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Electrical conductivity of the nutrient solution for soilless cultivation of kohlrabi

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ABSTRACT

The electrical conductivity of the nutrient solution directly affects production and quality of the plants. We evaluated the electrical conductivity suitable for soilless cultivation of kohlrabi. The experiment was carried out in a completely randomized design, with four replicates and five treatments, composed of different nutrient solution's conductivities (1.31, 1.71, 2.37, 2.98 and 3.75 dS m^{-1}). We evaluated number of leaves, leaf area, specific leaf area, leaf area ratio, fresh and dry masses of leaves, bulb, roots and total, bulb volume, water content in the bulbs and pH, soluble solids, vitamin C, firmness, titratable acidity and SS/TA ratio of the bulbs. All variables related to growth were affected by the nutrient solutions, showing the highest values with the use of the nutrient solutions with EC close to 2.0 dS m^{-1}. Considering the commercial part of the plant, the most developed bulbs were obtained with EC of 1.96 dS m^{-1}, being 49.9 g and 41.15 cm^3 per bulb. On the other hand, except for pH, the other variables responded to the increase of EC. Higher values for pulp firmness and titratable acidity occurred with EC close to 2.0 dS m^{-1}, whereas the other variables showed higher values using a more concentrated nutrient solution.

Keywords: *Brassica oleracea* var. gongylodes, hydroponic cultivation, coconut fiber.

RESUMO

Condutividade elétrica da solução nutritiva no cultivo sem solo de couve rábano

A condutividade elétrica da solução nutritiva afeta a produção e a qualidade das plantas. O objetivo deste trabalho foi determinar a condutividade elétrica adequada para o cultivo sem solo da couve rábano. O experimento foi desenvolvido seguindo o delineamento inteiramente casualizado, com quatro repetições e cinco tratamentos, compostos pelas CE das soluções nutritivas de 1,31; 1,71; 2,37; 2,98 e 3,75 dS m^{-1}. As variáveis analisadas foram número de folhas, área foliar, área foliar específica, razão de área foliar, massa fresca e massa seca de folhas, bulbo, raízes e total, volume de bulbo, teor de água nos bulbos e pH, sólidos solúveis, vitamina C, firmeza, acidez titulável e razão SS/AT dos bulbos. Todas as variáveis de crescimento foram afetadas pelas soluções nutritivas, com maiores valores obtidos em soluções nutritivas com CE próximo a 2,0 dS m^{-1}. Considerando a parte comercial da cultura, os bulbos mais desenvolvidos foram obtidos com CE de 1,96 dS m^{-1}, sendo 49,9 g e 41,15 cm^3 por bulbo. Por outro lado, exceto para o pH, as demais variáveis responderam ao aumento da CE. Maiores valores para firmeza de polpa e acidez titulável ocorrem com CE próximo a 2,0 dS m^{-1}, enquanto as demais variáveis apresentaram valores maiores com solução nutritiva mais concentrada.

Palavras-chave: *Brassica oleracea* var. gongylodes, cultivo hidropônico, fibra de coco.

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Kohlrabi (*Brassica oleracea* var. gongylodes) belongs to Brassicaceae family. It is rich in β-carotene, vitamin C, calcium, lutein, phenolics and substances with important anticancer functions, such as glucosinolates, anthocyanins and carotenoids (Park *et al.*, 2012). The edible part of kohlrabi is the bulb, formed by the tissue swelling at the stem base entirely above the soil surface, and which is used mainly as a cooked vegetable. The consumption has become popular due to the high content of ascorbic acid and potassium, combined with high dietary fiber and low amount of lipids (National Food Composition Database, Fineli®, 2011).

Vegetable cultivation under protected environment has been growing in Brazil, mainly under Nutrient Film Technique (NFT) or substrate, mostly using coconut fiber. Hydroponic system using substrate is generally adopted to grow fruit vegetables, such as green pepper (Silva *et al.*, 2020) and tomato (Santos *et al.*, 2016), among others. However, recently, several researchers have been adopting this system to grow leafy vegetables (Oliveira *et al.*, 2018; Targino *et al.*, 2019). This system shows many advantages in relation to NFT, mainly due to a reduction in irrigation time, resulting in a lower energy consumption, providing savings of up to 92% (Andriolo *et al.*, 2004).

Like in NFT system, in the substrate cultivation system, a nutrient solution with adequate electrical conductivity shall be adopted in order to provide greater plant development and yield. The suitable concentration of nutrients in the nutrient solution is a key factor for plants to express their maximum productive potential (Andriolo *et al.*, 2009).

Kohlrabi is classified as moderately sensitive to saline stress, with a threshold salinity of 1.3 dS m^{-1}, with a 13.0% reduction in yield per unit increase in electrical conductivity of the soil saturation extract (Shannon & Grieve, 1999). In hydroponic cultivation, the effects of salinity are mitigated due to the high frequency of irrigation and the high availability of nutrients in the nutrient solution. In addition, the low influence of the matrix potential provides a greater tolerance of plants to saline stress compared with soil cultivation (Santos *et al.*, 2016).

No recommendation for nutrient solution to cultivate kohlrabi can be found, as well as for any other vegetables of the same botanical family. Thus, in most research, carried out in Brazil, on hydroponics, nutrient solution recommended for leafy vegetables is used, especially for lettuce (Furlani *et al.*, 1999), considering the studies on collard (Noboa *et al.*, 2019) and cauliflower (Soares *et al.*, 2020).

Given the above, the aim of this study was to determine the electrical conductivity suitable for soilless cultivation of kohlrabi.

MATERIAL AND METHODS

The experiment was carried out in a greenhouse, from February to April 2017, in the Departamento de Ciências Ambientais e Tecnológicas (DCAT) at Universidade Federal Rural do Semiárido (UFERSA), West Campus, in Mossoró, RN (5°11'S, 37°20'W and average altitude 18 m).

Cultivation was performed in a greenhouse, arch type, oriented the east-west direction, covered with low-density polyethylene film, 150 microns thick and anti-ultraviolet additive. The lateral sides were covered with 50% black mesh, 18 m long, 7.0 m wide, 3.5 m ceiling height.

The experimental design used was randomized blocks, with five treatments and four replicates. The treatments consisted of nutrient solutions with different nutrient concentrations resulting in average electrical conductivity (EC) of 1.31; 1.71; 2.37; 2.98 and 3.75 dS m^{-1}, equivalent concentrations of 50, 75, 100, 125 and 150%, respectively, recommended by Furlani *et al.* (1999) for hydroponic cultivation of leafy vegetables. Each experimental unit consisted of six pots, with one plant each.

The standard nutrient solution presented the following fertilizer concentration, in mg L^{-1}: calcium nitrate, 750; potassium nitrate, 500; magnesium sulfate, 400; MAP, 150. The micronutrients were provided using a commercial compost (Rexolin® BRA Yara), with 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 authors applied the dose recommended by the manufacturer (30 grams of the compost for 1,000 liters of water). We applied solutions 0.1 mol L^{-1} of HCl for adjusting the pH of the solution (6.0 - 6.5). The nutrient solutions were prepared using water collected in the supply system of the central campus of UFERSA, showing the following characteristics: pH = 8.30; EC = 0.50 dS m^{-1}; Ca^{2+} = 3.10; Mg^{2+} = 1.10; K^+ = 0.30; Na^+ = 2.30; Cl^- = 1.80; HCO_3 = 3.00; CO_3^{2-} = 0.20 ($mmol_c$ L^{-1}).

Kohlrabi seeds, cv. 'Branca' (Isla®), were sown in expanded polystyrene trays of 128 cells, filled with coconut fiber substrate, using five seeds in each cell. Emergence began five days after sowing and thinning was performed six days after emergence, leaving in each cell the most vigorous seedling. After thinning, the seedlings were fertigated through mini floating system, using a nutrient solution (Furlani *et al.*, 1999) diluted to 50%. The seedlings were transplanted at 35 days after sowing, putting one seedling in each pot (16 cm high x 15 cm wide), with 2.8-L capacity, containing 2.5 liters of coconut fiber. The pots were placed on bricks, 10 cm high and 25 cm apart.

All irrigations were done using nutrient solution, via an independent system for each treatment, consisting of a 60-liter-capacity PVC reservoir, a circulating electric pump Metalcorte/Eberle, self-ventilated, model EBD250076, driven by a single-phase motor, 210 V voltage, 60 Hz frequency. The lateral lines of the system were made of flexible polyethylene pipes, 16 mm diameter hoses. Microtubes emitters (spaghetti) were used, 1.0 mm internal diameter, 30 cm long and average flow of 3.5 L h^{-1}, one emitter for each pot. The irrigation system was controlled by a digital timer, with capacity for eight events (On/Off), adopting the frequency of six daily events, the first at 06:00 and the others at two-hour intervals. The duration of each event ranged along the experiment: two minutes from the transplant up to 20 days after transplant (DAT), three minutes from 21 DAT up to 30 DAT and four minutes from 31 DAT up to harvest (45 DAT). In each fertigation, we adopted time enough for 10% nutrient solution leaching, in order to reduce salt accumulation in the substrate.

Plants were harvested at 45 days after transplant. The plants were cut close to the substrate, and the root was left to be collected later. The roots were taken after drying the substrate and were used only to determine the root dry mass. After harvest, the plants were put in plastic bags and taken to the Laboratório de Hidroponia da UFERSA. Three plants of each plot were used to determine growth, whereas the other plants were used for analyzing the bulb quality.

The number of leaves (NL) was determined by direct counting and considering the leaves with the leaf blade from five centimeters on. Leaf area (LA) was determined using the disc method, considering the obtained values expressed in cm^2 $plant^{-1}$. The specific leaf area (SLA) was evaluated by LA/LDM ratio, being expressed in cm g^{-1} LDM. The leaf area ratio (LAR) was determined by LA/TDM ratio, expressed in cm^2 g^{-1} TDM.

Fresh mass was determined right after the harvest, considering the leaf fresh mass (LFM), bulb (BFM) and shoot area (SFM) (leaves + bulb), weighed on an analytical scale, expressed in g $plant^{-1}$. The volume of the bulb (VB) was obtained through the displacement of water caused by immersing the bulbs in a 1000 mL beaker containing 500 mL water, so that the volume of each bulb was determined by the difference between the final and initial volume, expressed in cm^3. The samples of leaves, bulbs and roots were placed in paper bags previously identified and dried in an oven at 65ºC, with forced air circulation until reaching constant mass (±1). After drying, the samples were weighed using an analytical scale (0.01 g), in order to obtain the dry masses of leaves (LDM), bulb (BDM), roots (RDM) and total mass (TDM) (TDM = LDM + BDM + RDM), expressed in g $plant^{-1}$.

Bulb firmness (BF) was obtained with the aid of an analogical penetrometer, using a tip of 8 mm in diameter and penetration of 5 mm, expressed in Newton. The chemical qualities were determined in bulb juice, obtained using a food processor, collecting a sufficient volume to perform all analyses. Hydrogen potential (pH) was determined using a benchtop pH meter (Model Mpa-210A). Soluble solids content (SS) was measured using a digital refractometer (PAL-1 ATAGO), being the results expressed in ºBrix. Titratable acidity (TA), determined by the titration method, using sodium hydroxide (0.02N) and phenolphthalein as an indicator, showing a slightly pink color after turning. Vitamin C content (VIT C), determined by titration with DFI (0.094 mg L^{-1}), expressed in mg of ascorbic acid per 100 g of juice. The authors determined SS/TA ratio using the results obtained for soluble solids (SS) and titratable acidity (TA) content.

Statistical analysis of the data was performed using the statistical software Sisvar (Ferreira, 2014), through analysis of variance by the F test. The variables which showed significant response were submitted to polynomial regression analysis.

RESULTS AND DISCUSSION

Number of leaves (NL) and leaf area (LA) were affected similarly with an increase of EC of the nutrient solution, showing quadratic response for both variables, being the highest values observed in EC of 1.98 dS m^{-1} (12 leaves) and 1.87 dS m^{-1} (9,106.8 cm $plant^{-1}$), corresponding to increases of 9.5 and 6.7%, for NL (Figure 1A) and LA (Figure 1B), respectively, comparing with the values obtained using the lowest EC of the nutrient solution. Moreover, the authors verified that in the highest EC of the nutrient solution, the lowest values were verified, resulting in losses of 55.5% for NL and 68.6% for LA (Figures 1A and 1B), in comparison with the values obtained in the lowest EC (1.31 dS m^{-1}). These results showed that the effect of EC was similar, both for leaf emission and for leaf blade expansion.

In some studies on other crops belonging to the same botanical family, other authors have also observed

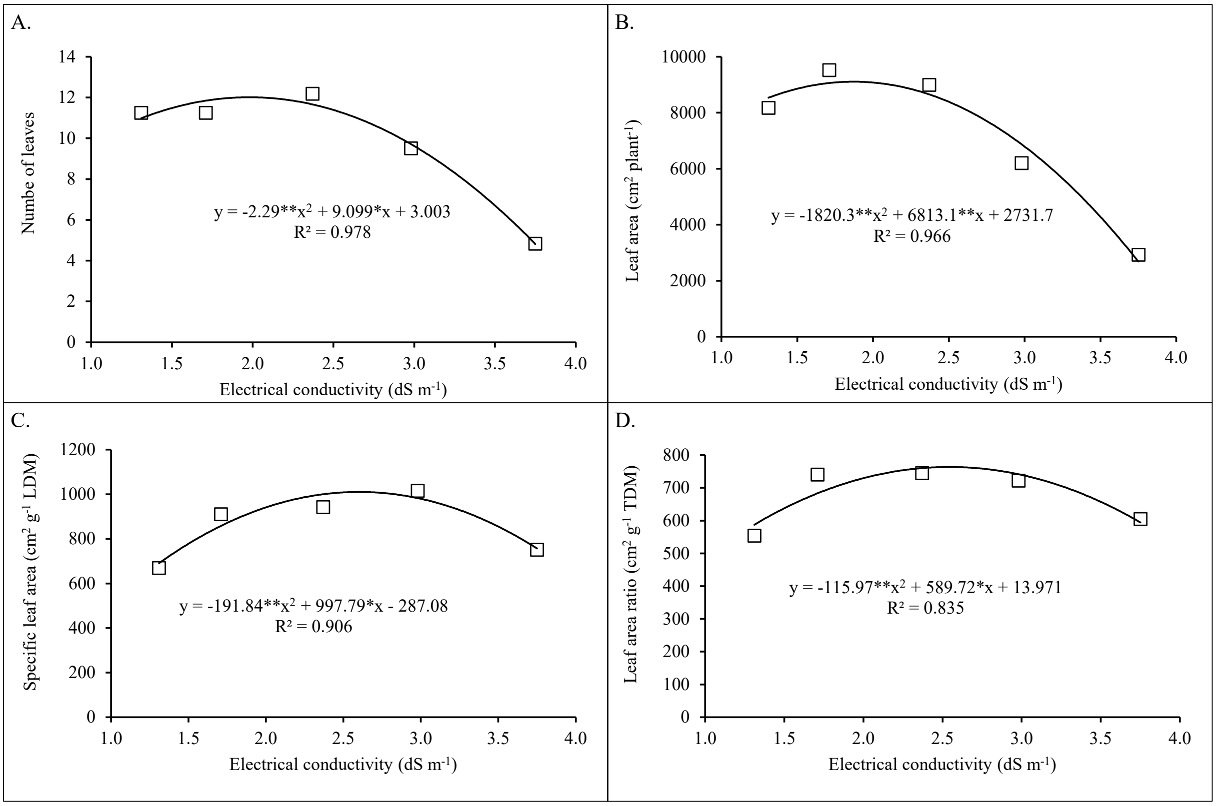

Figure 1. Number of leaves (A), leaf area (B), specific leaf area (C) and leaf area ratio (D) of kohlrabi grown in coconut fiber and fertigated with different electrical conductivities of nutrient solution. Mossoró, UFERSA, 2017.

a reduction in leaf development in relation to an increase of the electrical conductivity of the nutrient solution, such as in the study on cauliflower (Costa *et al.*, 2020) and collard (Viana *et al.*, 2021).

Quadratic responses were also observed with an increase of EC of the nutrient solution for specific leaf area (SLA) and leaf area ratio (LAR), with the highest values for 2.60 dS m^{-1} (1010.34 cm^2 g^{-1} LDM) and 2.54 dS m^{-1} (763.67 cm^2 g^{-1} TDM), showing increases of 46.2 and 29.9%, for SLA and LAR, respectively (Figures 1C and 1D).

The specific leaf area expresses the ratio between the leaf area available to perform photosynthetic activity and to accumulate photoassimilates in the leaves. Thus, an increase in this variable showed a reduction in leaf blade thickness, showing that the effect of the electrical conductivity of the nutrient solution was more expressive on the net assimilation rate than on the formation of phytomass. This behavior shows the plant's capacity to regulate transpiration due to a greater number of cell extracts or an increase in intercellular spaces, thus representing a mechanism for acclimatizing the crop to saline stress (Taiz *et al.*, 2017).

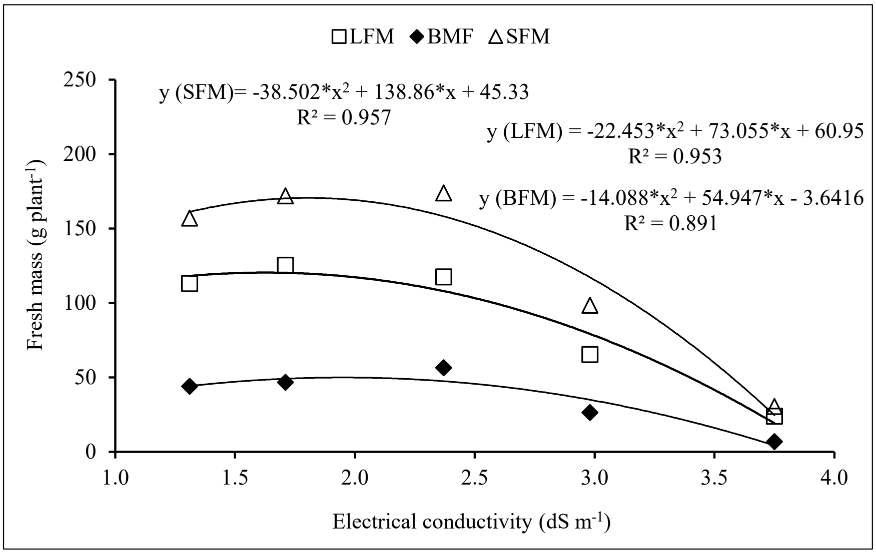

Figure 2. Leaf fresh mass (MFF), bulb fresh mass (MFB) and shoot fresh mass (MFPA) of kohlrabi grown in coconut fiber and fertigated with different electrical conductivities of nutrient solution. Mossoró, UFERSA, 2017.

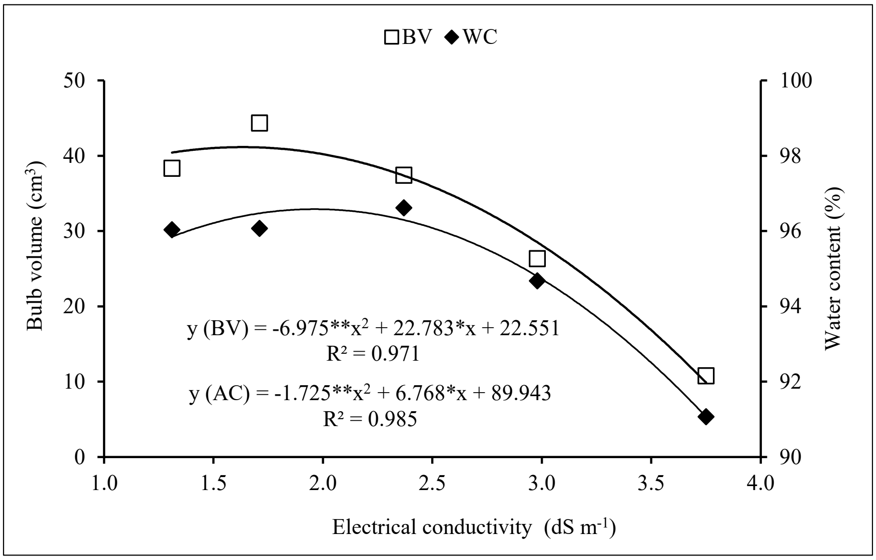

Figure 3. Bulb volume (VB) and water content (TA) in kohlrabi bulbs grown in coconut fiber and fertigated with different electrical conductivity of nutrient solution. Mossoró, UFERSA, 2017.

Leaf area ratio expresses the ability of plants to take advantage of photosynthetically active area in the production of plant-wide biomass. An increase in this index shows stress, since considering the same leaf area, less conversion of photoassimilates into biomass is verified. This alteration can occur due to both lower photosynthetic efficiency and higher expenditure on maintenance and restoration of carbon compounds (Atkin & Macherel, 2009).

Leaf fresh mass (LFM), bulb fresh mass (BFM) and shoot fresh mass (SFM) showed quadratic response in relation to an increase in EC of the nutrient solution, with higher values for levels 1.63; 1.95 and 1.80 dS m^{-1}, obtaining maximum values of 120.4; 49.9 and 170.5 g $plant^{-1}$, for LFM, BFM and SFM, respectively. On the other hand, the authors verified reductions when the plants were submitted to a more concentrated nutrient solution (3.75 dS m^{-1}), verifying losses of 83.8% for LFM, 77.5% for BFM and 84.7% for SFM, when comparing with values obtained in EC of 1.31 dS m^{-1} (Figure 2).

These results showed that the maximum production of kohlrabi is obtained with a nutrient solution of 1.9 dS m^{-1}, and reduces in 91% using EC of 3.75 dS m^{-1}, equivalent to a 49.4% reduction per CE unit increase. Therefore, kohlrabi can be classified as a moderately salinity-sensitive crop, confirming the classification proposed by other authors (Osman & Salim, 2016).

Other species of *Brassicas* were also classified as moderately salinity-sensitive, such as cauliflower (*B. oleracea* var. botrytis), Chinese cabbage (*B. campestris*) and broccoli (*B. oleracea var.* italica) (Machado & Serralheiro, 2017; Costa *et al.*, 2020).

The average bulb volume (BV) and its respective water contents (WC) were affected by EC, showing, initially, a positive response in relation to an increase of EC up to levels 1.63 and

1.96 dS m^{-1}, with 41.15 cm^3 and 96.58%, respectively. Moreover, the authors verified a significant reduction in BV (75.51%) in plants which were fertigated with more concentrated nutrient solution (3.75 dS m^{-1}). Loss in TA using higher EC of nutrient solution was also verified, only 4.99%, though (Figure 3).

In general, the authors observed that high EC of the nutrient solution provided significant reduction for both VB and TA in bulbs, corroborating the results presented by Biswas *et al.* (2016), who also verified a reduction in bulb size of kohlrabi in relation to a high EC of the nutrient solution. A reduction in TA in high ECs is due to an increase in fiber content of the bulbs (Osman &

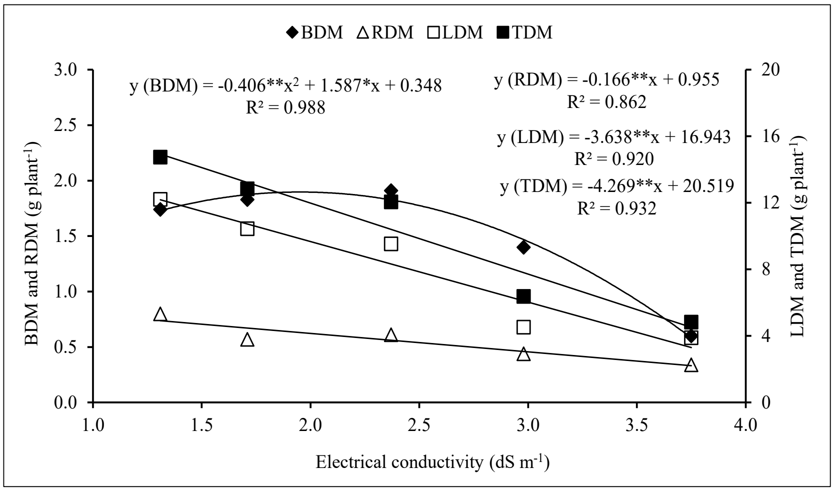

Figure 4. Leaf dry mass (MSF), root dry mass (MSR), bulb dry mass (MSB) and total dry mass (MST) of kohlrabi grown in coconut fiber and fertigated with different electrical conductivities of nutrient solution. Mossoró, UFERSA, 2017.

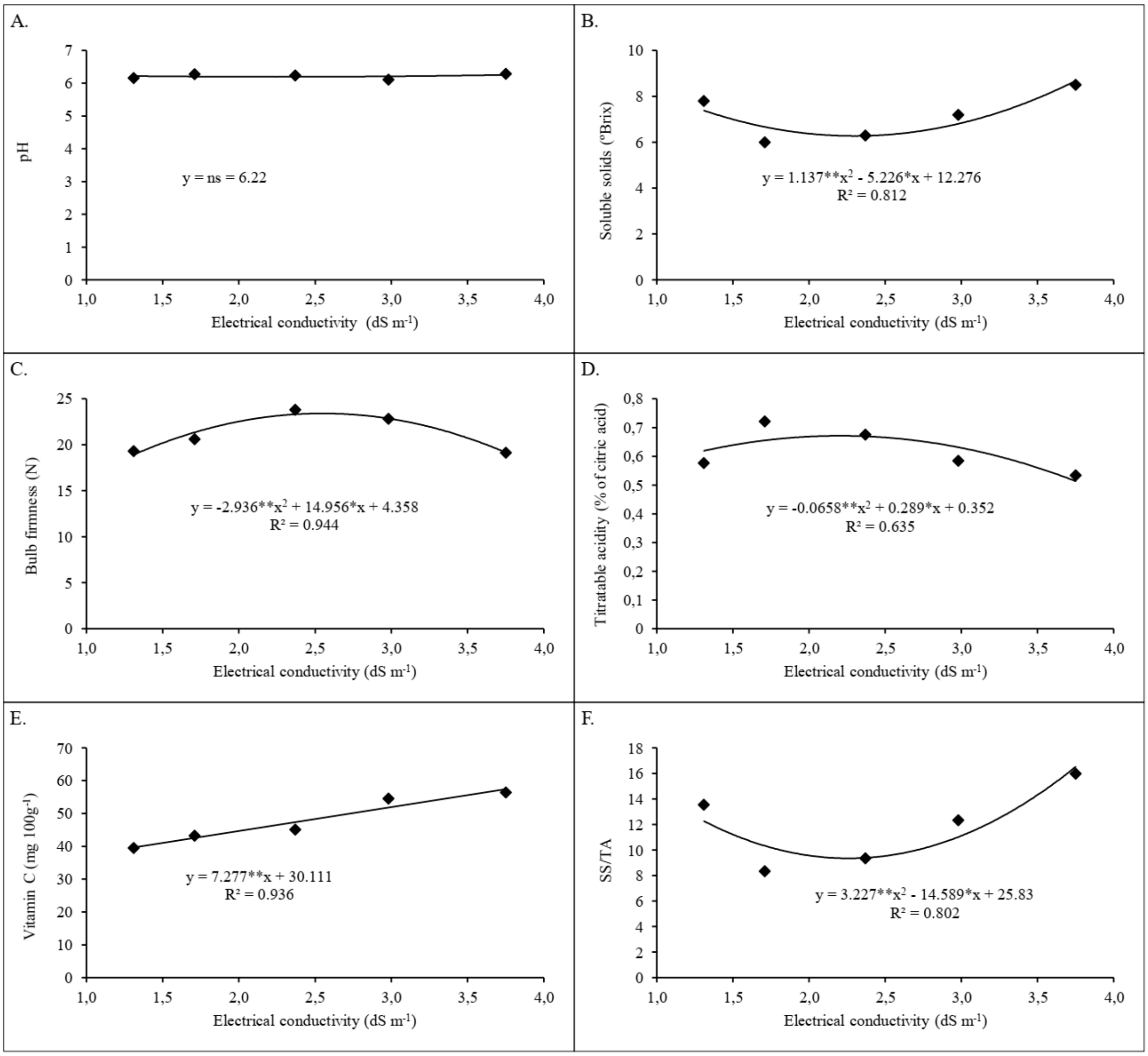

Figure 5. Hydrogen potential (A), soluble solids (B), bulb firmness (C), titratable acidity (D), vitamin C (E) and SS/AT ratio (F) of kohlrabi grown in coconut fiber and fertigated with different electrical conductivities of nutrient solution. Mossoró, UFERSA, 2017.

Salim, 2016).

Evaluating the dry mass accumulation, the authors verified that an increase in EC of the nutrient solution provided a linear reduction for leaf dry mass (LDM), root dry mass (RDM) and total dry mass (TDM), so that the highest values were obtained in the nutrient solution with the lowest EC (dS m^{-1}), 12.18; 0.74 and 14.60 g $plant^{-1}$, whereas the plants fertigated with more concentrated nutrient solution (3.75 dS m^{-1}) showed lower values, with losses of 72.90; 54.92 and 71.36%, for LDM, RDM and TDM, respectively. On the other hand, for bulb dry mass (BDM), a quadratic response was observed, with higher values for EC of 1.95 dS m^{-1} (1.89 g $plant^{-1}$), equivalent to an increase of 9.74% in relation to the BDM obtained in the lowest EC (1.73 g $plant^{-1}$). Furthermore, a significant reduction in BDM was verified in plants fertigated with more concentrated nutrient solution, 65.39% losses (Figure 4).

The reduction in dry mass production can be due to the metabolic energy cost associated with salt stress acclimatization and reduction in carbon gain (Atkin & Macherel, 2009). Thus, a reduction in the supply of photoassimilates and plant hormones to the growing tissues can be noticed, and, consequently, a reduction in the dry mass of the different organs of kohlrabi.

Except for pH, all the variables related to bulb quality were affected by EC of the nutrient solution, with a linear adjustment for vitamin C content and quadratic adjustment for other variables (Figure 5).

Soluble solid content (SS) and soluble solid and titratable acidity ratio (SS/TA) were affected similarly by EC, showing initially a reduction of up to ECs of 2.30 and 2.22 dS m^{-1}, in which the lowest values could be verified, being 6.27ºBrix for SS (Figure 5B) and 9.67 for SS/TA (Figure 5F). From these levels on, increases in these variables with an increase of EC were observed. That means, using the highest EC (3.75 dS m^{-1}), the highest values of SS (8.67ºBrix) and SS/TA (16.50) were verified.

The increase in soluble solids in the highest EC may be attributed to the lowest water accumulation in the bulbs, due to an osmotic effect in the more concentrated nutrient solution (Moya *et al.*, 2017). The increase in soluble solid content in relation to an increase of EC was also observed by Giuffrida *et al.* (2017, 2018) and Gioia *et al.* (2018), working with cauliflower and broccoli, respectively.

For vitamin C (VITC), the authors verified that the highest content (57.40 mg 100 g^{-1}) was in the highest EC of the nutrient solution, 3.75 dS m^{-1}, corresponding to an increase of 44.79% in relation to VITC content obtained in the lowest EC (1.31 dS m^{-1}), 39.64 mg 100 g^{-1} (Figure 5E).

Other authors, working with other crops, such as the cauliflower (Giuffrida *et al.*, 2013, 2017) and lettuce (Sarmento *et al.*, 2014), also observed an increase in VITC content in relation to the saline stress. According to Zandi & Schnug (2022), the content of ascorbic acid, a precursor of vitamin C, is normally increased in salt-stressed plants in order to protect plant cells from salt-induced oxidative stress, resulting from the increased formation of reactive oxygen species.

For bulb firmness (Figure 5C) and titratable acidity (Figure 5D) the highest values were obtained with ECs 2.55 and 2.32 dS m^{-1}, obtaining 23.40 N and 0.69%, corresponding to an increase of 23.75 and 13.25%, for fimness and titratable acidity, respectively, in comparison to the values obtained at the lowest EC.

An increase in kohlrabi bulb firmness in response to salinity was also observed by Osman & Salim (2016) who found that the increase in firmness occurred both by a reduction in water content and an increase in fiber concentration. Giuffrida *et al.* (2013), evaluating the effect of salinity in cauliflower crop, also verified an increase in titratable acidity in response to an increase in electrical conductivity.

In general, the authors verified that all growth variables were affected by the nutrient solutions, with higher values obtained in nutrient solutions with EC close to 2.0 dS m^{-1}, and significant reductions in nutrient solutions with EC of 3.75 dS m^{-1}. Considering the commercial part of the crop, the most developed bulbs were obtained with EC 1.96 dS m^{-1}, being 49.9 g and 41.15 cm^3 per bulb. On the other hand, except for pH, the other variables responded to the increase in EC of the nutrient solution. Higher values for pulp firmness and titratable acidity occurred with EC close to 2.0 dS m^{-1}, whereas the other variables showed higher values with more concentrated nutrient solution.

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