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Physiological responses of beet plants irrigated with saline water and silicon application

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Abstract

Although not considered an essential element, silicon can be used to increase crop productivity, especially under stress conditions. In this sense, the objective was to evaluate the gas exchange of beet plants irrigated with saline water depending on the application of silicon. The experiment was conducted in a randomized block design, in a 5 x 5 factorial, referring to five levels of electrical conductivity of irrigation water (ECw): (0.5; 1.3; 3.25; 5.2 and 6.0 dS m^{-1}) and five doses of silicon (0.00; 2.64; 9.08; 15.52 and 18.16 mL L^{-1}), with six beet plants as an experimental unit. The effect of treatments on beet culture was evaluated at 30 and 60 days after irrigation with saline water from measurements of internal carbon concentration, stomatal conductance, net photosynthesis rate, instantaneous water use efficiency and instantaneous carboxylation efficiency using the LCpro+Sistem infrared gas analyzer (IRGA). Irrigation with saline water reduced the gas exchange of beet plants at 60 days after irrigation, but at 30 days after irrigation, the use of saline water increased stomatal conductance, transpiration rate and internal carbon concentration. The application of silicon decreased stomatal conductance, internal carbon concentration and efficiency in the use of water, but increased the rate of net photosynthesis, the rate of transpiration and instantaneous efficiency of carboxylation at 30 and 60 days after irrigation.

Keywords: *Beta vulgaris* L., saline stress, photosynthesis, potassium silicate, gas exchange

Introduction

One of the main obstacles to agricultural production in the Brazilian northeastern region is low rainfall. In addition, most waters have a high salt concentration, corresponding to electrical conductivity values above 4 dS m^{-1}, affecting water absorption and causing toxic effects (Munns & Tester 2008; Taiz et al., 2017), hindering several physiological and biochemical processes, and consequently, resulting in less growth and development of cultures (Sá et al., 2013; Sá et al., 2015; Oliveira et al., 2017).

Several studies have shown that salinity in irrigation water causes several phytotoxic effects on plants, including loss of photosynthetic activity, attributed to stomatal and non-stomatal limitations (Kusvuran, 2012; Freire et al., 2014; Sousa et al., 2016).

Alternatives to mitigate or reduce the harmful effects of salt stress, such as attenuating substances, such as silicon (Si), are fundamental, and although silicon is not considered an essential element for plants, it has beneficial effects on the development of plants (Guntzer et al., 2012). In recent years, studies have shown that Si can alleviate the effects of abiotic stresses, such as salinity and drought (Ali et al., 2012; Zhu & Gong, 2014; Sahebi et al., 2016). In addition, its application can provide greater growth of many plant species (sunflower, cotton and castor) under saline conditions (Silva et al., 2009; Ferraz et al., 2014; Ferraz et al., 2015).

In crops such as wheat, sorghum, tomatoes and corn under stress conditions, the application of silicon promoted greater leaf area, chlorophyll content and improved the structure of chloroplasts, which provided an increase in photosynthetic activity (Tahir et al., 2012; Bae et al., 2012; Yin et al., 2013; Haghighi & Pessarakli, 2013; Rohanipoor et al., 2013). However, for beet studies involving the application of possible attenuators for salt stress are scarce.

As a result, studies to assess the potential of Si as an alternative to reduce the harmful effects of saline waters on beet cultivation are extremely relevant. In this sense, the objective was to evaluate the physiological responses of beet irrigated with saline water depending on the application of silicon.

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Materials and Methods

The experiment was conducted from August to October 2017 in a greenhouse located in the Fruit sector, belonging to the Federal University of Paraíba, in the city of Areia-PB, Brazil, located at the geographical coordinates 6°51'47 "and 7°02'04" south latitude and 35°34'13" and 35°48'28" west longitude of the Greenwich meridian, with an elevation of 575 m above sea level.

During the conduction of the experiment, climatic data (Figure 1) were recorded daily with an HT-600 Instruthermr® digital thermohygrometer, installed inside the experimental area, at plant height. The average climatic values of temperature were close to the range considered ideal (15 to 25°C) during the culture cycle, according to Filgueira (2008).

Beet seedlings of cv. Maravilha were produced in trays and planted in pots 22 cm in diameter, 16 cm in diameter and 18 cm in height, with a volumetric capacity of 8 dm^3, and with circular holes 1 cm in diameter on its underside, in order to allow better aeration of the roots and percolation of excess water.

The pots were filled with horizon A soil collected at a depth of 0-20 cm, classified as Planosol Haplic Eutrophic (Embrapa, 2014), the chemical and physical characteristics (Table 1) were analyzed according to Embrapa's methodology (2014), respectively. The soil was previously air-dried and duly homogenized, being placed in the canvas (tulle fabric) and 200 g gravel pots, to prevent soil from leaving the pots through their lower holes.

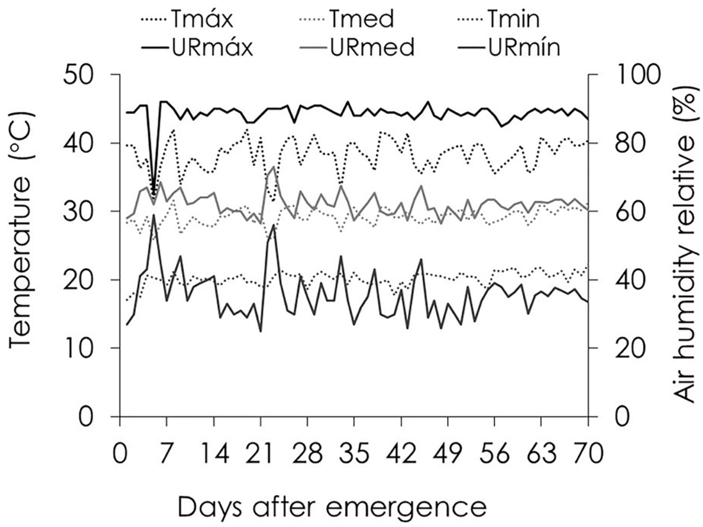

Figure 1. Graphical representation of the relative humidity and temperature in the period of conduction of the experiment. Maximum (Tmax), average (Tmed) and minimum (Tmin) air temperatures in °C; maximum relative humidity (URmax), average (URmed) and minimum (URmin) in %.

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

Chemical attributes		Physical attributes	
pH	6.26	Ds	1.38
P (mg dm^{-3})	11.35	Dp	2.67
K^+ (mg dm^{-3})	40	PT	0.48
Na^+ (cmol dm^{-3})	0.22	CC	78
H+Al (cmol dm^{-3})	1.82	PMP (g g^{-1})	43
Al^{+3} (cmol dm^{-3})	0	Sand (g kg^{-1})	756.9
Ca^{+2} (cmol dm^{-3})	3	Silt (g kg^{-1})	59.1
Mg (cmol dm^{-3})	1.9	Clay (g kg^{-1})	184
SB (cmol dm^{-3})	5.22	-	-
CEC ($cmol_c$ dm^{-3})	7.03	-	-
V (%)	74.34	-	-
M (%)	0	-	-
OM (g Kg^{-1})	17.53	Textural classification	Sandy loam

SB = ($Na^+ + K^+ + Ca^{2+} + Mg^{2+}$); CEC (cation exchange capacity) = SB + ($H^+ + Al^{3+}$); V = (100 x SB/CTC); OM = organic matter. Ds = soil density; Dp = particle density; Pt = total porosity; (1- (Ds/Dp) * 100) Ucc = Volumetric humidity at the level of field capacity – 0.033 Mpa; Upmp = Humidity at the level of the permanent wilting point – 1.5 Mpa.

The beet plants were irrigated daily, with sufficient water volume to raise the soil moisture to the level of field capacity and recording all applied volume. These irrigations were carried out with non-saline waters (ECw= 0.5 dS m^{-1}) and saline waters (ECw= 1.3; 3.25; 5.2 and 6.0 dS m^{-1}), and every 15 days, soil washes were performed with each type of water used. The different ECw were obtained by using the salts of NaCl, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$, in the proportion of 7: 2: 1 (Medeiros, 1992) as shown in Table 2. Irrigation with water sources of different salinities was started 10 days after emergence.

Table 2. Chemical characteristics of the waters used in the experiment

	Water electric conductivity (dS m^{-1})				
Attributes	0.50	1.30	3.25	5.20	6.00
	Values				
pH	7.00	7.50	7.40	7.30	7.40
$SO4^{-2}$	3.22	3.70	3.67	3.35	3.90
Mg^{2+}	1.33	1.78	1.93	2.03	2.98
Na^{+}	1.70	5.92	12.57	20.5	24.20
K^{+}	0.20	0.21	0.20	0.20	0.21
Ca^{2+}	0.73	1.58	1.78	1.88	2.53
CO_3^{-2}	0.00	0.00	0.00	0.00	0.00
HCO_3^{-}	2.75	3.50	4.00	4.25	4.25
Cl^{-}	3.40	10.90	30.40	48.90	58.15
SAR (mmol L^{-1}) ^{0,5}	1.28	1.87	2.60	3.23	2.96
Classification	C2S1	C3S3	C4S4	C4S4	C4S4

ECw = Electrical conductivity at 25 ° C; SAR = Sodium adsorption ratio $[Na^+/(Ca^{2+}+Mg^{2+}/2)^{1/2}]$; Water classification according to Richards (1954).

The silicon was applied in the form of potassium silicate (K_2SiO_3), liquid, with 12% Si and 15% K_2O. The doses of Si from the treatments were applied through a hand sprayer. The application was made weekly, totaling 7 applications during the development of sweet potato. The doses of (Si) were diluted in distilled water, with 50 ml of this solution applied to each plant. Because the source of silicon (potassium silicate) contains 15% K_2O, compensation was performed via fertigation for each treatment, subtracting the amount of K applied via foliar in KCl top dressing, thus maintaining the homogenization of this element, regardless of the treatment.

The planting and covering fertilization were carried out with 40, 180 and 90 kg ha^{-1} of NPK, respectively, with urea, simple superphosphate and potassium chloride, according to the chemical analysis of the soil and fertilization recommendation for the State of Pernambuco (IPA, 2008). During the conduct of the experiment, pest and weed control was performed based on manual picking and weeding of invasive plants.

The effect of treatments on beet culture was evaluated at 30 and 60 days after irrigation with saline water from measurements of the internal carbon concentration (Ci - μmol mol air^{-1}), stomatal conductance (gs - mol H_2O m^{-2} s^{-1}), transpiration (E - mmol H_2O m^{-2} s^{-1}), net photosynthesis rate (A - μmol m^{-2} s^{-1}), water use efficiency (WUE – A/E), instantaneous water use efficiency (iWUE – A/E) calculated by relating it to net photosynthesis with transpiration [(μmol m^{-2} s^{-1})/(mmol H_2O m^{-2} s^{-1})] and instantaneous carboxylation efficiency (iCE – A/Ci) [(μmol m^{-2} s^{-1})/(μmol mol air^{-1})] from the relationship between net photosynthesis and internal carbon concentration using the LCpro+Sistem infrared gas analyzer (IRGA).

The experimental design was in randomized blocks, in a 5 x 5 factorial, referring to five levels of electrical conductivity of the irrigation water (ECw): (0.5; 1.3; 3.25; 5.2 and 6.0 dS m^{-1}) and five doses of silicon (0.00; 2.64; 9.08; 15.52 and 18.16 mL L^{-1}), combined according to the experimental matrix Central Compound of Box (Mateus et al., 2001), totaling ten treatments, with four replications, with six beet plants as an experimental unit. Statistical analyzes were performed with their confidence interval to compare the two evaluation dates using the statistical program R (R Core Team, 2018).

Results and Discussion

Stomatal conductance showed a difference in all ECw in relation to the evaluation periods. At 30 DAI, there was an average increase in stomatal conductance as the ECw increased, which may be related to the plant's effort to stand out from stress. However, at 60 DAI, it is clear that there was a drastic reduction in stomatal conductance compared to 30 DAI. Either this can be linked to the excess of salts in the root zone or even to the age of the plant, considering that there is no significant variation between ECw (Figure 2A).

The same behavior was observed for sweating, which is related to stomatal opening (gs), because as the stomata close, consequently, there is a decrease in the transpiratory rate (Figure 2C). This reduction can be attributed mainly to the lower water absorption by beet plants, thus an alternative to reduce the rate of transpiration is the closure of stomata. However, the closure of stomata also reduces the photosynthetic rate due to the lower availability of CO_2 (Pereira et al., 2013; Ghobadi et al., 2013; Cerqueira et al., 2015), causing the reduction in the growth and development of the plants, corroborating the data obtained in the present work.

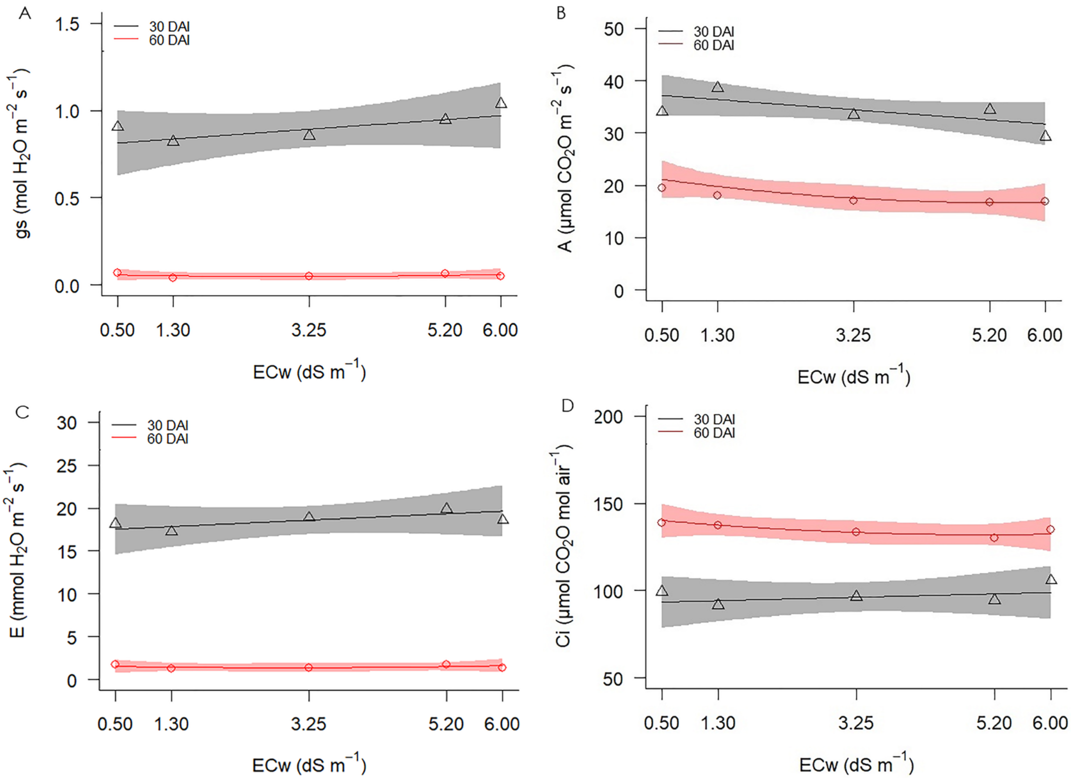

Figure 2. Stomatal conductance (gs - A), net photosynthesis (A - B), transpiration (E - C) and internal carbon concentration (Ci - D) of beet plants at 30 and 60 days after the beginning (DAI) of irrigation with saline water.

As for the rate of net photosynthesis, it was observed that there were differences between the two evaluation periods in the evaluated ECw. At 60 DAI, the net photosynthetic rate was lower (Figure 2B). For the internal CO_2 concentration (Figure 2D) there was a difference between the evaluation periods, however, the lowest Ci was at 30 DAI. This behavior may be linked to the fact that at 60 DAI there is a higher concentration of internal carbon in the intercellular spaces, and that this is not being used for photosynthetic processes.

It was observed that the stomatal conductance of the beet plants, at 30 DAI, decreased as the dose of Si increased, at 60 DAI it was observed that there was an increase up to the dose of 9.08 mL L^{-1}, decreasing in subsequent doses (Figure 3A). These results corroborate those obtained by Ferraz et al. (2014) in cotton culture, when observing that the increase in Si doses reduced stomatal conductance, obtaining the highest conductances in plants that did not receive Si. The same behavior was observed for transpiration (E), which decreased as the Si doses increased to 30 DAI. At 60 DAI there was an increase up to the dose of 9.08 mL L^{-1}, decreasing in subsequent doses (Figure 3C). The results obtained in the present study corroborate those observed by Jesus et al. (2018) in arugula, when they found that the application of silicon increased the rate of transpiration.

The reduction in stomatal conductance and transpiration can be attributed to the accumulation of Si in the epidermal cells and, in the stomatal walls, being in the form of H_4SiO_4 (monosilicic acid). Thus, with the loss of water, the monomeric form of Si becomes the polymeric form, that is, Si begins to form heavier chains of polysilicic acid. Subsequently, there is a reduction in the flexibility of the stomatal walls and the tendency is to be closed, reducing stomatal conductance and transpiration (Luz et al., 2006) as observed in the present study.

At 30 DAI, the rate of net photosynthesis showed a weighted decrease with the dose of 9.08 mL L^{-1} of Si, obtaining in this the lowest rate of net photosynthesis (30 µmol m^{-2} s^{-1}) and the highest net photosynthetic rate (39 µmol m^{-2} s^{-1}) with the application of 15.52 mL L^{-1} of Si (Figure 2B). At 60 DAI, the beet plants showed an increase as the

Si doses increased, with the highest net photosynthetic rate (19 μmol m^{-2} s^{-1}) with the application of 15.52 mL L^{-1} (Figure 3B). Jesus et al. (2018) also found that the rate of net photosynthesis increased with the foliar application of silicon in arugula, corroborating the results obtained in the present study.

The increase in the net photosynthetic rate can be attributed to the beneficial effects of Si, among them, the formation of a physical layer on the leaves, promoting a reduction in transpiration, which may have facilitated the opening of the stomata of beet plants (Heckman, 2013; Cantuário et al., 2014), promoting a higher photosynthetic rate of these plants.

In other studies it was also observed that Si promotes an increase in photosynthetic activity and growth of many species of plants (canola, soybeans, wheat, sorghum, tomatoes and corn) submitted to salt stress conditions, which had a larger leaf area, the chlorophyll content and improved the structure of chloroplasts (Tahir et al., 2012; Bae et al., 2012; Yin et al., 2013; Haghighi & Pessarakli, 2013; Rohanipoor et al., 2013).

At 30 and 60 DAI it was observed that the internal CO_2 concentration increased up to the dose of 9.08 mL L^{-1}, decreasing in subsequent doses, obtaining in this dose the highest internal CO2 concentrations (140 μmol m^{-2} s^{-1}) and (105 μmol m^{-2} s^{-1}), respectively. The higher concentration of CO_2 in the beet plants indicates low activity of the enzyme ribulose-1,5-bisphosphate carboxylase-oxygenase (Rubisco), however, in the present study the highest concentration of CO_2 coincided with the highest photosynthetic activity, which may have been a high activity of Rubisco (Silva et al., 2011).

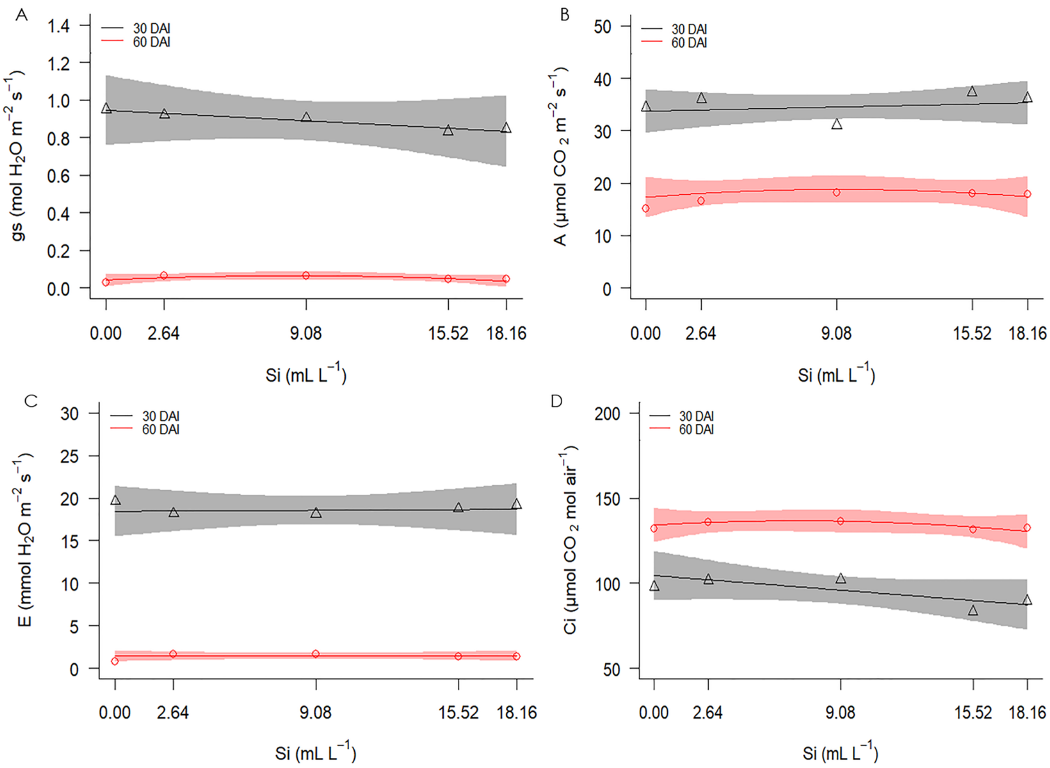

Figure 3. Stomatal conductance (gs - A), net photosynthesis (A - B), transpiration (E - C) and internal carbon concentration (Ci - D) of beet plants at 30 and 60 days after application (DAI) of silicon.

However, the reductions observed in the internal carbon concentration are due to decreases in the rate of CO_2 dioxide assimilation, which can be attributed to the fact that during gas exchanges, the absorption of CO_2 coincides with the loss of water and, conversely, the reduction of this loss limits the assimilation of CO_2 and, consequently, less internal concentration of CO_2 occurs (Shimazaki et al., 2007).

The intrinsic efficiency of carboxylation (iCE), water use efficiency (WUE) and instantaneous water use efficiency (iWUE) showed differences in both evaluation periods in relation to ECw. For iCE, WUE and iWUE, there was a difference in all the ECWs in relation to the evaluation period. For the WUE and iWUE the highest averages were observed at 60 DAI, the opposite being the case for iCE.

The intrinsic efficiency of carboxylation, at 60 DAI, decreased as the levels of ECw increased, obtaining the highest value in beet plants irrigated with water of 0.5 dS m^{-1}, and the smallest with 1.23 dS m^{-1} water irrigation. At 30 DAI, the intrinsic efficiency of the carboxylation of beet plants oscillated (Figure 4A).

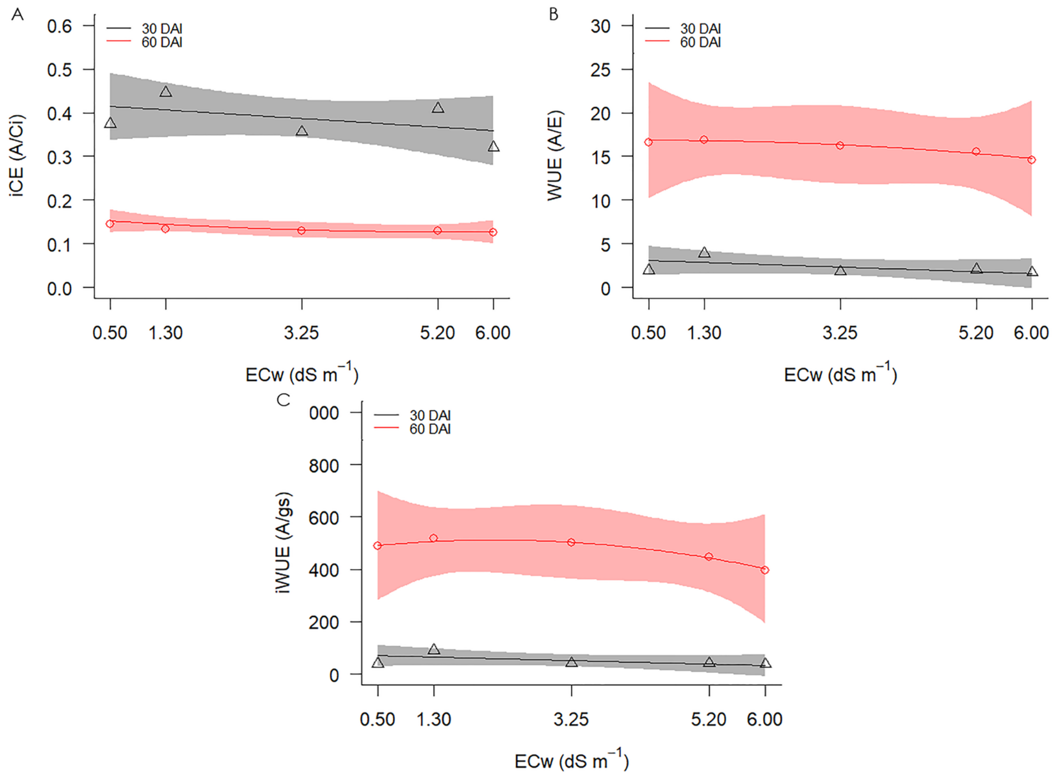

Figure 4. Intrinsic carboxylation efficiency (iCE - A), water use efficiency (WUE - B) and instantaneous water use efficiency (iWUE - C) of beet plants at 30 and 60 days after the start of irrigation (DAI) with saline water.

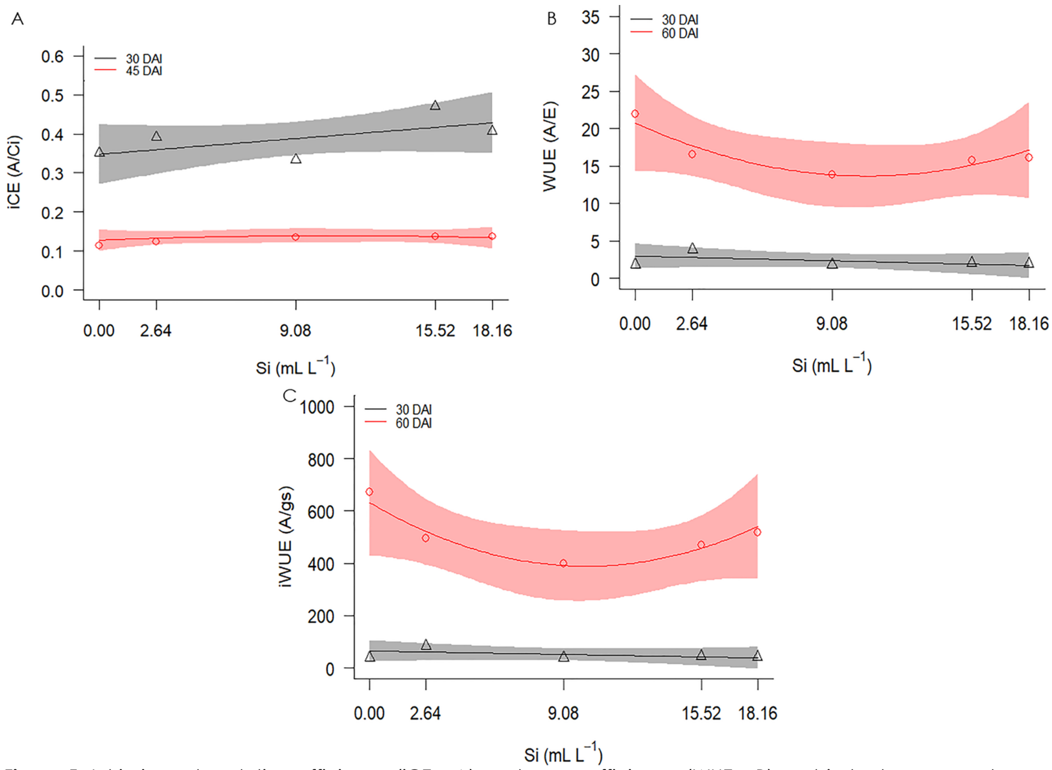

Figure 5. Intrinsic carboxylation efficiency (iCE - A), water use efficiency (WUE - B) and instantaneous water use efficiency (iWUE - C) of beet plants submitted to silicon application (Si) at 30 and 60 days after the beginning of irrigation (DAI) with saline water.

The increase in ECw levels reduced the water use efficiency of beet plants, presenting the highest value in plants irrigated with water of 0.50 dS m^{-1}, at 60 DAI the lowest value under irrigation with water of 3.25 dS m^{-1} (Figure 4B).

As for the application of Si, there was a difference between the evaluation periods for the iCE, WUE and iWUE. As for the behavior in relation to the evaluation period, WUE and iWUE had higher averages at 60 DAI, while the iCE was at 30 DAI. It was noted that in all variables, except for iCE, the application of Si up to the dose of 9.08 mL L^{-1} showed a decrease, increasing in subsequent doses. The opposite was observed for iCE. These results corroborate those observed by Jesus et al. (2018) in arugula, when they found that the application of silicon reduced the efficiency in the use of water.

Conclusions

Irrigation with saline water reduced the gas exchange of beet plants at 60 days after irrigation, but at 30 days after irrigation, the use of saline water increased stomatal conductance, transpiration rate and internal carbon concentration.

The application of silicon decreased stomatal conductance, internal carbon concentration and efficiency in the use of water, but increased the rate of net photosynthesis, the rate of transpiration and instantaneous efficiency of carboxylation at 30 and 60 days after irrigation.

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