of 61.3; 50.4; 60.2; 32.7; 46.6 and 42.2%, for MgF-50, MgF-64, MgF-120, MgC-120, MgR-120 and MgF-120, respectively. The extra addition of 50% $Ca(NO_3)_2$ in saline nutrient solution reduced the effect of salinity on Mg uptake for all the variables, with more expressed action for MgF-78, MgF-120, MgC-120 and MgR-120 (Table 5).

Considering that the appropriate range for Mg^{2+} contents in kale leaves is 3-7 g/kg (Trani *et al*., 2015), the authors observed that the use of saline solution S2 resulted in Mg contents lower than the recommended. Except of the first harvest, the extra addition of 50% $Ca(NO_3)_2$ (S3) and 100% (S4) were sufficient to increase Mg content in the desired interval.

These results are in accordance with the studies carried out by Muchecua *et al*. (2022) working with parsley crop under salt stress. Other authors (Soares *et al*., 2016; Silva *et al*., 2021a) also observed a reduction in Mg^{2+} uptake under salt stress conditions.

Mg contents were affected, both for NaCl addition in nutrient solution and for extra addition using high doses of $Ca(NO_3)_2$, which can be explained by an antagonistic interaction between the Mg^{2+} ion and the Na^{+} and Ca^{2+} ions (Marschner, 2012). The plants depend on homeostatic balance between these ions so that they present greater growth and development, since the excess of Ca^{2+} reduces Mg^{2+} uptake, damaging the absorption and efficiency of the light energy use in the leaves (Liang *et al*., 2021).

Sulfur

Evaluating the effect of the nutrient solution on sulfur contents, the authors verified significant effect for SF-50 and SR-120 ($p<0,01$), and for SF-78 ($p\leq0.05$). No significant response was found for SF-64, SF-120 and SC-120 (Table 6). The use of saline water for preparing the nutrient solution (S2) resulted in a reduction of 27.7% for SF-50, and 33.0% for SR-120. For S content

Table 3. Average potassium contents (g/kg) on plant tissues of kale fertigated with saline nutrient solutions enriched with calcium nitrate. Mossoró, UFERSA, 2020.

Treatments	KF-50	KF-64	KF-78	KF-120	KC-120	KR-120
S1	57.44 a	49.14 a	43.63 a	42.20 a	36.39 a	49.58 a
S2	26.25 b	30.60 b	25.30 c	31.71 b	19.35 b	30.44 b
S3	34.39 b	36.78 ab	37.48 abc	21.06 b	20.38 b	34.30 b
S4	29.91 b	29.59 b	29.27 bc	32.57 ab	19.88 b	36.31 b
S5	23.46 b	34.78 b	40.83 ab	35.15 a	25.16 b	37.12 b
F test	**	**	**	**	**	**
CV (%)	11.18	14.21	13.36	12.44	8.97	10.72

*; ** = significant at 5 and 1%, respectively. S1 = standard nutrient solution (SNP), S2 = SNP + NaCl (7.0 dS/m), S3 = S2 + $Ca(NO_3)_2$ (50% extra), S4 = S2 + $Ca(NO_3)_2$ (100% extra), S5 = S2 + $Ca(NO_3)_2$ (150% extra). KF, KC and KR = K contents in the leaf, stem and root, respectively. Averages followed by the same letter, in the columns, do not differ significantly by Tukey test ($p<0.05$).

Table 4. Average calcium contents (g/kg) on plant tissues of kale fertigated with saline nutrient solutions enriched with calcium nitrate. Mossoró, UFERSA, 2020.

Treatments	CaF-50	CaF-64	CaF-78	CaF-120	CaC-120	CaR-120
S1	22.02 a	23.84a	22.08 a	21.15 a	20.41 a	25.48 a
S2	13.22 c	14.82b	10.49 c	17.23 b	15.82 b	17.32 b
S3	19.59 ab	24.53a	18.40 ab	18.86 ab	15.10 b	21.88 ab
S4	17.11 bc	19.00ab	16.31bc	19.77 ab	17.10 ab	21.57 ab
S5	21.16 a	18.18b	14.27 c	20.97 ab	14.30 b	19.44 ab
F test	**	**	**	**	**	**
CV (%)	12.32	12.71	10.97	8.51	12.48	15.04

*; ** = significant at 5 and 1%, respectively. S1 = standard nutrient solution (SNP), S2 = SNP + NaCl (7.0 dS/m), S3 = S2 + $Ca(NO_3)_2$ (50% extra), S4 = S2 + $Ca(NO_3)_2$ (100% extra), S5 = S2 + $Ca(NO_3)_2$ (150% extra). CaF, CaC and CaR = Ca contents in the leaf, stem and root, respectively. Averages followed by the same letter, in the columns, do not differ significantly by Tukey test ($p<0.05$).

in the leaf tissue at 78 DAT (SF-78), the extra addiction of 50% $Ca(NO_3)_2$ (S3) reduced the S content in the leaf tissue, showing a loss of 28.9%, comparing with the values obtained in the standard nutrient solution (S1). Considering these variables, the extra addition of 150% $Ca(NO_3)_2$ (S5) reduced the effect of the salt stress on the sulfur uptake. On the other hand, we noticed no effect of salinity or extra addition of $Ca(NO_3)_2$ for SF-64, SF-120 and SC-120, with average values of 3.41; 2.81 and 1.49 g/kg, respectively (Table 6).

Few studies highlighting the effect of salt stress on sulfur uptake can be found in literature. Soares *et al*. (2016) observed that the uptake of this nutrient is not affected by NaCl concentration in nutrient solution. Maintaining adequate S concentration in plant tissue is essential for plants to maintain development and growth, even under saline conditions. S shall regulate the formation of osmolytes by its influence on nitrate reductase activity and N assimilation, being also of great importance in maintaining the tertiary structure of proteins (Soares *et al*., 2016).

Production and agronomic efficiency of $Ca(NO_3)_2$

The addition of NaCl in the nutrient solution (S2) resulted in a reduction of 55.6% in leaf production, in comparison with the production obtained in fertigated plants with the standard nutrient solution (S1). Moreover, we verified that an extra addition of $Ca(NO_3)_2$ had not changed the deleterious effect of salt stress (Figure 1A). Reduction in kale leaf production has been reported by other authors (Šamec *et al*., 2021; Viana *et al*., 2021).

This reduction can be associated with morphological strategies developed by the plants under stress conditions which result in a reduced leaf expansion, causing stomatal closure, and consequently a reduction in CO_2 availability in the leaves (Sousa *et al*., 2021). Since the leaves represent the commercial product of kale, this reduction in leaf development, due to leaf emission or the size of the leaf blade, directly reflects in the crop production.

Studies on leafy vegetables have shown that the response of the crops to calcium nitrate may vary according to the level of salinity used. Oliveira *et al*. (2018), working with lettuce cultivars grown in substrate, observed positive response in relation to an increase of $Ca(NO_3)_2$ concentration; these authors reported that the response depends on the genotype used, though. Studying parsley, in NFT system, Chondraki *et al*. (2012) observed that foliar application of $Ca(NO_3)_2$ was efficient to mitigate saline stress at medium salinity, but did not show any improvement under high salinity.

The greatest agronomic efficiency (EA) for vegetable fertilization using $Ca(NO_3)_2$ was obtained in the standard nutrient solution (2.37 g MF/mg of $Ca(NO_3)_2$, reducing to 1.05 g MF/mg of $Ca(NO_3)_2$ with an addition of NaCl (S2), resulting in a loss of 55.6%. An increase in concentration of $Ca(NO_3)_2$ in saline nutrient solution reduced the EA, with losses of 67.8, 76.7 and 81.1%, in the solutions S3, S4 and S5, respectively (Figure 1B).

These results showed that, under salt stress, an increase of $Ca(NO_3)_2$ concentration shall not be possible. This fact corroborates partly the results presented by Oliveira *et al*. (2014) working with eggplant crop, in which they observed a reduction in EA of nitrogen fertilization in response to an increasing salinity of the irrigation water.

Table 5. Average magnesium contents (g/kg) on plant tissues of kale fertigated with saline nutrient solutions enriched with calcium nitrate. Mossoró, UFERSA, 2020.

Treatments	MgF-50	MgF-64	MgF-78	MgF-120	MgC-120	MgR-120
S1	4.34 a	5.30 a	6.26 a	4.49 a	4.48 a	4.45 a
S2	1.68 c	2.63 c	2.49 b	3.02 b	2.39 c	2.57 bc
S3	2.70 b	3.85 b	4.29 ab	4.29 ab	4.29 ab	3.30 abc
S4	1.69 c	3.21 bc	3.30 bc	3.30 bc	3.65 ab	3.87 ab
S5	2.44 b	3.46 bc	2.65 c	2.65 c	3.22 bc	2.36 c
F test	**	**	*	**	**	**
CV (%)	12.99	13.28	20.29	14.30	13.21	18.97

*; ** = significant at 5 and 1%, respectively. S1 = standard nutrient solution (SNP), S2 = SNP + NaCl (7.0 dS/m), S3 = S2 + $Ca(NO_3)_2$ (50% extra), S4 = S2 + $Ca(NO_3)_2$ (100% extra), S5 = S2 + $Ca(NO_3)_2$ (150% extra). MgF, MgC and MgR = Mg contents in the leaf, stem and root, respectively. Averages followed by the same letter, in the columns, do not differ significantly by Tukey test ($p<0.05$).

Table 6. Average sulfur contents (g/kg) on plant tissues of kale fertigated with saline nutrient solutions enriched with calcium nitrate. Mossoró, UFERSA, 2020.

Treatments	SF-50	SF-64	SF-78	SF-120	SC-120	SR-120
S1	3.54 a	3.67 a	4.64 a	3.31 a	1.69 a	2.06 a
S2	2.56 b	3.12 a	3.80 ab	2.30 a	1.42 a	1.38 bc
S3	2.83 b	3.32 a	3.30 b	2.95 a	1.41 a	1.42 bc
S4	2.48 b	3.24 a	3.41 b	2.72 a	1.42 a	1.09 c
S5	2.49 b	3.72 a	4.26 ab	2.76 a	1.49 a	1.89 ab
F test	**	ns	*	ns	ns	**
CV (%)	7.91	16.52	14.37	16.89	10.36	14.91

ns; *; ** = not significant, significant at 5 and 1%, respectively. S1 = standard nutrient solution (SNP), S2 = SNP + NaCl (7.0 dS/m), S3 = S2 + $Ca(NO_3)_2$ (50% extra), S4 = S2 + $Ca(NO_3)_2$ (100% extra), S5 = S2 + $Ca(NO_3)_2$ (150% extra). SF, SC and SR = S contents in the leaf, stem and root, respectively. Averages followed by the same letter, in the columns, do not differ significantly by Tukey test ($p<0.05$).

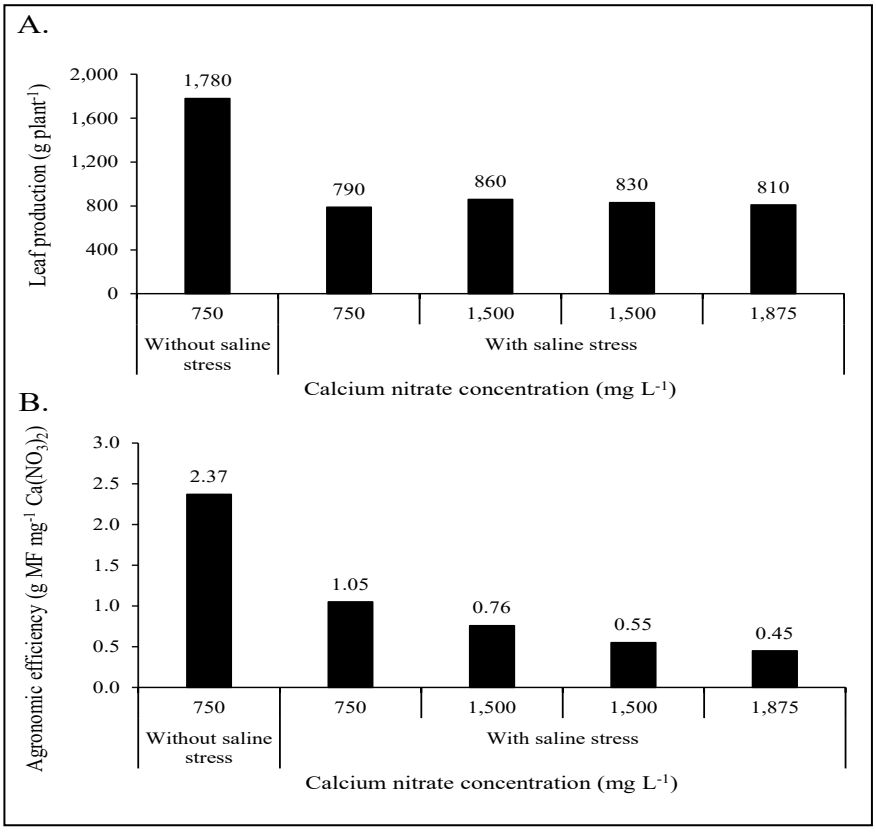

Figure 1. Leaf production (A) and agronomic efficiency of fertigation (B) using $Ca(NO_3)_2$ in kale crop in relation to salinity in nutrient solution and calcium nitrate concentrations. Mossoró, UFERSA, 2020.

The reduction in EA in response to an increase in $Ca(NO_3)_2$ concentration can be related to a secondary effect of an increase of the electrical conductivity of the nutrient solution. Nutrient solutions with higher electrical conductivity show lower water potential and, consequently, make it difficult for plants to absorb water, affecting their growth (Cometti *et al*., 2018).

The extra addition of 50% $Ca(NO_3)_2$ in the saline nutrient solution reduced the effect of salinity on Mg absorption for all the variables and reduced the effect of NaCl addition on kale production. The addition of NaCl in nutrient solution (S2) reduced the production of leaves on 55.62% of leaf kale production, when comparing with the production obtained in plants fertigated with the standard nutrient solution (S1).

The authors concluded that the results obtained in this study showed that, despite the fact that the extra addition of 50% $Ca(NO_3)_2$ (1125 mg/L) reduced the effect of salinity on the absorption of some macronutrients, this reduction had not shown either an improvement in performance of leaf production or in agronomic efficiency. Given the above, for crop cultivation using saline water, an increase in $Ca(NO_3)_2$ concentration is not viable, and the standard concentration (750 mg/L) should be the one to be used.

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